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# Assessing the Impact of the Iberian Exception on Day-Ahead Prices in Spain

*A Difference in Difference and Quantile Regression Approach*

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# Abstract

The energy crisis of 2021 and 2022 has had severe consequences for Europe. The sky-high energy prices have reduced economic growth, created inflation, and increased GHG emissions. In an effort to tackle the record high prices, Spain and Portugal have been granted an exception by the EU to implement a cap on the price of gas used for generating electricity. The price cap, best known as the Iberian exception, has sought to limit the impact of volatile gas prices in the electricity market by decoupling the gas price from the electricity price. Within the context of the crisis, it is vital to assess whether the implemented measures have achieved their objectives.

This thesis studies the Iberian exception's impact on day-ahead electricity prices in Spain. By estimating a difference in difference model, we find a causal effect of the Iberian exception on day-ahead prices, confirming that the instrument does reduce electricity prices. Furthermore, the results from our quantile regression models show that the gas cap has reduced electricity prices across the price distribution, and reduced price volatility. The results confirm a partial decoupling of the gas price and the electricity price, and the price reducing effect of the instrument is only evident in conjunction with the gas price.

While our thesis provides evidence that the Iberian exception has been efficient in reaching its goal, it also highlights multiple adverse effects. The decoupling of gas and electricity prices has led to increased gas generation, alongside increased exports to France, thereby benefitting French consumers. Our analysis show that the Iberian exception can be considered a success in Spain. However, based on our results we do not recommend similar interventions in other European countries, as the adverse effects would exceed the benefits.

***Keywords*** – Electricity Markets, Electricity Prices, Energy Crisis, Iberian Exception, Price Cap, Spain, Difference in Difference, Quantile Regression

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# List of Abbreviations

| | |
|---|---|
| BBC | British Broadcasting Corporation |
| CET | Central European Time |
| CO2 | Carbon dioxide |
| EU | European Union |
| EUA | European Union Allowance |
| EUPHEMIA | Pan-European Hybrid Electricity Market Integration Algorithm |
| GHG | Greenhouse Gas |
| GW | Gigawatt |
| GWh | Gigawatt hour |
| IEA | International Energy Agency |
| KV | Kilovolt |
| LNG | Liquified natural gas |
| MIBEL | Iberian Electricity Market |
| MW | Megawatt |
| MWh | Megawatt hour |
| NTC | Net Transfer Capacity |
| OECD | Organization for Economic Cooperation and Development |
| OLS | Ordinary Least Squares |
| OMIE | Spanish and Portoguese power exchange |
| PV | Photovoltaics (Power) |
| PVPC | Voluntary Price for the Small Consumer |
| TSO | Transmission System Operator |

# 1 Introduction

In 2021 and 2022, Europe experienced its most severe energy crisis since the 1970s (OECD, 2022). The reduced natural gas imports from Russia, which started in the fall of 2021 and escalated further after the invasion of Ukraine, created critical shortages of natural gas in Europe. This led to sky-high commodity prices, which further caused record-high electricity prices across Europe. The shortage of natural gas, coupled with a 1-in-500-year drought restricting hydro production and nuclear energy struggles in France, created a perfect storm in both commodity markets and electricity markets (Jones, 2023). To combat the soaring prices, countries in Europe, as well as the European Union, introduced different kinds of measures. Most measures focused on reducing energy consumption and alleviating the cost for consumers. Yet the most drastic measure, which intervened directly in the electricity market, came from the Iberian Peninsula.

The topic of this thesis is the Royal Decree-Law 10/2022, better known as the "Iberian exception" or the "gas cap". In June 2022, Portugal and Spain were granted an exception by the European Commission allowing the countries to put a cap on the price of gas and coal used for electricity generation (The European Comission, 2022). The instrument has put a maximum limit of 40 €/MWh for the cost of fuel as an input to generation in the wholesale electricity market (The Spanish Government, 2022). Regardless of the market price of gas, gas-fired power plants can only bid 40 €/MWh to cover the cost of gas. The difference between the market price and the reference price is then compensated to the power plants, and this compensation is financed primarily with an additional tax on consumers' electricity bills. The main objective of the reform has been to reduce electricity prices for consumers by decoupling volatile gas prices from the wholesale electricity price.

The energy crisis has had severe consequences. It has reduced economic growth in Europe, created inflation and increased GHG emissions due to increased coal generation (OECD, 2022). It is therefore crucial to implement measures that can lift Europe out of the crisis, in addition to measures that can alleviate the negative effects in the short term. Consequently, it is also vital to evaluate whether existing measures have accomplished their goals, as well as studying the possible adverse effects. Since the Iberian exception's goal is to reduce day-ahead electricity prices, it is important to study whether the mechanism has had this intended effect, as well as examining the possible adverse effects.

To analyze the effect of the Iberian exception on day-ahead electricity prices, we utilize two different models. Frist, we apply a difference in difference model to evaluate the causal effect of the Iberian exception on the electricity prices. To do this, we compare the day-ahead prices in Spain and Germany. Secondly, we fit a quantile regression model to the data before and after the implementation of the Iberian exception. To capture the instrument's effect, we use a dummy variable while controlling for other factors that influences day-ahead prices. The quantile regression model is inspired by a thesis examining the impact of the NordLink interconnector between Norway and Germany (Myrvoll and Undeli, 2022). While the Iberian exception is not an interconnector, the quantile regression model is nonetheless suited for examining the impact of the instrument on electricity prices. We investigate the Iberian exception's impact on price levels, price volatility and peak prices with the quantile regression model. This, along with evaluating the causal effect with the difference in difference model, forms this thesis' research question:

*How has the implementation of the Iberian exception affected day-ahead electricity price levels and price volatility in Spain?*

The Iberian exception is a fundamentally new measure in the electricity market. The implementation of such a drastic measure would have been considered nearly inconceivable prior to the energy crisis. Therefore, research on how such a gas cap would impact the electricity price is limited. Nevertheless, there are some reports on the Iberian exception. Hidalgo-Pérez et al. (2022), Eicke et al. (2022) and Fuster (2022) all found a price reducing effect of the measure. These reports have investigated the price cap within the first couple of months. In contrast, our thesis aims to identify the causal effect of the gas cap on day-ahead electricity prices over a six-month time period.

Furthermore, to the best of our knowledge, there have not been any studies examining how the Iberian exception impacts different quantiles. By studying different quantiles of the electricity price, it is possible to get a greater understanding of how the gas cap impacts prices across the price distribution, enabling us to examine how the instrument impacts price volatility.

The results of the thesis show a significant price reducing effect from the Iberian exception on day-ahead electricity prices, providing evidence of a causal relationship between the gas cap and electricity prices. The gas cap has reduced electricity prices across the whole price distribution, and we also find volatility reducing effect. Furthermore, when examining possible underlying drivers of the results, we find that gas prices' positive impact on day-ahead prices have been reduced. This, in addition to the fact that we only find the price reducing effect of the Iberian exception in conjunction with gas prices, provides evidence for a partial decoupling of gas and electricity prices. Lastly, the results show that export capacity has pushed prices upwards, partially explaining the observed volatility reducing effect from the Iberian exception. The results regarding the gas price and export capacity are connected to the two main adverse effects of the Iberian exception. Increased gas generation, which is not beneficial with shortage of natural gas, and increased electricity exports, which leads to French consumers benefitting from the reform paid by Spanish consumer.

The thesis is divided into seven sections. Chapter 2 describes the characteristics of a general electricity market and the details about the Spanish electricity market, before explaining the energy crisis and lastly the Iberian exception in detail. In Chapter 3, a comprehensive overview of the data utilized to model electricity prices in Spain is presented, including detailed descriptions of the price data and the rationale behind the inclusion of each control variable. Chapter 4 explains the fundamental aspects of the difference in difference and quantile regression models, in addition to outlining our model specifications and the expected results. In Chapter 5, the results derived from the models are presented and interpreted. Furthermore, in Chapter 6 the results are discussed further and compared to other relevant studies, including recommendations for policy implications in Europe. Lastly, Chapter 7 comprises the concluding remarks, summarizing the main findings of the thesis, and presents suggestions for future research.

# 2 The Electricity Market and the Energy Crisis

Prior to the 1990s, the electricity markets in Europe were structured as vertically integrated monopolies with minimal cross-border interaction. However, with the initiation of deregulation processes in various countries' markets, competition was introduced in both production and retail (Bolton, 2022). In 1996, the EU approved the first European Directive concerning the liberalization of the electricity market starting the deregulation in Europe and creating the European electricity market. The goals of the reform were to organize the provision of electricity more efficiently by introducing market forces where possible, but also keeping regulation where needed (Pepermans, 2019). This separation between unregulated activities operating in a market and regulated activities was one of the key principles of the reform. The regulated activities included transmission and distribution of electricity, while unregulated included generation, marketing, and trade, which was now exposed to market competition. Spain followed this up by approving the policy Electricity Sector law in 1997 which built upon the EU regulation improving the liberalization and market competition (Ibeas Cubillo, 2011). With the regulations, the government did not longer have full control of the power market and market participants, both retailers and producers, could compete in a free market.

The energy producers and the retailers represent the supply and demand side of the electricity market, and electricity prices are determined by the intercept between supply and demand. Therefore, electricity markets are exposed to possible shocks in supply or demand which can drastically affect prices. Furthermore, electricity markets are particularly exposed because these markets need to be in balance, meaning that supply and demand are always equal, to avoid outages. Consequently, shocks, especially on the supply side, for instance an unprecedented increase in natural gas prices, can lead to exceptionally high electricity prices.

Fossil fuel generators are generally the most expensive sources of electricity needed to cover demand, though it varies between markets and the given time. Although coal-powered and nuclear generators have dominated in Europe both prior and after the liberalization, Europe has in the last decade seen a large increase in both renewables and gas-fired powerplants (IEA, 2023b). As such, Spain had a renewable energy share of 48.4% and a natural gas share of 25.7% in 2021 (Red Electrica, 2022). Because of the high share natural gas share in the last decade, natural gas often sets the price in the power market in Europe and Spain.

In the fall of 2021, the prices in Europe for coal and especially natural gas started to increase at a rapid pace. The primary reason for this increase was the reduced supplies of natural gas from Russia (Zettelmeyer et al., 2022). The high commodity prices lead to high electricity prices and the situation escalated further following the invasion of Ukraine by Russia, leading to record high electricity prices across Europe (Jones, 2023). The high prices lead to a debate on the Iberian Peninsula regarding the structure of the electricity market and whether there could be a solution to decouple gas prices from the price formation in the wholesale electricity market. One proposal was to implement a price cap on natural gas used for electricity generation (The Spanish Government, 2022). The cap at 40 €/MWh meant that generators using fossil fuels could only bid 40 euros for the cost of gas in the market, even though the market price of natural gas might be considerably higher. The eligible power plants would then be compensated for the difference between the cap and the market price. The goal of the proposal was to limit the wholesale electricity price and save money for the consumers. The details of the reform will be described further in this chapter.

As Spain and Portugal are a part of the EU, changes to their electricity market needs to be approved by the European Commission (The European Comission, 2022). In May 2022, the governments notified the Commission about their proposals, which subsequently approved the reform. The Commission highlighted that the power market on the Iberian Peninsula, MIBEL, has key differences compared to the rest of the EU. MIBEL has limited interconnection to the rest of the EU, consumers in the market have a high degree of exposure to wholesale prices and the market is highly influenced by the natural gas price. Consequently, the Commission granted an exception to the European electricity market under EU state aid rules, hence the name Iberian exception.

The deregulated and liberalized market has exposed the price of electricity to the price of natural gas. The gas cap further imposes a fundamental change in the dynamics of the Iberian electricity market, with several possible benefits and drawbacks. Therefore, further in this chapter we will examine the characteristics of the power market. Moreover, we will examine in detail the characteristics of the Spanish electricity market. Thereafter, the European energy crisis will be described. Finally, the Iberian Exception will be explained, and we will present some of the results and research on the gas cap.

## 2.1 Power Market Characteristics

### 2.1.1 Electricity Demand

Electricity demand in a market follows the consumptions patterns of consumers such as households and industry, but it is close to inelastic in the short-term suggesting that consumers are not overly sensitive to prices (Cretì, 2019). Demand also exhibits a baseline level, known as baseload, which it seldom falls below, and it follows a periodic pattern across days, weeks and seasons. For instance, demand is usually lower during the summer than the winter and lower on the weekends compared to weekdays. Due to the short-term inelasticity of electricity demand, the supply side is the primary driver of electricity prices.

### 2.1.2 Electricity Supply

Various power plants have different marginal production costs, which refers to the costs of generating one extra unit of electricity (Cretì, 2019). In energy markets suppliers of energy want to sell electricity when the price they can receive is equal to or higher than their marginal costs. This is not a unique feature in electricity markets. In fact, this is the basic dynamic in all free markets (Hirth, 2022). In liberalized electricity markets each supplier will submit the amount of electricity they want to sell for different prices, which makes up the supply curve for electricity. Further, various technologies have different marginal costs. Coal and gas generators are dependent on fuel to produce electricity, hence their marginal costs are influenced by the cost of the required fuel. This means that if natural gas prices are high, gas-fired generators will also have high marginal costs. On the other hand, renewable energy is not dependent on any type of fuel which is the reason for their marginal costs being close to zero (Cretì, 2019).

### 2.1.3 Auctions, Marginal Pricing and the Merit Order

There are different ways to organize deregulated and liberalized electricity markets. Most European countries have chosen to organize competition in the wholesale electricity market in an auction model (Cretì, 2019). There are two primary ways of organizing auctions in an electricity market. Either pay-as-bid where each cleared bid is remunerated at the bid, or pay-as-cleared, which is also called uniform auction. Uniform auction uses a concept called marginal pricing which refers to a mechanism where the price of electricity is determined by the marginal cost of the most expensive power plant necessary to cover the demand for electricity (Hirth, 2022). This means that the most expensive power plant needed to meet the demand becomes the "price setter", and that the price of electricity equals the marginal cost of that plant. All consumers and generators will receive and pay the same uniform price. This mechanism is often illustrated with the merit order curve, which is another name for the supply curve in electricity markets, in a chart which shows the marginal generation costs for different technologies (Hirth, 2022). Figure 2.1 and Figure 2.2 depict the same electricity market, but at different points in time, and their respective demand and merit order curve.

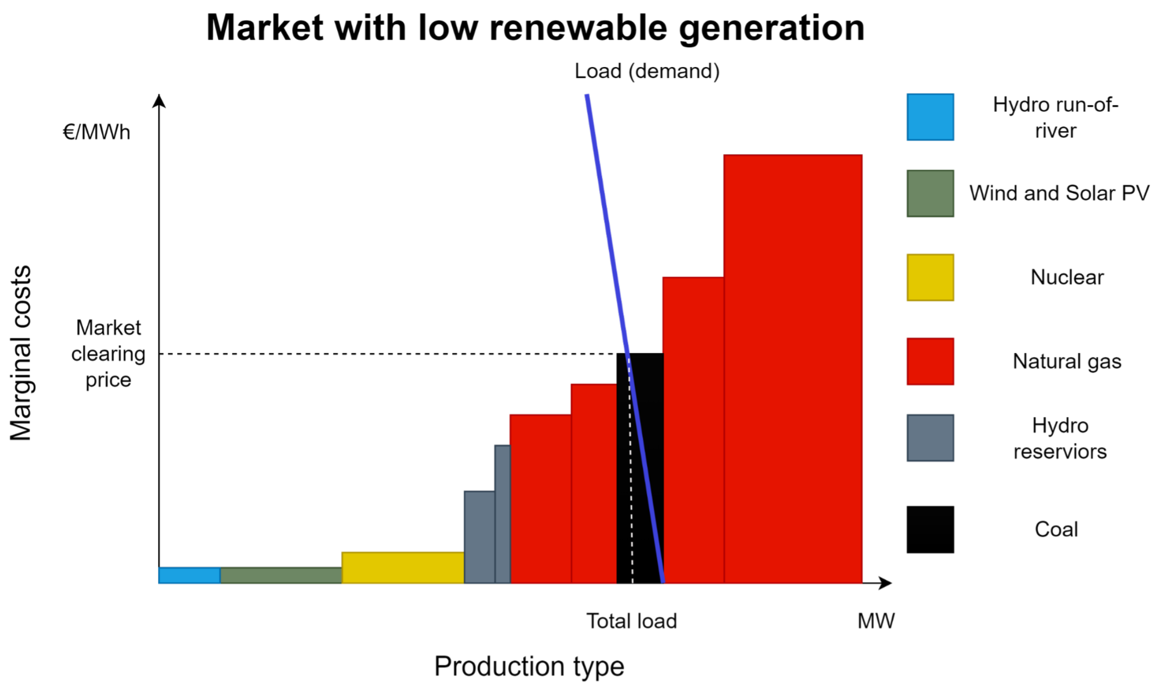



**Figure 2.1:** Market with low renewable generation. Source: Authors own elaboration.

Figure 2.1 shows an electricity market at a time with relatively low renewable energy production. We observe that various technologies have different marginal costs, but also that there is variation within technologies due to different efficiencies. The bids from producers compose the merit order curve. We see that in this instance, more expansive coal generation is needed to cover the demand. The marginal costs of this coal power plant set the electricity price in the market for all players.

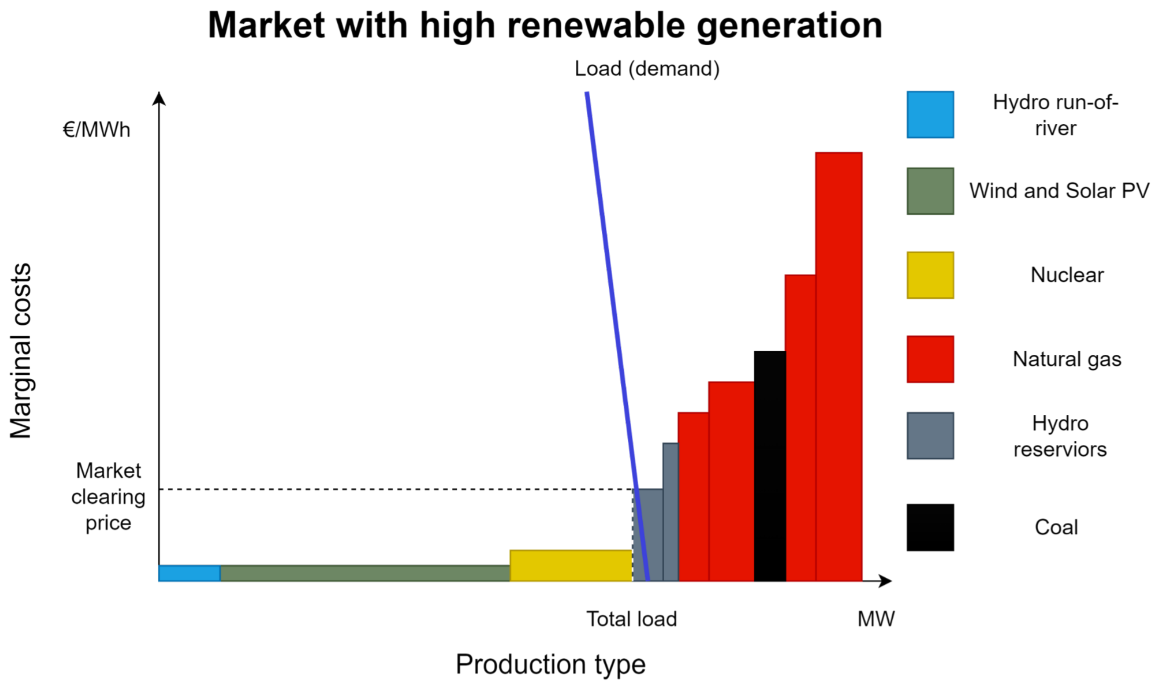



**Figure 2.2:** Market with high renewable generation. Source: Authors own elaboration.

In Figure 2.2, we observe the same electricity market with a higher output from wind and solar PV. In this instance, more expansive fossil fuel driven generators are not needed to cover the demand which consequently pushes prices downwards. Instead, a hydro reservoir is on the margin and sets the price in the market. Hydro reservoirs have low marginal costs, but because they can store energy, they will factor in the alternative cost of generating at a later stage in their marginal costs (Statkraft, 2022). Here, the hydro plant on margin does not expect to get a higher price for the water in its reservoir at a later stage.

### 2.1.4 Day-ahead Markets

As electricity moves close to the speed of light, exchange of electricity in most markets happens before the physical delivery (Cretì, 2019). In Europe, the electricity markets are organized on a power exchange which as a day-ahead auction in addition to a complementary intraday auction. The day-ahead market is the largest one in terms of both volume and liquidity (OMIE, 2022). Market participants, both producers and sellers of electricity, which are often called retailers, submit their bids in a closed auction the day before delivery for every hour of the following day. The players submit their orders after the publication of available capacities and interconnectors at 10:00 CET, indicating the volumes they wish to buy or sell at specific price levels (Spodniak et al., 2021). The submission deadline is 12:00 CET, after which orders are matched to create aggregated supply and demand curves for the specific market or area (OMIE, n.d.c). These supply and demand curves are as described in the prior section, and the market equilibrium for the given hour is the intersection between the curves. The prices for all 24 hours of the next day are announced at 12:45 CET.

The intraday market allows market participants to adjust to the day-ahead market's schedule by submitting takeover and selling bids for electricity corresponding to expected needs in real-time (OMIE, n.d.c). The market contributes to securing the necessary balance between generation and consumption, and with intermittent renewables this is becoming increasingly challenging. Since the emphasis of this thesis is the day-ahead market, the intraday market will not be explained further.

### 2.1.5 Coupling of European Markets

So far, we have looked at electricity markets which are isolated, but electricity markets are in most cases coupled with other electricity markets. This is especially the case in Europe, which is a highly integrated electricity market with interconnectors allowing for imports and exports of electricity between countries and different price areas (Cretì, 2019). Most European countries, including Spain, have one bidding zone, but some countries have several areas due to congestion in the electricity grid (Bjørndal et al., 2013). In coupled electricity markets, electricity flow between different countries and areas, therefore the supply and demand are no longer constrained to a given geographical area (OMIE, n.d.c).

The project Price Coupling of Regions is an initiative from eight different power exchanges in Europe to develop a single price coupling solution to compute electricity prices across Europe (NEMO Committee, 2020). The project is vital to realizing the EU's goal of a harmonized electricity market, and the project has resulted in the algorithm EUPHEMIA (NEMO Committee, 2020). EUPHEMIA calculates prices and energy allocation across Europe with the goal of maximizing the overall welfare. To calculate the market-clearing price for every price area for each trading period, EUPHEMIA is dependent on each area's supply and demand curves, i.e., each area's bids from both generators and retailers which the power exchanges in the given area provides. But the algorithm also requires the transmission capacity and constraints in the electricity grid, both within the given area, but also for interconnectors between countries, which is provided by the TSO's (NEMO Committee, 2020).

If the demand for electricity trade between two areas exceeds the physical capacity of the transmission lines, congestion in the electricity grid will occur, leading to different electricity prices in the two areas (Gugler et al., 2018). On the other hand, if the flow between the areas is lower than the capacity of the interconnectors, then the prices should be identical. Price difference between two coupled areas leads to congestion revenues (Cretì, 2019). This income is calculated as the difference in price multiplied with the flow in the transmission cable. If congestion happens within a country, the TSO in the given country collects the revenue. If congestion occurs between two areas, the TSO's of the countries split the income evenly (Cretì, 2019).

## 2.2 The Spanish Electricity Market

The electricity market on the Iberian Peninsula is called MIBEL and consists of Spain and Portugal. In 2007 the two countries' electrical systems were integrated to provide more benefits to consumers. MIBEL represents an economic, physical, legal, and regulatory convergence of the two markets (edp, 2022). However, even though MIBEL connects the two countries' electricity markets, each country still has its own bidding zone. This means that each country has its own wholesale electricity prices. Furthermore, the Iberian exception includes the entire MIBEL. Our primary focus is how the Iberian exception has impacted the Spanish electricity market, therefore we focus on Spain.

### 2.2.1 Electricity Demand in Spain

The total consumption of electricity on the Spanish mainland was 242 TWh in 2021, a 2.4% increase from 2020 (Red Electrica, 2022). However, 2020 was an unusual year with low electricity demand due to the ramifications of Covid-19. Figure 2.3 below shows the evolution of the electricity demand on the Spanish mainland in the last decade.

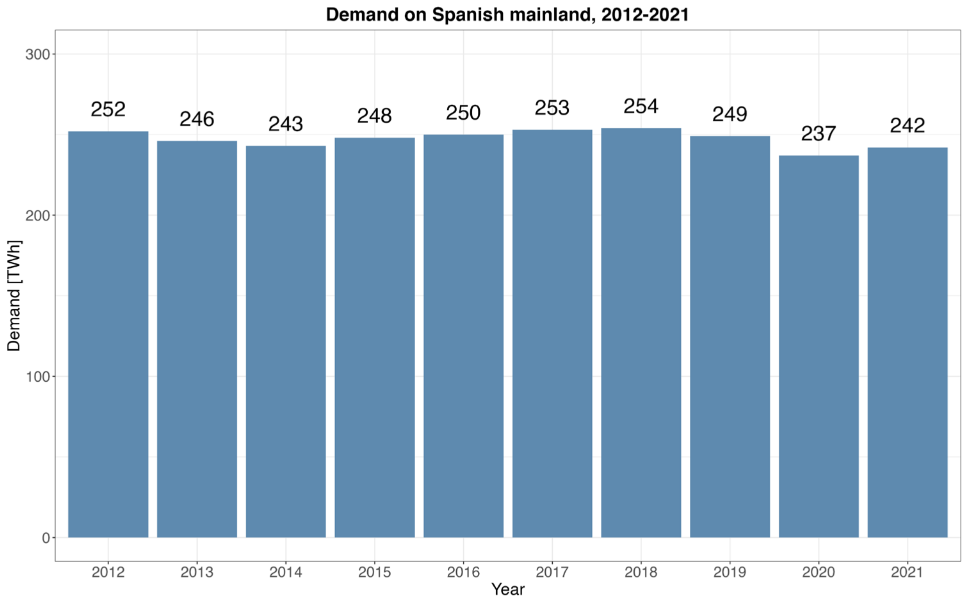



**Figure 2.3:** Annual electricity demand on the Spanish mainland (Red Electrica, 2022).

As of 2012, the demand for electricity has been relatively stable. The variations in demand have primarily been because of variations in temperature and GDP (Red Electrica, 2022). However, the demand is expected to increase going forward as several sectors in Spain is set for widespread electrification to reduce GHG emissions. While estimates vary, the demand for electricity in 2050 is expected to reach at least 300 TWh annually (Statista, 2021).

### 2.2.2 Electricity Supply in Spain

Total generation on the Spanish mainland reached 247 TWh in 2021, making Spain the fourth largest producer of electricity in the EU behind Germany, France, and Italy (Red Electrica, 2022). Coal and nuclear generators have historically dominated the electricity mix, both before and after the liberalization of the power market. However, since 2000, the share of natural gas and wind energy has increased considerably. Furthermore, in the last decade, solar PV has grown while coal has gone from dominating to becoming negligible (IEA, 2023c). The electricity mix for Spain in 2021 is summarized in Table 2.1.

| **Production type** | **Share** |
|---|---|
| Wind | 24.0% |
| Hydropower | 12.0% |
| Solar PV | 8.3% |
| Solar Thermal | 1.9% |
| Nuclear | 21.9% |
| Coal | 2.0% |
| Combined Cycle (natural gas) | 15.2% |
| Cogeneration (natural gas) | 10.5% |
| Other | 4.2% |

**Table 2.1:** Electricity mix on Spanish mainland. Data from 2021 (Red Electrica, 2022).

The renewable energy share of 48.4% in 2021 was record high with an increase of 9.6% from 2020, making Spain the second-largest generator of renewable energy in Europe (Rystad Energy, 2022). The increase was largely due to solar PV which increased its generation by 37.4% from the last year. On the other hand, natural gas fell from 27.3% in 2020 to 25.7% in 2021. Natural gas generation comes primarily from two different technologies, combined cycle and cogeneration. Combined cycle is put simply a traditional natural gas power plant, while cogeneration, also called Combined Heat and Power, will in addition to selling electricity also sell heat, which makes this technology more efficient. Spain imports most of its natural gas through their seven LNG terminals, in addition to pipelines from North Africa. In 2021, Algeria was the biggest exporter to Spain with approximately 44%, followed by the US with 13% and Nigeria with 11% (Archyde, 2022).

Regarding power capacity, the Spanish mainland had 108 GW installed at the end of 2021, in which 58.7% were renewables, the second highest in Europe after Germany (Red Electrica, 2023). Table 2.2 below shows the share of installed capacity from the different production types.

| Production type | Share |
|---|---|
| Wind | 25.8% |
| Hydropower | 15.9% |
| Solar PV | 13.8% |
| Solar Thermal | 2.1% |
| Nuclear | 6.6% |
| Coal | 3.3% |
| Combined Cycle (natural gas) | 22.8% |
| Cogeneration (natural gas) | 5.2% |
| Other | 4.6% |

**Table 2.2:** Installed capacity on Spanish mainland. Data from 2021 (Red Electrica, 2022).

Spain is a part of the EU which has put in place several initiatives for renewable energy and decarbonization. The Fit for 55 package refers to the EU's target of reducing net GHG emissions by at least 55% by 2030. The package is a set of proposals to revise and update EU legislation as well as new initiatives to align EU policy to its climate goals. One of the goals is to increase the overall renewable energy share in the electricity mix in 2030 to 40% (The European Council, 2023).

Spain also has national ambitious targets of increasing the renewable energy in the country. Spain's Long-Term Decarbonization Strategy 2050, which was approved in 2020, includes for instance goals for increasing the renewable energy share to 74% by 2030 and 97% by 2050, far above EU targets (MITECO, 2020). The Spanish Prime Minister, Pedro Sanchez, has a goal of turning Spain into Europe's energy powerhouse (Müller, 2022). Spain especially has ambitious goals for green hydrogen exports by utilizing its vast resources within solar and wind energy and well-developed port infrastructure (Wetselaar, 2023).

### 2.2.3 OMIE - The Power Exchange

OMIE is the nominated electricity market operator for MIBEL with responsibilities of managing the Iberian Peninsula's day-ahead and intraday electricity markets (OMIE, n.d.a). OMIE was established in Spain after the deregulation of the electricity market. In 2015, Portugal appointed OMIE as their nominated electricity market operator creating the fully integrated Iberian marketplace (Europex, n.d). The market on OMIE is connected to other European markets through Price Coupling of Regions.

The majority of the volume traded at OMIE is settled in the day-ahead market, which has the same characteristics as other European day-ahead markets explained in Section 2.1.4. Out of the volume traded on OMIE in 2021, including both Spain and Portugal, 85% was traded in the day-ahead market, while the remaining 15% was traded in the intraday market (OMIE, 2022). In the day-ahead market, market players can submit different types of orders. Simple bids are single hourly orders which indicate a price and an amount of power, meaning that there is no dependency between hours for these bids. Complex bids on the other hand are bids that incorporate complex sale terms and conditions, which do create dependencies between hours. They can for instance include load gradients, which are conditions that set a maximum difference between generation in one hour and the next to avoid sudden changes in the generation units (OMIE, n.d.b). In Spain, the total amount of electricity in the day-ahead market was 248 TWh, where 176 TWh, or 71.1%, were traded in the spot market at OMIE, while the rest was trough bilateral contracts (Red Electrica, 2022).

Table 2.3 shows which production type that determined the price in the day-ahead market in Spain in 2021. Hydropower plants with reservoirs have the ability to store energy and if the producers expect higher prices in the future they will hold back production, explaining why hydro often sets the electricity price in Spain (Statkraft, 2022). In addition to hydropower, natural gas, either through cogeneration or combined cycle, often sets the price in the market, as expected following the merit order principles explained in Section 2.1.

| **Production type** | **Share** |
|---|---|
| Hydropower | 54.9% |
| Renewables, cogeneration and waste | 23.6% |
| Combined cycle (natural gas) | 15.9% |
| Pumping generation | 10.2% |
| Coal | 1.5% |
| Imports Portugal | 0% |

**Table 2.3:** Production type that sets the price on Spanish mainland (OMIE, 2022).

### 2.2.4 The Electricity Grid and Export Balance

The TSO in the Spanish electricity grid is Red Eléctrica, responsible for operating the electricity system and guaranteeing security and continuty of supply (Red Electrica, 2021).

The electrical grid in Europe is designed to be at 50 hertz at all times, and unbalance between generation and consumption makes the frequency deviate from 50 hertz. Therefore, Red Eléctrica manages the transmission facilites in real-time to secure the stability of the system. The TSO is responsible for ancillary services markets, which are markets aimed to resolve technical constraints in the system by changing production from generation and storage units at the lowest costs for the system (Red Electrica, 2021). These markets follow the day-ahead and intraday markets, meaning that the TSO will use them if balancing is still needed after the auctions are finished.

The electricity network in Spain consists of several layers, where the transmission system has the highest capacity as they cross the country with 400 kV lines (Red Electrica, 2022). These lines transport electricity from large powerplants to the distribution system which at lower volatages delivers electricity to the end consumers. Spain's electricity network is particularly flexible compared to other grids in Europe, which allows electricity to flow with less congestion from wherever it is created to wherever it is needed, noteably integrating renewables more efficently in the grid (Wetselaar, 2023).

The grid in Spain is also connected to other countries, namely Portugal, France, Marocco and Andorra. The capacities of the interconnections vary throughout the day, week and year. The maxiumum capacites of the different connections is shown in Table 2.4. The overall capacity has increased the last decade, but it is still far below the targets for the EU regarding interconnections. However, there are several plans for new interconnections, particularly with France where the target is to increase the capacity to 8 000 MW. (Red Electrica, 2022)

| **Interconnection** | **Capacity (MW)** |
|---|---|
| France | 2 800 |
| Portugal | 2 300 |
| Marokko | 900 |

**Table 2.4:** Interconnection capacities on Spanish mainland (IEA, 2022).

Spain has been an annual net importer of electricity from 2016 to 2021, altough the net imports have been declining since 2018 (Red Electrica, 2022). While Spain were a net exporter to Portugal in 2021, they were a net importer of electricity from France. Net imports from France amounted to approximately 6 TWh in 2021. The cross-border connection with France had a high utilization rate of 81.9%, with the flow going from France to Spain 62% of the hours. There was no congestion between the countries for 34.8% of the time in 2021, meaning that the demanded exchange of electricity were lower than the capacities of the grid for only a third of the time. This further means that the interconnectors had insufficiently low capacites to even out the electricity prices in the markets for two thirds of the time, demonstraiting the low capacity for electricity exchange. The congestion revenue from the interconnection was €438 million in 2021 (OMIE, 2022).

## 2.3 The European Energy Crisis

In the late summer of 2021 commodity prices in Europe started to increase. Natural gas prices, coal prices, EUA and electricity prices all started to increase over levels that were deemed normal (IEA, 2021). The high prices were predicted by several analysts to fall in the medium to long term, but the high prices persisted. The situation escalated further after Russia invaded Ukraine with commodities breaking price record after price record (Jones, 2023).

### 2.3.1 Shortages of Russian Natural Gas

The primary reason for the energy crisis in Europe is the shortages of Russian natural gas (BBC, 2022c). Natural gas is a key commodity in Europe, and it is used in power generation, industry and for heating purposes (Jones, 2023). Europe and especially the EU does not produce much natural gas themselves, hence they are dependent on imports. Russia has been a stable exporter of gas to Europe for several decades and before the crisis they covered about 40% of the consumption of gas in Europe (BBC, 2022c). In 2021, the flow of natural gas from Russia started to decrease. While Russia delivered the quantities they were required, the supply of Russian gas in the spot market fell. This caused the price of natural gas in Europe to increase. At the same time, and to some degree as a consequence of the increasing gas prices, the price for coal, EUA and electricity increased as well (IEA, 2021).

In late February 2022, the situation escalated further when Russia invaded Ukraine. The EU, together with other countries, imposed sanctions towards Russia, which they responded to by cutting the gas supply further, increasing the prices to sky-high levels. From September 2021 to September 2022, Russia cut its gas supplies to the EU by 88% according to the research firm Argus Media (BBC, 2022b). The shortfall forced European countries to find other suppliers for natural gas. While Norway increased its exports, it was LNG that became the lifeline for Europe. But LNG is a global market which means that Europe had to overbid other players, particularly Asian countries, to get the shipments of gas towards Europe. The demand shock in the LNG market led to extreme prices on the cargos, which further led to higher prices for gas in Europe, but also in other markets. To visualize how extreme natural gas prices have been in Europe, we can look at the Spanish gas price index, called MIBGAS Natural Gas futures index, shown in Figure 2.4.

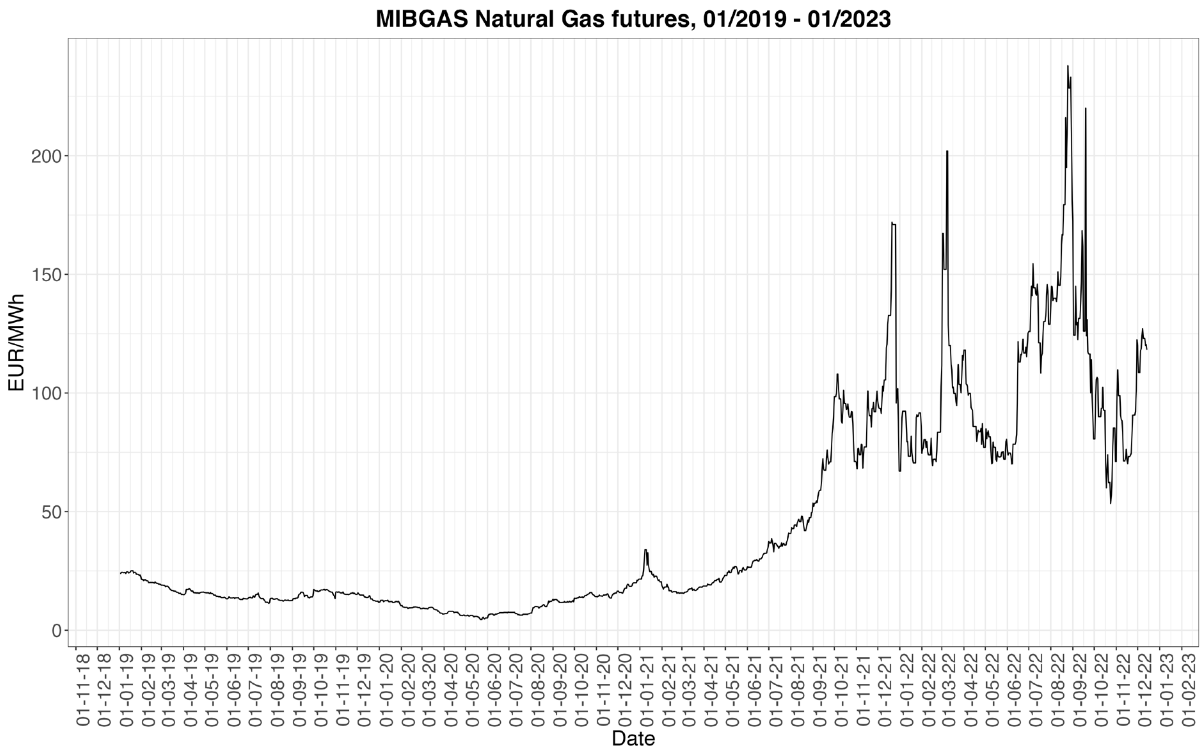



**Figure 2.4:** MIBGAS Natural Gas futures Bloomberg, Ticker: MIBGRPMA.

Compared to other European countries, Spain is not as dependent on Russian natural gas. Before the Ukraine war, Spain received just below 10% of its imported natural gas from Russia through LNG (Archyde, 2022). However, primarily due to diplomatic challenges with Algeria, Spain increased its imports of Russian LNG after the war in Ukraine broke out. In May of 2022, Russian LNG accounted for 12% of the gas imports to Spain (Reuters, 2022). As Spain has several terminals for LNG, the country does not have the same barriers when it comes to access to natural gas compared to other European countries. However, Spain still experienced the extraordinarily high prices on natural gas and the effects it further had in the electricity market.

### 2.3.2 Draught and Nuclear Maintenance

In addition to shortages of natural gas, Europe experienced what is likely the worst draught in 500 years in the summer of 2022 (BBC, 2022a). The alps and Iberia were particularly affected, and both Spain and France experienced a hydro output reduction of over 10 TWh, with the year-on-year change in output down by 37% in Spain (Jones, 2023).

The drought had further consequences than just hydropower production. The heatwave in the summer of 2022 led to high temperatures in rivers used for cooling nuclear plants, which forced several French nuclear plants to reduce generation. Furthermore, during planned maintenance problems with corrosion were detected leading to longer maintenance and unplanned shutdowns of 12 additional reactors (IEA, 2023a). In total, the French nuclear fleet's output fell by 82 TWh, a reduction of 22% from 2021. The lower output put a substantial upwards pressure on electricity prices in France, and thus Spain who in a normal year imports several TWh of electricity from France. On the other hand, the Spanish nuclear reactors increased their production with approximately 3%, but this was far from enough to upset the reduction in France (Jones, 2023).

### 2.3.3 Sky-high Electricity Prices

The reduced hydro and nuclear output and especially the extraordinary high natural gas prices had a big impact on the electricity price in Europe and in Spain. To understand how the high gas prices impact the electricity market, we can look at the merit order curve and the market equilibrium explained in Section 2.1 shown in Figure 2.5. To simplify, in this market we will exclude imports and exports.

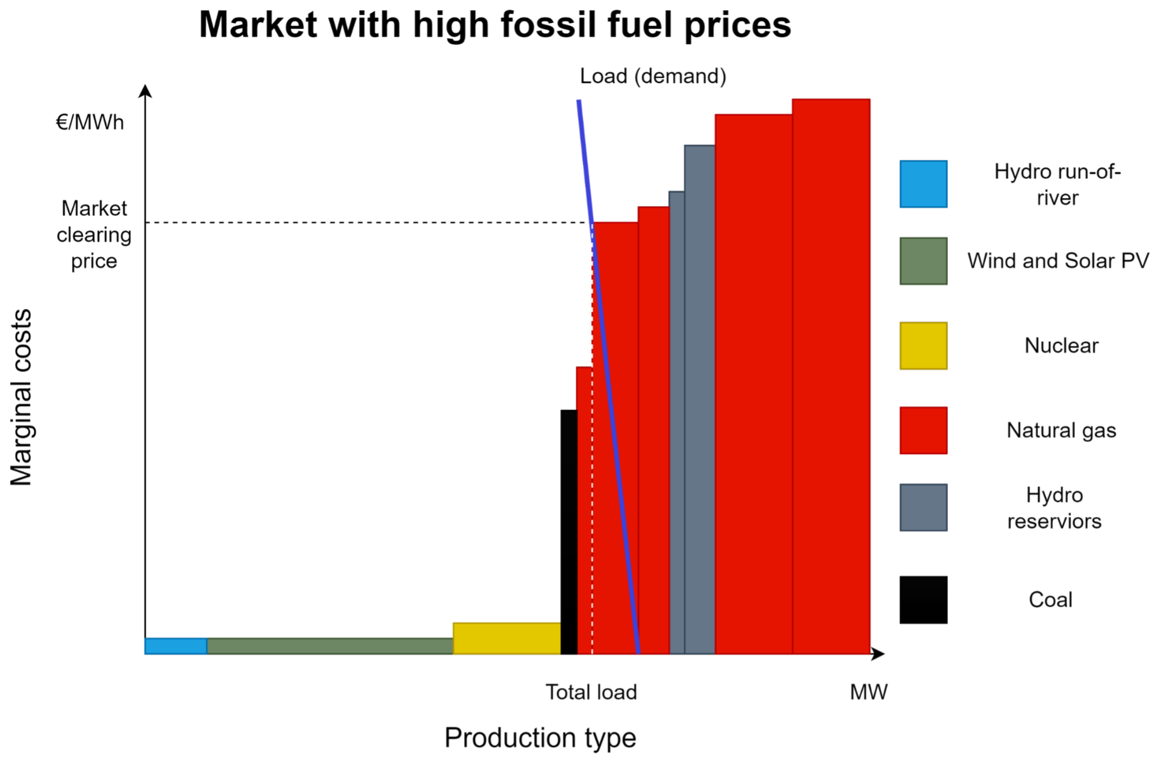



**Figure 2.5:** Market with high fossil fuel prices. Source: Authors own elaboration.

In this market the renewable energy output is relatively high, but still there is a high market clearing price. The reason for this is that the bids from the gas-driven power plants have increased drastically because their marginal costs have increased substantially due to the high gas prices. In this case, even though almost all demand is covered by renewables and nuclear which have low marginal cost, the electricity price is high since a small part of the demand needs to be covered by expensive gas. Furthermore, because the increase in gas prices increases the forward electricity price that market operators expect, hydro reservoirs will also require a higher price for their production. Therefore, with such high gas prices, gas generators will more often be on the marginal and set the electricity price at a high level. In fact, combined cycle sat the electricity price twice as high in Spain in 2022 compared to the previous year (OMIE, 2023).

The energy crisis has been met by assertive responses from European countries and the EU. The EU introduced the REPower EU packages in response to the war, describing it as the 11th floor on a ten story building where the ten floors below is the Fit for 55 packaged (Ask, 2022). For instance, the goal of renewables in the electricity mix by

2030 have increased from 40% to 42.5% with the new package (The European Comission, 2023b). Moreover, the package included several plans for reducing the demand for energy. Furthermore, in August 2022, the EU also agreed to a voluntary 15% cut in consumption of natural gas (Liboreiro, 2022). The EU has also introduced different taxes on excess profits made by various energy companies (BBC, 2022c). However, the most drastic response to the energy crisis did not come from the EU, but from the Spanish government.

## 2.4 The Iberian Exception

In June 2022, Spain and Portugal were granted an exception by the European Commission allowing the countries to put a cap on the price of coal and gas used for electricity generation (The European Comission, 2022). Royal Decree-Law 10/2022, or better known as the “Iberian exception” or the “gas cap”, is a measure that Spanish and Portuguese governments had been working on for several months pending the approval from the EU. The measure is a consequence of the energy crisis, and its primary goal is to reduce the wholesale electricity price in the Iberian electricity market (The Spanish Government, 2022).

### 2.4.1 What is the Iberian Exception?

The Iberian exception is a compensation paid to certain fossil-fuel driven power plants to reduce the wholesale electricity price. Natural gas combined cycle power plants, coal-fired power plants and some cogeneration plants are eligible for the compensation (The Spanish Government, 2022). However, only power plants not operating under physical bilateral contracts are included, meaning plants which have hedged themselves by selling electricity in derivative markets do not receive compensation. The cap is a maximum limit of 40 €/MWh for gas and coal as an input to generation, meaning that regardless of current gas price, a gas-driven power plant can only bid 40 €/MWh in the market to cover the cost of the fuel. Despite that fossil-fuel generation has other marginal costs, the fuel costs are an substantial part. Therefore the cap will in theory reduce the bids from fossil generators in the market. The plants that are eligible will be compensated for the difference between the market price, the MIBGAS gas price is used as a benchmark, and the reference price at 40 €/MWh, so that their marginal costs are fully covered (IEA, 2023a).

The Iberian exception went into effect on the June 15th, 2022 and was intended to last until May 31st, 2023. The reference price of 40 €/MWh was for the first six months, before it was intended to increase by 5€ monthly before reaching 70 €/MWh. The compensation is financed through an extra charge to consumers with contracts based on regulated tariffs, in addition to congestion revenue on the interconnector between France and Spain (IEA, 2023a). The regulated tariff Voluntary Price for Small Consumers, known as PVPC in Spain, is a tariff that directly replicates the wholesale price, in addition to including payments for transmission and taxes (Red Electrica, n.d.). There are around 10 million households that use the PVPC, and they bear the cost of the reform because they are the first to benefit from the measure. However, the costs will in a second phase also be covered by consumers on the free retail market (Hidalgo-Pérez et al., 2022).

The main objective of the reform is to reduce the electricity prices for consumers, mainly the PVPC, by decoupling gas prices from electricity prices in the wholesale market (The European Comission, 2022). However, decoupling the two commodity prices requires invasive measures in the electricity market, which is highly controversial. While the EU approved the measures from Spain and Portugal, they emphasized why the Iberian Peninsula had been granted the exception. MIBEL has limited interconnectors to the rest of the European electricity market, which constraints the impact that the measure can have on the rest of Europe. Furthermore, MIBEL has a high influence of gas in electricity price setting in addition to consumers being highly exposed to the wholesale electricity price. Moreover, the energy crisis has caused serious disturbance to the economy of the Iberian Peninsula. Importantly, the single European electricity market is preserved, and the measure keeps competition distortions to a minimum, in addition to avoiding potential negative impacts on the functioning of spot and forward electricity markets (The European Comission, 2022).

### 2.4.2 How Does the Gas Cap Work?

There are already a few caps on energy in Europe. For instance, France has implemented a cap which only allows retail companies to increase the price of electricity by 4% annually (Pearson, 2022). However, there are key differences between this cap and the Iberian exception. The French cap does not directly intervene in the electricity market. Instead, it forces retail companies, primarily state majority owned EDF, to buy electricity in the wholesale market and then sell the electricity to consumers for increased prices, with a maximum increase of 4% annually, despite selling the electricity with a loss (Schofield and Kirby, 2023). Furthermore, the EU has put a cap on natural gas prices on the Dutch TTF commodity exchange, which is activated if the price is above 180 €/MWh for three days (BBC, 2022c). Nevertheless, this cap limits the price of natural gas itself, not natural gas used for electricity generation. The Iberian exception, unlike other caps, impacts the electricity market directly by reducing the marginal costs of the fossil-fuel driven generators.

We can once again use the merit order curve to illustrate how the gas cap should in theory reduce electricity prices shown in Figure 2.6. The shaded bars represent the bids from the gas-generators if there is no gas cap.

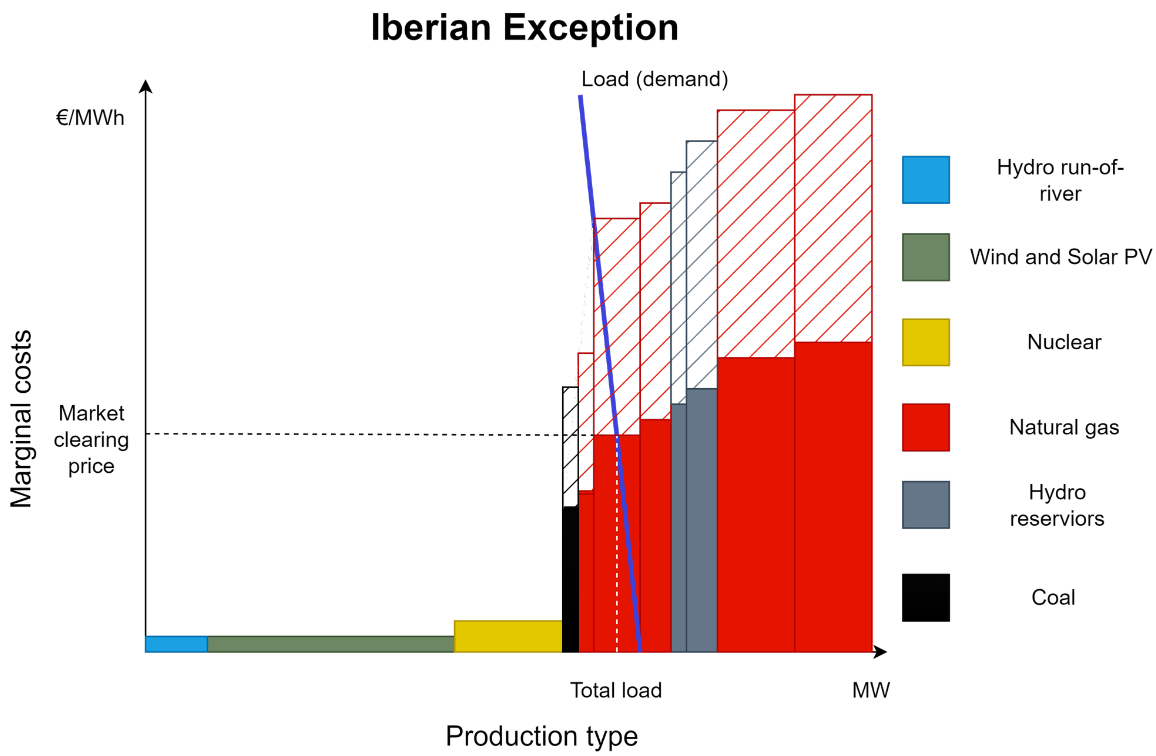



**Figure 2.6:** Market with the Iberian exception. Source: Authors own elaboration.

We observe that the marginal costs from the fossil-fuel driven generators have fallen from the levels without the gas cap implemented, but we also see that the marginal costs for the hydro reservoirs have fallen. The Iberian exception has reduced the expected future prices for electricity, therefore the hydro producers are willing to sell for lower prices. The reduction in marginal costs reduces the merit order curve pushing down the electricity price, showing in theory how the gas cap should reduce prices.

The savings for the consumers on the PVPC, especially if we ignore the congestion income, occurs because the compensation paid, despite being borne by them, to fossil-fuel generators is smaller than the savings on the wholesale price. The consumers pay the entire marginal costs for gas generation through the market and the compensation, meaning the savings does not come from here. Instead, the savings comes from inframarginal technologies such as renewables and nuclear. Because the cap reduces the wholesale electricity price, these generators receive a smaller profit, leading to savings for the consumers.

### 2.4.3 Research on the Iberian Exception

There has been limited research on the Iberian exception since the reform started under a year ago of the time of writing. There is however some research with interesting findings. Hidalgo-Pérez et al. (2022), researchers from the Madrid-based research institute EsadeEcPol, examined the impact of the gas cap on the PVPC tariff from June 15th , 2022 until August 31st , 2022. They compared the actual evolution of the PVPC tariff with a statistical model that created a hypothetical price from a market with no Iberian exception. The findings showed that the electricity price in the regulated market would have been 19% - 30% higher without the cap and that this decrease is likely due to the reform. However, they also found several other effects of the Iberian exception.

First, the authors found that the gas generation increased significantly after the implementation. Even though this happened at the same time as hydro output decreased due to the drought, the findings still suggested that the reform may have reduced the incentive for transition to clean sources and even incentivizing increased gas generation, which during gas shortages in Europe is the opposite of what is needed. Lastly, the results showed that exports to France increased considerably after the cap. While the challenges with French nuclear reactors complicates the interpretation, it is likely that the gas cap has increased exports. This presents another drawback of the gas cap. Due to increased export to France, it is likely that French consumers have benefited from the cap in the form of lower prices without having to pay for the measure themselves.

Furthermore, the findings of Fuster (2022) support the results from Hidalgo-Pérez et al. (2022). By using a regression analysis, Fuster found that the gas cap has had a clear weaking effect on the correlation between the MIBGAS gas price and the PVPC tariff. Before the implementation, a 10% increase in gas price led to 6.3% increase in the PVPC, whilst after the cap this increase was down to 2.9%. The author also found that the Iberian exception has reduced the wholesale electricity price by 62% and the PVPC price by 35% since the implementation. Lastly, Fuster also founds that exports to France have increased, with the maximum export capacity from Spain to France being reached daily, and that the cap has led to increased gas generation.

In addition, Eicke et al. (2022) found a reduced wholesale price following the implementation. They estimated that without the cap the average spot price from June 15th , 2022 until August 13th , 2022 would have been 299 €/MWh, while the average spot price at OMIE for the same period was 144 €/MWh. However, the authors emphasized that consumers using the PVPC would have to pay the compensation, which was at 109 €/MWh giving a net benefit of 46 €/MWh to the consumers. Moreover, Eicke et al. (2022) highlighted the mentioned problems with increased exports to France and increased gas generation, which increased by 42% after June 15th.

# 3 Data

In this chapter we will present the data in our thesis. First, we will focus on the details of the electricity prices, where we will discuss the distinct electricity spot price characteristics and describe the dataset of electricity prices. Afterwards, we will discuss the Iberian exception and how we account for the reform in our model. To conclude, we will discuss the fundamental factors which influence the electricity spot prices and motivate the selection of variables we will include in various models.

## 3.1 Electricity Spot Prices

Our data set of hourly day-ahead spot prices spans from October 1st, 2021, until December 15th, 2022. The reasoning for the starting point of our analysis is the surging gas prices in October 2021 as shown in Section 2.3, Figure 2.4. As the Iberian exception is an act to reduce the extreme prices on energy, we see it appropriate to examine the impact of the reform in the period of the energy crisis. Thus, we do not include the time period of the normal state before the crisis. Furthermore, we recall that the gas cap is capped at 40 €/MWh for the first six months, before it increases with 5 €/MWh per month. In addition, the energy crisis deescalated from December 2022 and onwards with the market price for gas frequently being under the gas cap (MIBGAS, n.d.). Therefore, we evaluate the impact of the Iberian exception in the first six months of the reform making the end point of our analysis December 15th, 2022.

The data on day-ahead spot prices for the Spanish bidding area have been obtained from Entso-e, the European transmission system operator. Data on day-ahead spot prices for the German bidding area have been collected from Nord Pool's FTP server. The price data includes hourly observations and is measured in €/MWh. We use German electricity spot prices as a counterfactual for Spanish electricity prices for the specified models in our thesis. The reason for using German electricity prices is that they tend to move together with Spanish prices in the period before the Iberian exception.

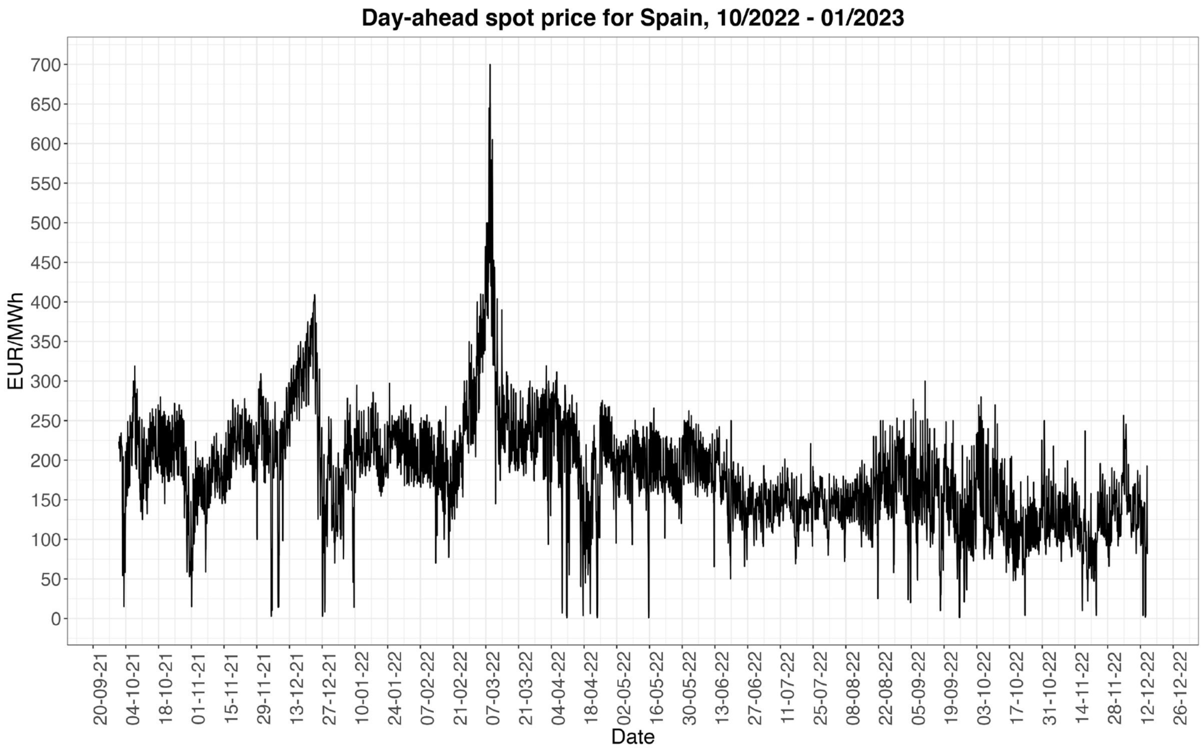



**Figure 3.1:** Spanish day-ahead spot prices for each hour of the day from 01.10.2021 - 15.12.2022.

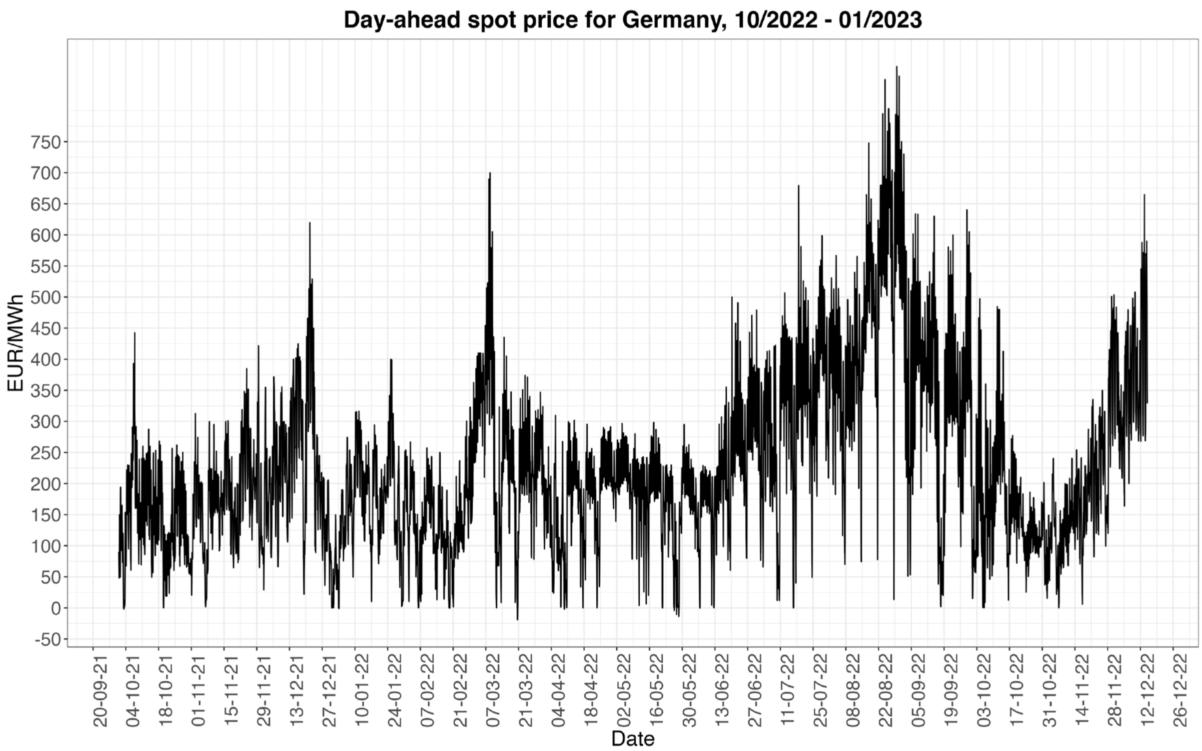
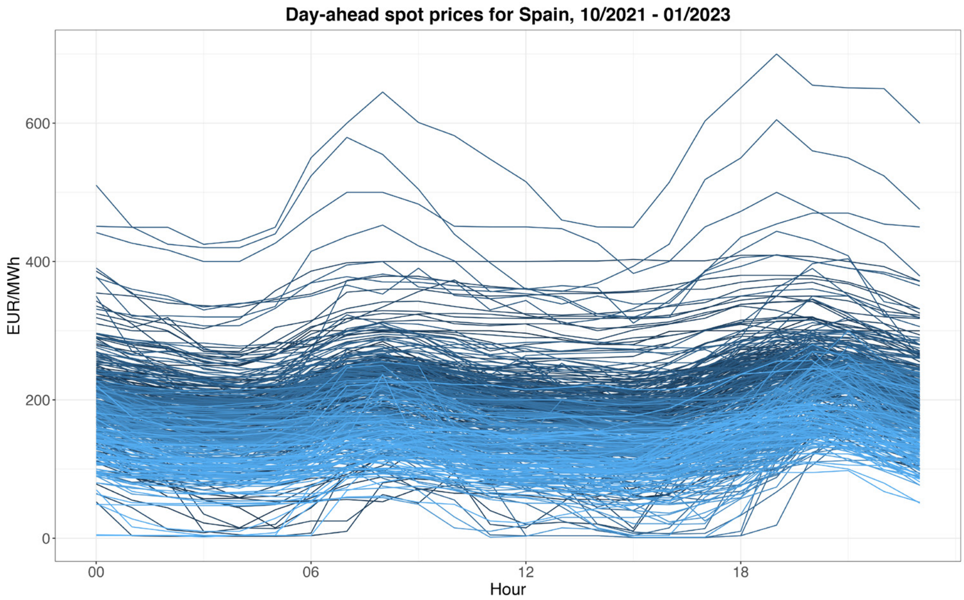


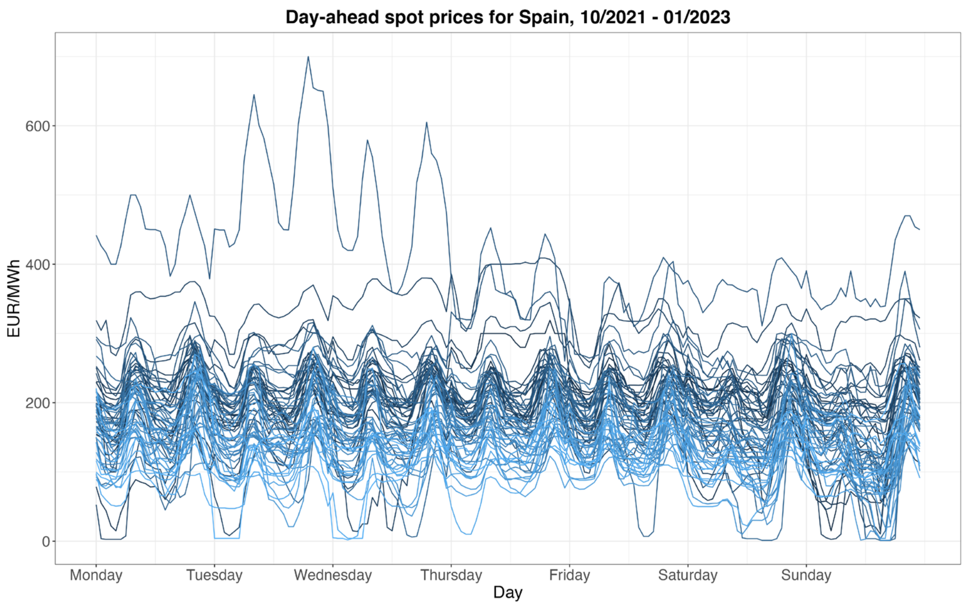

**Figure 3.2:** German day-ahead spot prices for each hour of the day from 01.10.2021 - 15.12.2022.

The day-ahead spot price series for Spain and Germany are shown in Figure 3.1 and Figure 3.2. The data exhibits price spikes in the positive and negative direction in the short term. Price spikes are most prominent in cases of intermittency in non-storable electricity, forced outages of power plants or sudden fluctuations in demand. Further, the extreme price spikes have mean reverting tendencies. Mean reversion is the tendency of the price of a commodity or financial asset to move to its long-term price level (Bunn and Karakatsani, 2003). Moreover, the spot prices show high volatility where the magnitude of the volatility is higher compared to other commodities and financial assets.

Furthermore, electricity spot prices exhibit strong seasonal patterns with respect to yearly seasons, weekdays and intraday. Further, Figure 3.3 shows the weekly and daily seasonal subseries of day-ahead spot prices for Spain and Germany. Looking at Figure 3.3b, we observe that the electricity spot prices exhibit lower spot prices during the weekends compared to the weekdays. The spikes on the weekends are also different than the spikes during the weekdays in that the first spike in the weekend is lower than the second spike, while in the weekdays the spikes are equal to the height of the spikes of the average spot prices. Finally, as seen in Figure 3.3a, the electricity spot price exhibits higher prices in the morning and the afternoon.




**(a)** Seasonal plot showing daily seasonal patterns for Spanish day-ahead spot prices.




**(b)** Seasonal plot showing weekly seasonal patterns for Spanish day-ahead spot prices.

**Figure 3.3:** Seasonal plots for Spanish day-ahead spot prices in the period 10/2021 - 01/2023.

### 3.1.1 Descriptive Statistics

Table 3.1 summarizes the descriptive statistics for the electricity spot price dataset for each country that we will use in the thesis. Mean spot prices differ for each country, with 180.658 €/MWh for Spain and 226.696 €/MWh for Germany. The standard deviation of prices is high, with 67.895 €/MWh for Spain and 136.040 €/MWh for Germany. The

| | **Spain** | **Germany** |
|---|---:|---:|
| Min | 1.03 | -19.04 |
| Max | 700.00 | 871.00 |
| Mean | 180.66 | 226.70 |
| Median | 177.00 | 200.34 |
| Standard Deviation | 67.89 | 136.04 |
| Skewness | 0.97 | 1.02 |
| Kurtosis | 6.99 | 4.24 |
| Jarque-Bera | 8671.18 | 2516.03 |
| N | 10560 | 10560 |

**Table 3.1:** Descriptive statistics of day-ahead spot prices for Spain and Germany.

maximum price of 871.000 €/MWh is observed for Germany, and 700.000 €/MWh for Spain. The minimum price observed for Spain and Germany is 1.030 €/MWh and −19.040 €/MWh respectively. The existence of negative prices in electricity markets is attributed to the market practice of generators. Negative prices occur when supply offered at negative prices is greater than demand, which typically happens in the middle of the day due to solar energy. The generators will bid negative prices because it is more profitable for them to pay to produce electricity than to reduce output, which can come with significant costs, in particular for thermal power sources such as nuclear and coal (Stanwell, n.d.).

The median spot price is lower than the mean for Germany and Spain. This indicates that spot prices are right skewed. Moreover, the distribution of spot prices for both countries display positive excess skewness with coefficients higher than 0.5, and high positive kurtosis with coefficients in the order of 1000. This is consistent with the findings of Bunn et al. (2016) and may be driven by the existence of extreme prices or negative prices. The Jarque-Bera statistics for both countries are very high and reject the null hypothesis of normal distribution at 1% level of significance. This is consistent with the findings of Bunn et al. (2016).

The empirical quantiles for Spanish spot prices are reported in Table 3.2, from the 5% quantile to 95% quantile. The data exhibits a broad spread of spot prices as the variability in the spot price is large, ranging from 85.000 €/MWh in the 5th quantile to 289.284 €/MWh in the 95th quantile.

| **Quantile** | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% |
|---|---|---|---|---|---|---|---|---|---|---|
| **Price** | 85.00 | 101.98 | 115.02 | 127.05 | 137.31 | 145.97 | 153.06 | 161.08 | 169.74 | 177.00 |

| **Quantile** | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|
| **Price** | 185.00 | 193.50 | 200.36 | 209.89 | 218.01 | 228.00 | 240.00 | 254.94 | 289.28 |

**Table 3.2:** Empirical quantiles for day-ahead spot prices for Spain for the complete data set.

Further, the different probability densities for spot prices before and after the adoption of the Iberian Exception can be seen in Figure 3.4. The probability densities suggest that the probability of observing lower spot prices is larger after the adoption of the Iberian Exception than before the adoption.

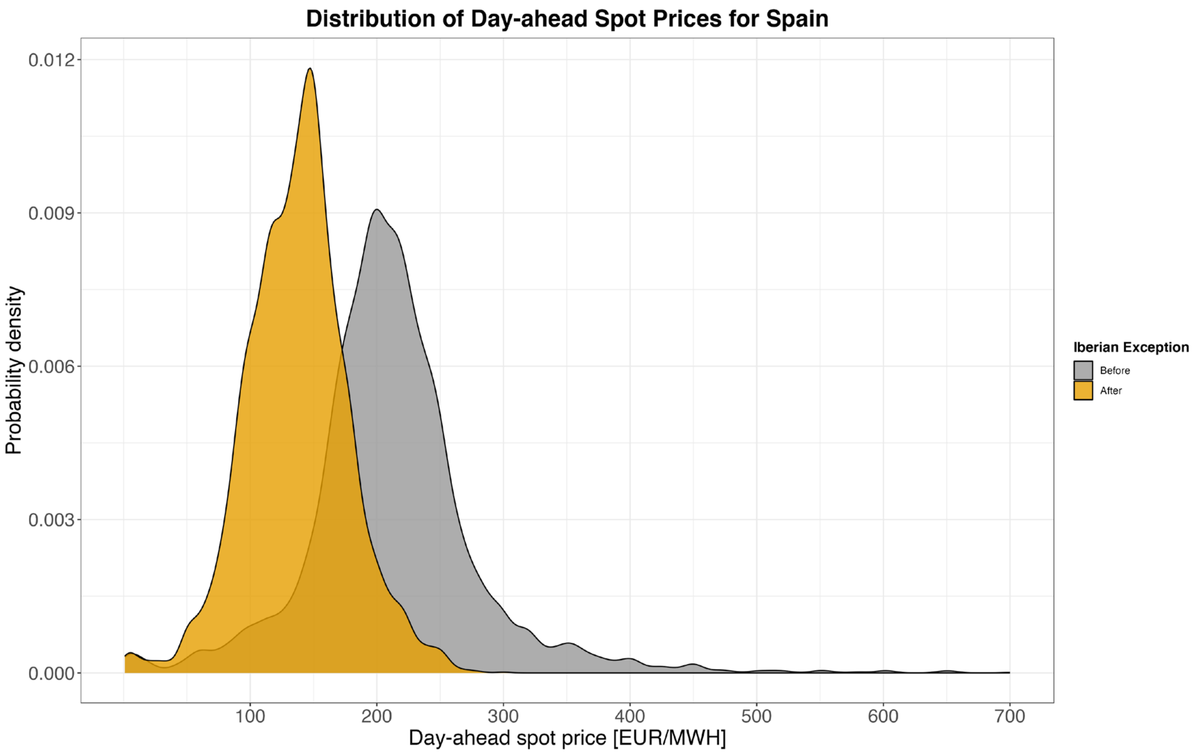



**Figure 3.4:** Distribution of Spanish day-ahead spot prices, before and after Iberian exception adoption.

### 3.1.2 Normal Prices versus Transformed Prices

When studying prices in financial markets, it is common to transform prices to their logarithmic form (Erni, 2012). However, for commodities such as electricity prices, studies do not necessarily follow the frequently applied approach of using log prices. In this thesis we will use normal prices instead of using log transformed prices.

The reason to log transform electricity prices is to obtain a series with more stable variances (Weron and Misiorek, 2006). Thus, mitigating the price spikes and high volatility of electricity prices. On the other hand, Karakatsani and Bunn (2010) and Paraschiv et al. (2014) reason that when investigating electricity prices' variability, stabilizing the variance of the original series may conceal statistical properties and result in multiplicative error effects. Furthermore, the logarithmic function is not defined for negative numbers. However, electricity prices can be negative due to the characteristics of electricity. In our thesis, we aim to explain price variability in electricity prices by the Iberian exception. Therefore, it is appropriate to use normal prices in our thesis.

## 3.2 Day-ahead Price and Compensation

As elaborated in the previous chapter, fossil-fuel generators are compensated for the difference between the market price on gas and the gas cap, and the cost of this compensation is included in the PVPC tariff. Therefore, to get a better understanding of the possible savings for the consumers on the PVPC tariff, it is useful to include the compensation they are obligated to pay. We therefore have a variable that consists of day-ahead price and the compensation. This can be understood as the total marginal cost of one MWh of electricity, excluding taxes and grid tariffs, which prior to the Iberian exception the day-ahead price represented. The compensation data is retrieved from epdata (n.d.). As the data on compensation is daily, we convert hourly electricity spot prices to daily average prices. Figure 3.5 shows the development of the day-ahead price before June 15th and the day-ahead price plus the compensation after June 15th. In the figure we can observe that the compensation, which is the difference between the green and blue lines, represents a significant part of the total marginal cost for the consumers.

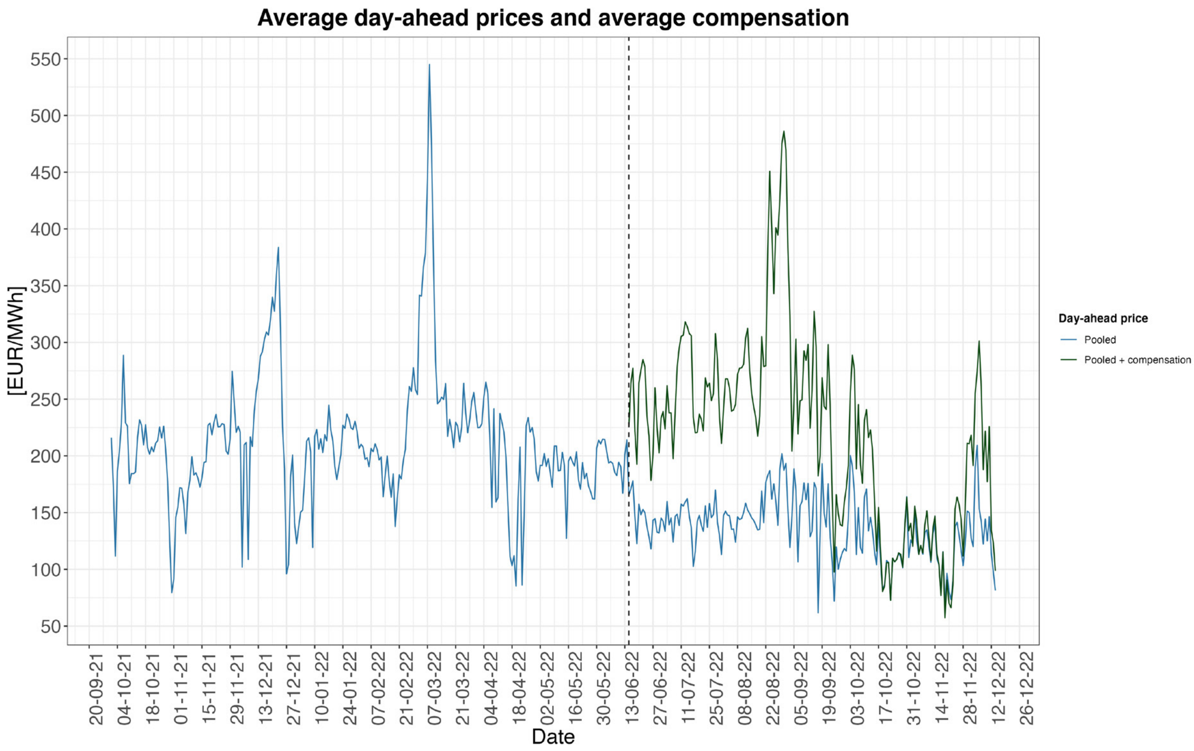



**Figure 3.5:** Spanish average day-ahead spot prices and average compensation, before and after Iberian Exception adoption.

## 3.3 The Iberian Exception

The main variable of interest in our analysis is the dummy variable representing the adoption of the Iberian exception in MIBEL. The Iberian exception price cap is represented by means of dummy variable taking unit value from June 15th, 2022.

We denote by $IberianException_t$ be the dummy variable indicating the time *before* and *after* the adoption of the price cap, with $IberianException_t = 0$ indicating the time before the adoption of the price cap and $IberianException_t = 1$ indicating the time after the adoption of the price cap.

## 3.4 Control Variables

In this section, we present the electricity price formation fundamental variables and how each variable is expected to influence electricity prices when estimating our models. Day-ahead spot prices are formed mainly by demand, technology, and competition amongst power producers. The reason for this is that consumers are price inelastic in the short term and cannot store electricity that is already generated (Bunn et al., 2016). Day-ahead spot prices are determined by several price formation fundamentals which we include as control variables in our models. Table 3.3 summarizes the fundamental variables included in the modelling of electricity spot prices. Additionally, data units and data granularity are presented.

We include the correlation between the explanatory variables in Figure A1.1 in Appendix A1. The variables do not show signs of collinearity.

| **Variable** | **Hour** | **Day** | **Week** | **Data Source** |
|---|---|---|---|---|
| Day-ahead spot price EUR/MWh | x | | | Nord Pool, ENTSO-E |
| Lag day-ahead spot price (1d), EUR/MWh | x | | | ENTSO-E |
| Lag day-ahead spot price (7d), EUR/MWh | x | | | ENTSO-E |
| Price volatility, EUR/MWh | x | | | ENTSO-E |
| Demand forecast, MW | x | | | ENTSO-E |
| Import capacity, MW | x | | | ENTSO-E |
| Export capacity, MW | x | | | ENTSO-E |
| Wind production forecast, MW | x | | | ENTSO-E |
| Photovoltaic production forecast, MW | x | | | ENTSO-E |
| Reservoir level, MWh | | | x | ENTSO-E |
| Coal price, EUR/1000mt | | x | | Bloomber, Ticker: API21MON OECM Index |
| Gas price, EUR/MWh | | x | | Bloomberg, Ticker: MIBGRPMA Index |
| Oil price, EUR/bbl | | x | | Bloomber, Ticker: CO1 Comdty |
| EUA price, EUR/tCO2 | | x | | European Energy Exchange: https://www.eex.com |

**Table 3.3:** Overview of fundamental variables with units and granularity.

### Adaptive bahavior

Paraschiv et al. (2014) argue that lagged spot prices can indicate historic price instability and risk signals that may change the market actor's price expectations and risk aversion. Moreover, the lagged spot price represents adaptive behavior (Bunn et al., 2016). The adaptive behavior of market actors is manifested by their behavior of reinforcing previously successful offers (Bunn et al., 2016). This implies that high prices will be followed by high prices. Furthermore, if there is an element of repeated gaming in power markets, this behavior will be encouraged by the signaling among market actors, resulting in a positive effect of lagged prices. In higher quantiles, the market becomes less competitive and gaming more possible and plausible, resulting in a stronger positive effect. Thus, we include the lagged spot price as this can explain electricity spot prices. Additionally, we include lagged spot prices as it can reduce autocorrelation in our data. We include the lagged spot price for the same hour of the last delivery day. Additionally, we include the 7 day lagged spot price for the same hour.

**Price Volatility**

We include a variable for the volatility of the spot price. The spot price volatility is an indicator of historic price instability and risk (Paraschiv et al., 2014). Karakatsani and Bunn (2010) find that volatility can be isolated from systematic risks priced by agents, and therefore including a price volatility variable can allow agents to substitute their own expectations. Thus, we find it appropriate to include a variable for spot price volatility that other fundamental factors do not capture when we explain the electricity price. We compute the spot price volatility as the standard deviation of spot prices for the same hour of the seven last delivery days.

**Demand Forecast**

We recall from Section 2.1.1 that demand for electricity is inelastic in the short run. In the short run, demand is driven by the hour of the day. Demand increases in the morning with households waking up and industry restarting, before reducing again in the evening when people get home from work and go to bed. Additionally, demand is determined by the season of the year, where in the summer (winter) time demand will increase in the noon and afternoon when households turn the air condition (heating) on. The price effect of demand is expected to be positive following Bunn et al. (2016). Further, we expect higher price effects at higher electricity prices levels.

We include hourly day-ahead demand forecasts for Spain. The reason for using day-ahead forecasts rather than actual demand is that the day-ahead forecasts are the information available for market actors, which sets the market clearing price for each hour the following day.

**Transmission Capacity – Import and Export**

As described in Section 2.1.5, transmission capacity is included in the calculation of area prices. The purpose of transmission cables is to reduce or eliminate price differences by facilitating the exchange of electricity between areas with a surplus or deficit. Consequently, imports and exports are treated as separate variables due to their distinct impacts on electricity prices. Since participants in the day-ahead market have access to information about cross-border capacities, these capacities are incorporated into the models. Because actual cross-border flow is likely influenced by trades in the intraday market, it is less suitable for examining day-ahead prices. We expect that import capacity will have a positive effect on prices across quantiles, while export capacity will have a negative effect on prices across quantiles. We include the day-ahead forecasted Net Transfer Capacity in MW per direction between Spain and France, and Spain and Portugal.

**Wind and PV**

We recall from Section 2.2.2 that wind is the leading source of renewable energy in the Spanish market with a share of 24% and solar PV of 8.3% of the total generation mix in 2021. The supply of wind and Solar PV is considerably determined by meteorological conditions which influences the day-ahead spot price (González-Aparicio and Zucker, 2015). Moreover, there has been an increase in renewable energies in Spain. Huisman et al. (2013) finds that the increase in wind and PV reduces the electricity spot price. Furthermore, wind and solar energy has a marginal production cost close to zero and will be one of the first bidders in the market. Paraschiv et al. (2014) finds that wind and PV infeed has a substitutional effect on the traditional fuels situated to the right of the merit order curve. Thus, we expect the substitutional effect of wind and PV infeed to have negative coefficients.

We include the day-ahead generation forecast for wind and PV energy sources. The reason for using day-ahead forecasts rather than actual wind and PV is that the day-ahead forecasts are the information available for market actors and which sets the market clearing price for each hour the following day.

**Water Reservoir**

Since hydropower from reservoirs is a dispatchable energy source, it allows producers to optimize the value of their stored water depending on the current prices and future expectations (Huisman et al., 2014). Hydropower producers want to sell when reservoir levels are high to prevent low water value and invaluable spillovers. In contradiction, low reservoir levels would make hydropower producers more reserved about their actions, making their competitive behavior more strategic. Hydro producers will then carefully pick the moments to produce based on when the water value is high. While the Iberian exception does not include any measures towards hydro reservoirs, their production patterns are considerably affected due to their ability to store energy. We expect reservoir levels to have negative coefficients because a higher level of energy stored should increase the supply of electricity. We represent the water reservoir level by linearly interpolating the aggregated weekly average filling rate of all water reservoir and hydro storage plants to daily interpolants.

**Fossil Fuels**

Fossil-fired power constitutes to a substantial share of Spain's total electricity mix in 2021. Fossil fuels heavily determines the merit order curve in the Spanish electricity market, and therefore they often determine spot prices. Burger et al. (2014) explains that the cost of fuels can be represented by the market fuel prices and transport costs between the extraction place and power plant. We present the relevant fuels that determines Spanish electricity prices that we include in the models to be estimated.

**Gas Price**

We recall that gas amounts to the greatest share of 25.7% in the electricity mix in Spain in 2021. Gas power plants have operational flexibility and are quick starting, and therefore when demand is high gas power plants are price setting (Sensfuß et al., 2008). Analogous to Bunn et al. (2016), we can expect the effect of gas prices on the electricity prices to have positive coefficients. We include the gas price, which is represented by the MIBGAS month-ahead Iberian gas market spot price on the day the electricity price auction takes place. We must take into consideration that the market for gas is closed during the weekend. Therefore, we let the gas price for Saturday and Sunday be the most recent observed price, that is the observed price of the corresponding Friday. This is the most recent information about fossil fuel prices for market actors.

**Coal Price**

Coal-fired power plants had a share of 2% in the Spanish electricity mix in 2021. In line with Bunn et al. (2016) we expect coal to have a positive effect on electricity prices. The value for the coal price is the latest available price of the Amsterdam-Rotterdam-Antwerp (ARA) futures contract. In accordance with the gas price, we let the coal price for Saturday and Sunday be the observed price of the corresponding Friday.

**Oil Price**

Oil is not used for electricity production in Spain. However, analogous to Paraschiv et al. (2014) we include oil as an explanatory variable since oil significantly impacts the transportation costs of imported coal. For the oil price, we use the last price of the ICE Brent Crude futures contract on the day before the electricity price auction takes place. Consistent with the other fossil fuel prices, we let the oil price for Saturday and Sunday be the observed price of the corresponding Friday.

**EUA Price**

EU Allowances (EUA) is the allowance to emit one ton of carbon dioxide in a given period by companies covered by the European Union Emission Trading System (EU ETS) (The European Comission, 2023a). Fossil-fired power plants are influenced by the price level of CO2 allowance because the cost of emitting CO2 is incorporated in the marginal costs of producing electricity (Bunn et al., 2016). Since coal has higher emissions than gas, coal-fired power plants need more EUA's to produce the same amount of electricity. Therefore, the EUA price can investigate fuel switching, which is when the marginal cost for gas falls below the marginal cost of coal, resulting in a relocation in the merit order curve.

Like Bunn et al. (2016) we expect that the carbon allowance prices have a positive effect on electricity prices. We represent the CO2 allowance by the latest available price of the EEX Carbon Index (Carbix). In accordance with the fossil prices, we let the EUA price for Saturday and Sunday be the observed price of the corresponding Friday.

**Seasonal Variables**

We include dummy variables for the seasonal, weekly and intraday seasonal patterns that may affect the day-ahead spot price. As seen in Figure 3.3a and Figure 3.3b, the spot price exhibits a seasonal behavior for the time of the year, week and day. Moreover, demand displays seasonal patterns for the time of the week and time of the day, shown in Appandix A1 in Figure A1.2. Furthermore, the electricity production from renewable energy strongly varies with the seasons. In Iberia, wind energy production is at its highest during the period from October to March, while solar PV has its highest capacity factor from April to May (Red Electrica, 2022). Thus, variation in the electricity supply likely affect the spot price.

The seasonal dynamics are captured by month dummy variables. For each month of the year, we include a dummy with January as the reference category. For the seasonality for the day of the week, we include a weekend dummy variable. The weekend dummy variable takes unit value for Saturday and Sunday. The intraday fluctuation is captured by hour dummy variables. We include hour dummies for each hour of the day, with 00:00:00 - 01:00:00 (time stored as number of seconds), as the reference category. Additionally, we include a holiday dummy variable which takes a unit value for Spain's public holidays. We report the included holidays in Table A1.1 in Appendix A1.

We include a variable that captures the time trend in our data set. The time trend variable represents the direction that the electricity spot price moves across time. We assume a positive linear trend in the electricity spot price in time. Thus, we let the time trend t increase by 1 unit with equal steps of 1 day That is $Timetrend_t = 1, 2, \ldots, N$ where $N$ is the number of days in our data.

# 4 Methodology

In this chapter we will discuss the theoretical framework in our thesis. First, some relevant theory behind panel data will be explained. Further, the theory behind the difference in difference models and quantile regression models will be introduced and we will reason the specific model choice. The model choice for the quantile regression models are inspired by Myrvoll and Undeli (2022). Lastly, we will present the expected results of the models.

## 4.1 Panel Data

Panel data sets consist of observations on individuals for multiple time periods. The distinguishing feature of panel data is that for each individual the same cross-sectional units are observed over a given period of time (Hansen, 2022). Panel data is widely used in natural experiments. A natural experiment arises when an exogenous event, for example a change in government policy, changes the surroundings in which individuals operate.

The observations in panel datasets are indexed by the individual $i$ and time period $t$. Thus, we can denote the observations by $Y_{it}$. The individuals can be indexed as $i = 1, \ldots, N$ and time periods as $t = 1, \ldots, N$. Further, panel data can be observed in pairs $(Y_{it}, X_{it})$, where $Y_{it}$ is the dependent variable, and $X_{it}$ is a $k$-vector of regressors.

## 4.2 Difference in Difference Model

One of the most frequently used approaches to estimate the effect of a reform is the difference in difference method, often called "diff in diffs". The difference in difference model is used to evaluate the causal effect of a treatment on some outcome of interest (Hansen, 2022). Thus, the method estimates a two period panel data regression that consists of a reform indicator variable as a regressor.

The method includes three important assumptions that must be held in order to interpret the difference in difference estimate as a policy effect (Hansen, 2022). Firstly, the method assumes that the estimated regression is the correct conditional expectation, that is the difference between the treated and control group are constant over time. This assumption is often called the parallel trend assumption. Secondly, the policy is exogenous. Thirdly, there are no other factors that coincide with the policy that is not included.

The difference in difference method relies on the parallel trend assumption. The assumption states that the treatment group, without the reform, would have followed the same trend as the control group. However, we cannot test the parallel trend assumption, as we do not observe the treatment group untreated. Fredriksson and Oliveira (2019) argue that one can provide support to the assumption by showing that the treatment and control group exhibits the same patterns for several time periods before the reform.

Card et al. (1994) evaluated the impact of New Jersey's 1992 increase in minimum hourly wage from \$4.25 to \$5.05. We let $Y_{it}$ denote the employment at restaurant $i$ surveyed at time $t$. We can denote the two groups by treatment status by $State_i$, where $State_i = 1$ for New Jersey and $State_i = 0$ for Pennsylvania. We denote the two time periods by $Time_t$, where $Time_t = 0$ indicated the period before the policy change, and $Time_t = 1$ for the period after the policy change. We can denote by $D_{it}$, the treatment dummy, with $D_{it} = 1$ if the minimum wage equals \$5.05 and $D_{it} = 0$ if the minimum wage is \$4.25. The outcome of $Y_{it}$ was modeled by Card et al. (1994) in the following equation:

$$Y_{it} = \beta_0 + \beta_1 \text{State}_i + \beta_2 \text{Time}_t + \theta \text{D}_{it} + \epsilon_{it} \tag{4.1}$$

Where $\beta_1$ is the difference estimand of the effect of "New Jersey vs. Pennsylvania" before the policy change, $\beta_2$ is the difference estimand of the time effect in the control group, and $\theta$ is the difference in difference estimand defined as the change in New Jersey relative to the change in Pennsylvania.

With basic notation the general difference in difference model may be written in the following regression equation:

$$Y_{it} = \theta \text{D}_{it} + u_i + v_t + \epsilon_{it} \tag{4.2}$$

**Day-ahead Spot Prices in Spain and Germany**

The difference in difference model formulation for Spanish and German electricity prices is given in Equation 4.3.

$$Y_{it} = \alpha + \beta \text{D}_{it} + \gamma \text{Country}_i + \delta \text{Time}_t + \epsilon_{it} \tag{4.3}$$

We let $Y_{it}$ denote the day-ahead spot electricity price $i$ at time $t$. We let $Country_i$ be a dummy variable indicating the country, with $Country_i = 1$ for Spain and $Country_i = 0$ for Germany. We let $Time_t$ be a dummy variable indicating the time period, with $Time_t = 0$ for the period before the policy adoption and $Time_t = 1$ for the period after the policy adoption. We let $D_{it}$ denote the treatment dummy variable, with $D_{it} = 1$ if the Iberian exception is adopted, and $D_{it} = 0$ if the Iberian exception is not adopted.

**Average Day-ahead Spot Price plus Compensation in Spain**

Further, Equation 4.4 show the difference in difference model formulation for Spanish day-ahead spot prices spot prices plus compensation.

$$Y_{it} = \alpha + \beta \text{D}_{it} + \gamma \text{Country}_i + \delta \text{Time}_t + \epsilon_{it} \tag{4.4}$$

Now, we let $Y_{it}$ denote the total marginal cost $i$ for the consumer at time $t$. The total marginal cost for the consumer is represented by the average day-ahead spot price plus compensation. We let $Country_i$ be a dummy variable indicating the treatment, with $Country_i = 1$ for Spanish average day-ahead spot price plus compensation and $Country_i = 0$ for German average day-ahead spot price, as the compensation for Germany equals zero. We let $Time_t$ be a dummy variable indicating the time period, with $Time_t = 0$ for the period before the policy adoption and $Time_t = 1$ for the period after the policy adoption. We let $D_{it}$ denote the treatment dummy variable, with $D_{it} = 1$ if the Iberian exception is adopted, and $D_{it} = 0$ if the Iberian exception is not adopted.

**Parallel Trend Assumption**

The above identified difference in difference model relies on the parallel trend assumption. We let the German market be the counterfactual in the case where the Iberian exception was not adopted. The reason for using the German market is that the Spanish and German day-ahead spot prices follow the same trend before the adoption of the Iberian exception. Thus, we see it reasonable to assume that the Spanish and German day-ahead spot prices would follow the same trend in the following period without the adoption of the Iberian exception in Spain.

## 4.3 Quantile Regression Model

Another model that lets us estimate the impact of an independent variable on a dependent variable is the quantile regression method. The quantile regression method was first introduced by Koenker and Bassett (1978) and assumes that the conditional quantile of a response variable is as a function of a set of explanatory variables. One version of the quantile regression method is the linear quantile regression which assumes that the quantile functions are linear in the independent variable. Contrary to Ordinary Least Squares, which assumes a linear relationship between the conditional mean of the dependent variable and the independent variable, the linear quantile regression assumes a linear relationship between the dependent variable and the independent variable conditioned on a quantile. Thus, the linear quantile regression allows us to assess how an independent variable affects a dependent variable in the entire distribution. In the panel data representation of the model, the response variable can be influenced by its past values and by current and past values of other exogenous explanatory variables.

We denote $Y_t$, $t = 1, \ldots, N$ the respone at time $t$ and $\boldsymbol{X}_t$ the corresponding set of explanatory variables at time $t$. With $k$ explanatory variables, $X$ is a $k$ x 1 vector. We denote the conditional quantile by$q$, $q \in [0, 1]$. We denote the conditional quantile function for the qth quantile by $Q_q(Y_t|\boldsymbol{X}_t)$. The quantile regression model for a given conditional quantile $q$ can be written as follows:

$$Q_q(Y_t|\boldsymbol{X}_t) = \alpha^q + \boldsymbol{X}_t\boldsymbol{\beta}_q + \epsilon_t \tag{4.5}$$

where $\beta_q$ is the $k$ x 1 vector of the coefficient of the independent variables and $\alpha^q$ is the $q$th individual effect.

The objective of the quantile regression is to find the q quantile coefficient estimates $\alpha^q$ and $\beta^q$. When solving for $\alpha^q$ and $\beta^q$, we can invoke the standard approach called the Frisch-Newton algorithm introduced by Koenker and Portnoy in 1997. We can derive the coefficient estimates of $\alpha^q$ and $\beta^q$ by solving the following minimization problem:

$$\min_{\alpha_q \beta_q} = \sum_{t=1}^{T} (q - \mathbf{1}_{Y_t \leq \alpha^q + \boldsymbol{X}_t\boldsymbol{\beta}_q})(Y_t - (\alpha^q + \boldsymbol{X}_t\boldsymbol{\beta}_t)) \tag{4.6}$$

where

$$\mathbf{1}_{Y_t \leq \alpha^q + \boldsymbol{X}_t \boldsymbol{\beta}_q} = \begin{cases} 1, & \text{if } Y_t \leq \alpha^q + \boldsymbol{X}_t \boldsymbol{\beta}_q \\ 0, & \text{otherwise} \end{cases} \tag{4.7}$$

Equation 4.7 represents the indicator function that takes the value 1 if the residual is zero or negative and 0 if the residual is positive. The difference between the observed spot price and the estimated spot price, $Y - \hat{Y}$, is the vector of residuals. Thus, the model minimizes the weighted absolute distance from the observed values to the fitted values of the model (Hao and Naiman, 2007). In other words, the optimal estimates of $\alpha^q$ and $\beta^q$ is the one that minimizes the weighted sum of absolute residuals.

### Naive Model

In the following, we specify a naive quantile regression model in which Spanish electricity prices are regressed only on the Iberian exception dummy. We let $q$, $q \in [0, 1]$ be the quantiles ranging from 5% to 95% separated by 5% intervals. We let $P_{it}$ denote the day-ahead spot price at hour $i$ and day $t$. We let $\boldsymbol{X}_{it}$ be the vector containing the explanatory variables based on the data in Section 3.3. Equation 4.8 shows the naive model formulation for day-ahead spot prices in Spain.

$$Q_q(P_{it}|\boldsymbol{X}_{it}) = \alpha^q + \beta^q_{IE}\text{IberianException}_{\ i,t} + \epsilon_{i,t} \tag{4.8}$$

Here, $P_{it}$ and $X_{it}$ replace $Y_t$ and $X_t$ in Equation 4.5, The number of explanatory variables is $k = 19$. For the variables in the vector $X_{it}$, we omit the subscript $i$ for the variables that are observed daily, as seen in Table 3.3.

**Fundamental Market Factors Model**

Next, we include the control variables to the above identified model using the same denotation as above. Equation 4.9 shows the fundamental market factor model formulation for day-ahead spot prices.

$$\begin{aligned} Q_q(P_{it}|\boldsymbol{X}_{it}) = \alpha^q &+ \beta^q_{IE}\text{IberianException}_{i,t} \\ &+ \beta^q_1\text{Demand}_{i,t} + \beta^q_2\text{ImportCapacity}_{i,t} + \beta^q_3\text{ExportCapacity}_{i,t} \\ &+ \beta^q_4\text{Wind}_{i,t} + \beta^q_5\text{PV}_{i,t} + \beta^q_6\text{ReservoirLevel}_t \\ &+ \beta^q_7\text{PriceVolatility}_{i,t} + \beta^q_8\text{P}_{i,t-1} + \beta^q_9\text{P}_{i,t-7} \\ &+ \beta^q_{10}\text{Coal}_{t-1} + \beta^q_{11}\text{Gas}_{t-1} + \beta^q_{12}\text{Oil}_{t-1} + \beta^q_{13}\text{EUA}_{t-1} \\ &+ \epsilon_{i,t} \end{aligned} \tag{4.9}$$

**Baseline Model**

In the baseline model we include the fixed variables to the above specified model using the same denotation as the naive model. Equation 4.10 shows the baseline model formulation for Spanish day-ahead spot prices.

$$\begin{aligned} Q_q(P_{it}|\boldsymbol{X}_{it}) = \alpha^q &+ \beta^q_{IE}\text{IberianException}_{i,t} \\ &+ \beta^q_1\text{Demand}_{i,t} + \beta^q_2\text{ImportCapacity}_{i,t} + \beta^q_3\text{ExportCapacity}_{i,t} \\ &+ \beta^q_4\text{Wind}_{i,t} + \beta^q_5\text{PV}_{i,t} + \beta^q_6\text{ReservoirLevel}_t \\ &+ \beta^q_7\text{PriceVolatility}\ _{i,t} + \beta^q_8\text{P}_{i,t-1} + \beta^q_9\text{P}_{i,t-7} \\ &+ \beta^q_{10}\text{Coal}_{t-1} + \beta^q_{11}\text{Gas}_{t-1} + \beta^q_{12}\text{Oil}_{t-1} + \beta^q_{13}\text{EUA}_{t-1} \\ &+ \beta^q_{14}\text{Month}_t + \beta^q_{15}\text{Weekend}_t + \beta^q_{16}\text{Hour}_i \\ &+ \beta^q_{17}\text{Holiday}_t + \beta^q_{18}\text{TimeTrend}_t + \epsilon_{i,t} \end{aligned} \tag{4.10}$$

Standard errors are computed by the bootstrap. The bootstrap is a resampling method that uses random sampling with replacement to estimate the sampling distribution of a statistic such as standard errors (Hesterberg, 2011). The bootstrap allows for statistical inference without making an assumption about the distribution of the data. Thus, the bootstrap is reasonable for estimating the standard errors when strong parametric assumptions may not hold.

**Timing of Variables**

We model the electricity spot price such that the model reflects the information available to market actors when they submit their bids in the day-ahead auction. Consequently, the price of gas, coal, oil, and CO2 emissions is lagged by one day in our models which is represented by the respective variables having the subscript $t-1$. That is, the day-ahead electricity prices on January 2nd are regressed on the fossil fuel and EUA prices on January 1st.

## 4.4 Expected Results: Iberian Exception

In this section we will discuss the expected results for the difference in difference model and the quantile regression model. As long as the parallel trend assumption holds for electricity prices, we can expect a causal effect of the reform. Provided that the variance of the electricity price depends on the explanatory variables, we can expect quantile regression coefficients to vary across quantiles (Sapio, 2019).

### 4.4.1 Difference in Difference Model Expectation

The expected results for the difference in difference model are summarized in the Table 4.1 and Table 4.2. We recall that $\beta$ is the Iberian exception's coefficient estimate in the models specified in Section 4.2.

| **Effect** | **Result** |
|---|---|
| Price reduction | $\beta < 0$ |

**Table 4.1:** Hypothesis for baseline difference in difference model and the corresponding expected results.

| **Effect** | **Result** |
|---|---|
| Price reduction | $\beta < 0$ |

**Table 4.2:** Hypothesis for the difference in difference model with the cost of the gas cap and the corresponding expected results.

**Price Reduction**

The main purpose of the reform is to reduce the cost of electricity and as we have shown using theory of electricity markets, the gas cap should reduce the electricity price. Furthermore, prior research has concluded on the same effect. Therefore, we do expect to see a price reducing effect of the Iberian exception, meaning that the $\beta$ coefficient is negative.

**Price Reduction with Compensation**

We recall that the savings on the Iberian exception reform are primarily from inframarginal energy sources. Therefore, we also expect a price reducing effect from the Iberian exception in the model where we include the costs of the reform borne by the consumers. Even with the full marginal costs from gas generators included, the Iberian exception is still designed to reduce the electricity price. However, we do expect the reduction to be smaller than with the previous model. This is consistent with the results from (Eicke et al., 2022).

### 4.4.2 Quantile Regression Model Expectation

The expected results for the quantile regression model are summarized in Table 4.3. Here, $\beta_{IE}^{q}$ is the Iberian Exception's coefficient estimates in the models specified in Section 4.3.

| **Effect** | **Result** |
|---|---|
| Price reduction | $\beta_{IE}^{0.5} < 0$ |
| Volatility reduction | $\beta_{IE}^{q}$ decreasing across quantiles |
| Peak shaving | $\beta_{IE}^{q}$ for $q$ large |

**Table 4.3:** Hypothesis for quantile regression model and their corresponding expected results.

**Price Reduction**

As with the difference in difference model we expect to see a price reducing effect of the gas cap. Therefore, we expect the Iberian exception dummy variable coefficients to be negative around the median of the price distribution.

### Volatility Reduction

The gas cap is designed to decouple volatile gas prices from the electricity price, hence part of the purpose of the reform is to reduce volatility. Furthermore, if the market price for gas is lower than 40 €/MWh, the cap should in theory have no impact on the market. If the gas price is below this reference price, it is likely at the same time as the lowest quantiles of the electricity price. Hence, it is possible that the Iberian exception will have a small or even negligible effect on the lowest quantiles. Which would reduce volatility because the cap would reduce prices when prices are high, smoothing the variability of prices.

Because the cost of gas is capped, the Iberian exception should have a stronger downward pressure on electricity prices for higher gas price levels. As we have seen with the energy crisis, gas and electricity prices are correlated. This suggests that the strongest downward pressure from the Iberian exception should be at the highest quantiles of the electricity price. Therefore, we expect the coefficient estimates for the Iberian exception to decrease across quantiles. This would imply a convergence between the lowest and highest price levels in the distribution, indicating a smaller variance in the price distribution and therefore reduced volatility.

### Peak Shaving

As explained above, we expect the gas cap to have a stronger downwards pressure on power prices for higher quantiles. Therefore, we also expect to see a peak shaving effect in the results. Negative and decreasing Iberian exception coefficients at the higher quantiles would confirm this hypothesis.

# 5 Results

In this chapter we will present the results for all models in Section 4. The results from the difference in difference models and the quantile regression models make up the main part of this thesis. The results will be interpreted with a focus on the hypothesis described in Section 4.4. Furthermore, we will extend the quantile regression model by including interaction terms between the Iberian exception dummy and other control variables to further assess how the price cap has affected the electricity price.

## 5.1 Difference in Difference Results

In this section we present the results of the difference in difference analysis. First, we assess the results from the difference in difference model with day-ahead prices from Spain and Germany before we examine the results from the model with the compensation included. Lastly, we test the difference in difference models' internal validity.

### 5.1.1 Wholesale Price in Spain and Germany

The results of the effect of the Iberian exception in the Spanish electricity market were conducted using the simple difference in difference model in Equation 4.3 in Section 4.2.

| | *Dependent variable:* |
|---|---|
| | Day-ahead Price [EUR/MWh] |
| Treatment | 32.962*** |
| | (1.733) |
| Post | 115.669*** |
| | (1.900) |
| Iberian Exception | −189.947*** |
| | (2.687) |
| Constant | 178.589*** |
| | (1.226) |
| Observations | 21,120 |
| $R^2$ | 0.234 |
| Adjusted $R^2$ | 0.234 |
| *Note:* | *p<0.1; **p<0.05; ***p<0.01 |

**Table 5.1:** Difference in difference regression results.

The coefficient estimates for the Constant ($\alpha$), Iberian Exception ($\beta$), Treatment ($\gamma$) and Post ($\delta$), and are all significant at 1% level of significance as shown in Table 5.1. The regression results for the $R^2$ is 0.234. The estimated coefficient value $\beta = -189.947$ indicates that the electricity price decreases on average by approximately 190 €/MWh in Spain after the adoption of the Iberian exception. This result confirms our hypothesis of a price reducing effect of the Iberian exception. The result aligns with (Eicke et al., 2022) who estimated that the cap led to an apparent reduction in the spot prices by 150 €/MWh from June 15th, 2022 up until August 13th, 2022.

### 5.1.2 Wholesale Price Spain and Germany: with Compensation

| | *Dependent variable:* |
|---|---|
| | Average day-ahead price + average daily compensation [EUR/MWh] |
| Treatment | 32.962*** |
| | (7.998) |
| Post | 115.669*** |
| | (8.769) |
| Iberian Exception | −106.706*** |
| | (12.402) |
| Constant | 178.589*** |
| | (5.655) |
| Observations | 880 |
| $R^2$ | 0.169 |
| Adjusted $R^2$ | 0.166 |
| *Note:* | *p<0.1; **p<0.05; ***p<0.01 |

**Table 5.2:** Difference in difference results.

Table 5.2 shows the results of the difference in difference model. All the coefficient estimates are significant at 1% level of significance, while the regression results for the $R^2$ is 0.169. The Iberian exception's coefficient estimate is -106.706, which suggests that the reduction in the costs for electricity for a consumer on the PVPC tariff has been approximately 107 €/MWh since the adoption of the Iberian exception. These results are as expected and they clearly show that consumers in Spain have benefited from the Iberian exception, even when including the costs for the compensation. Moreover, when comparing the Iberian exception coefficient estimates from the two models, we see that on average the difference is 83 €/MWh. This implies that the compensation is a substantial part of the cost for the consumers. Nonetheless, Spanish consumers have experienced cost savings.

### 5.1.3 Parallel Trend Assumption

We use the parallel trend assumption to test the models' internal validity. We check if the estimation of causal effects is non-biased. An estimation of causal effects is non-biased if the treatment group, absent the reform, would have followed the same time trend as the control group. Additionally, factors that may change the level of the outcome variable between treatment and control group, must be constant over time.

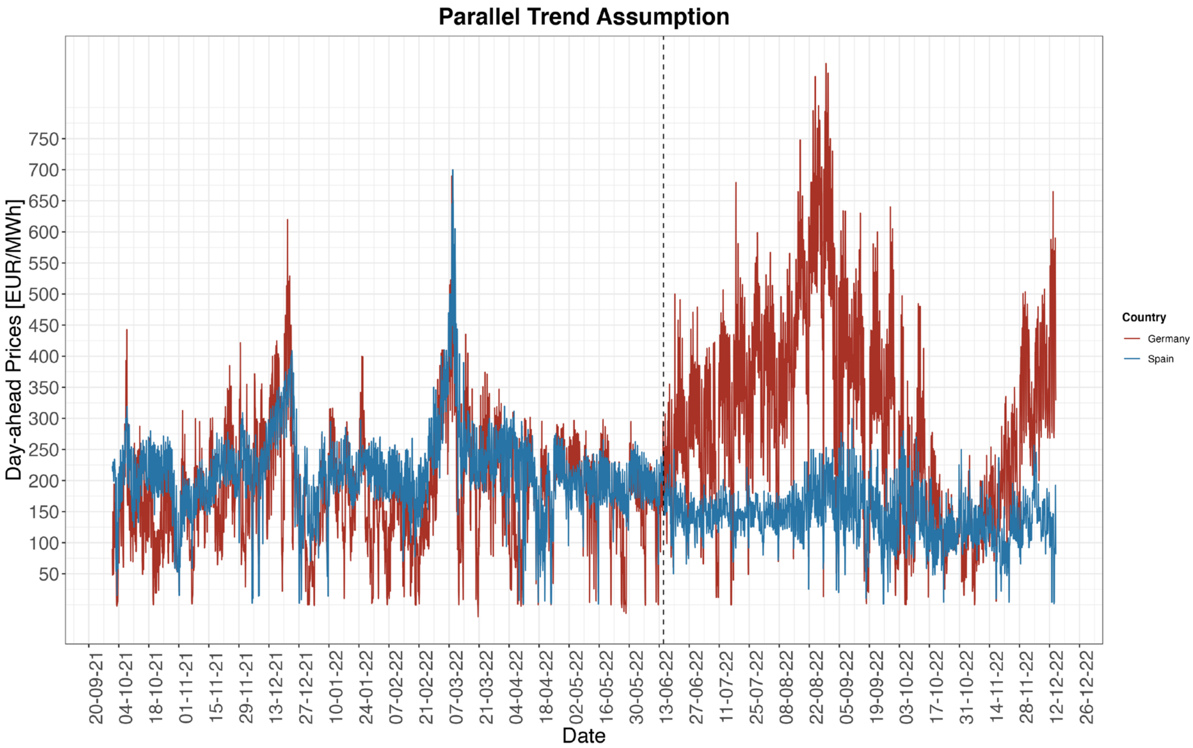



**Figure 5.1:** Spanish and German day-ahead spot prices, before and after Iberian Exception adoption. The visual inspection satisfies the Parallel Trend Assumption.

Figure 5.1 shows the Spanish and German day-ahead electricity prices from October 1st, 2021, to December 15th, 2022. We find that the electricity prices in Spain, the treatment area, and Germany, the control area, moves in tandem with each other until June 15th, 2022. We can observe that on June 15th, 2022, there were decreases in the Spanish electricity prices until December 15th, 2022. While for Germany, a constant trend for the electricity prices is observed during those periods, in which prices are highly volatile and fluctuating. Thus, the parallel trend assumption holds for the treatment area Spain and control area Germany

## 5.2 Quantile Regression Results

In this section we present the results of the quantile regression models. Each plot includes the quantile regression profile for the set of coefficient estimates for each variable, with their respective bootstrapped confidence intervals. Additionally, the plots include the OLS estimates, which are constant in quantiles, represented by the solid red line, and their confidence intervals in dotted red lines. Results of the control variables can be found in Appendix A2.

### 5.2.1 Naive Model

First, we estimate a naive model described in Section 4, Equation 4.8. In this model the electricity price is modelled as a function of the Iberian exception dummy. When exclusively including the Iberian exception dummy as the explanatory variable, this model demonstrates a strictly before-after assessment regarding the first market exchange after the Iberian exception was implemented on June 15th, 2022.

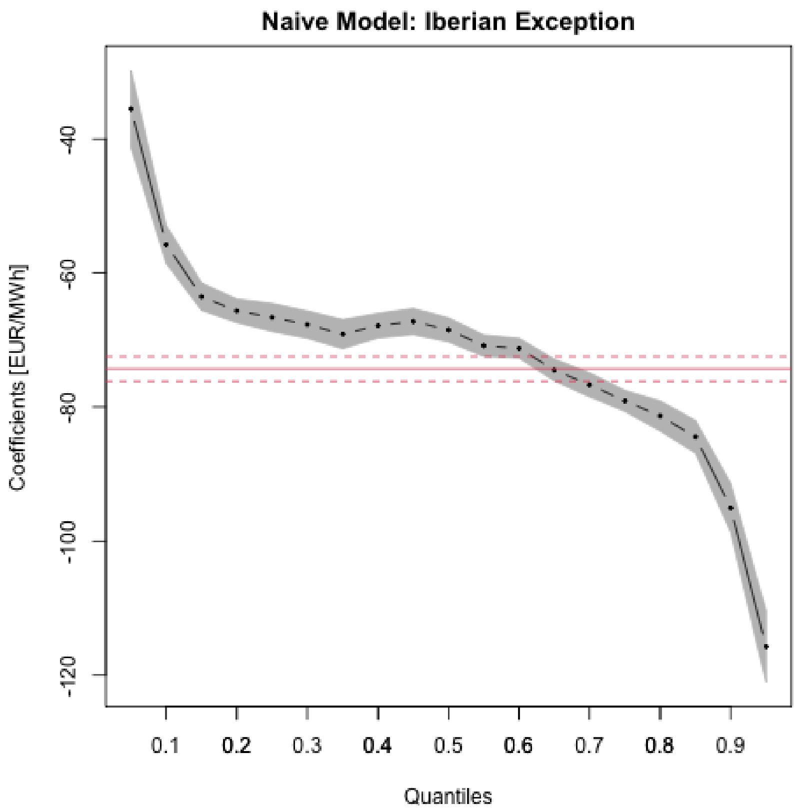



**Figure 5.2:** Quantile regression coefficient estimates of the Iberian Exception dummy using the naive model specification.

Figure 5.2 shows the coefficient estimates of the Iberian exception. The coefficient of the Iberian exception dummy is negative and statistically significant at 1% level of significance in all quantiles. The coefficient estimates decrease across quantiles, with the 5th quantile estimate at -36 €/MWh, the median at -68 €/MWh and the 95th at -116 €/MWh. The steeper decrease at the highest quantiles indicates that the effect the Iberian exception has had a more substantial effect on the highest price levels. Additionally, we see that the coefficient estimates of the Iberian exception are significantly different from the OLS estimates represented by the red line, except for the 65th quantile. This suggest that the price effect of the Iberian exception varies between most quantiles.

The results from the naive model are not surprising. Since the coefficient estimates are negative, the hypothesis about a price reducing effect is confirmed, which corresponds with the results from the difference in difference model. Furthermore, the estimates are decreasing across quantiles, especially for the highest price levels, confirming both the volatility reduction and peak shaving hypotheses.

However, without other explanatory factors it is hard to determine if the downward pressure from the dummy variable is solely due to the Iberian exception or if there are other factors. It is possible that the model overestimates the impact the gas cap has had on electricity prices, meaning some of the results we observe might be due to model specifications. Hence, we estimate a new model that controls for all fundamental variables.

### 5.2.2 Controlling for Fundamental Variables

In this model we add the fundamental variables to the naive model. The fundamental variables include all variables presented in Section 4, Equation 4.9. The variable are day-ahead forecasted demand, forecasted import and export capacities, forecasted wind and PV generation, reservoir level, fuel prices, EUA prices, price volatility, and lagged electricity price. The coefficient estimates of the Iberian exception is shown in Figure 5.3.

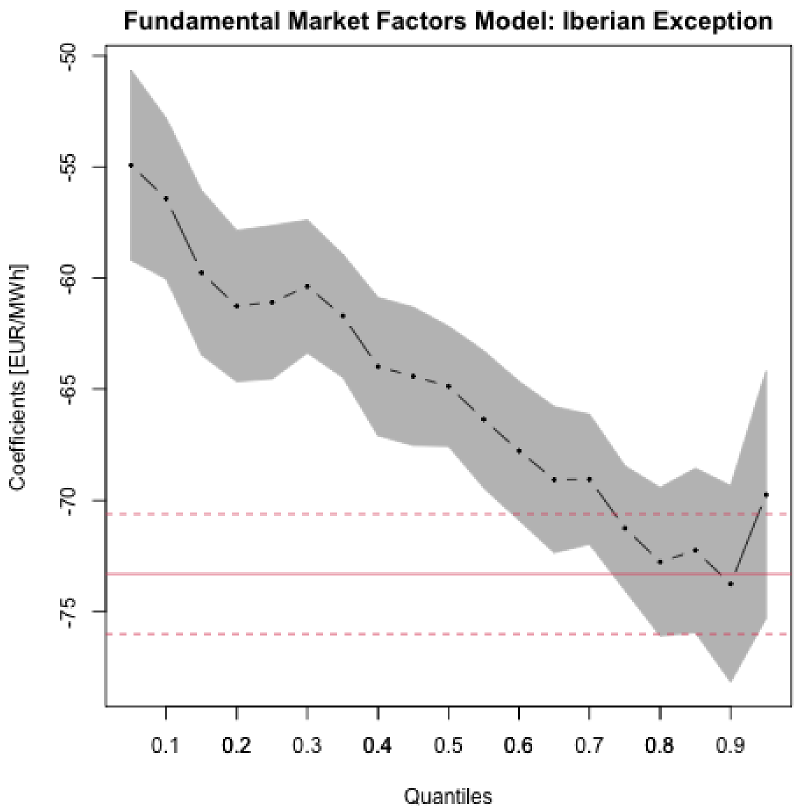



**Figure 5.3:** Quantile regression coefficient estimates of the Iberian Exception dummy using the fundamental market factor model specification.

The coefficient estimates of the Iberian exception are negative and significant at 1% level of significance in all quantiles. The value of the coefficient estimates varies from -55 €/MWh in the 5th quantile to -74 €/MWh in the 90th quantile. The quantile estimates decrease across quantiles, except for the 95% quantile estimate. Hence, the pattern across quantiles has changed slightly from the naive model, though the highest quantiles are still affected the most by the Iberian exception. The magnitude of the estimates has not changed considerably, except in the highest quantiles. The change in pattern and magnitude is a result of the effect that the fundamental variables have had on the Iberian exception variable in all quantiles.

The results from the model are as expected and confirm all of the hypotheses. However, our model does not control fixed effects that could be captured by the Iberian exception. Hence, we estimate another model that controls for fixed effects to further isolate Iberian exception's effect on electricity prices.

### 5.2.3 Controlling for fixed effects

In the baseline model we add the fundamental and fixed variables to the naive model. The fixed variables consist of month, hour, weekend, holiday, and time trend. The model formulation is described in Section 4, Equation 4.10. Figure 5.4 shows the coefficient estimates of the Iberian exception variable for our baseline model.

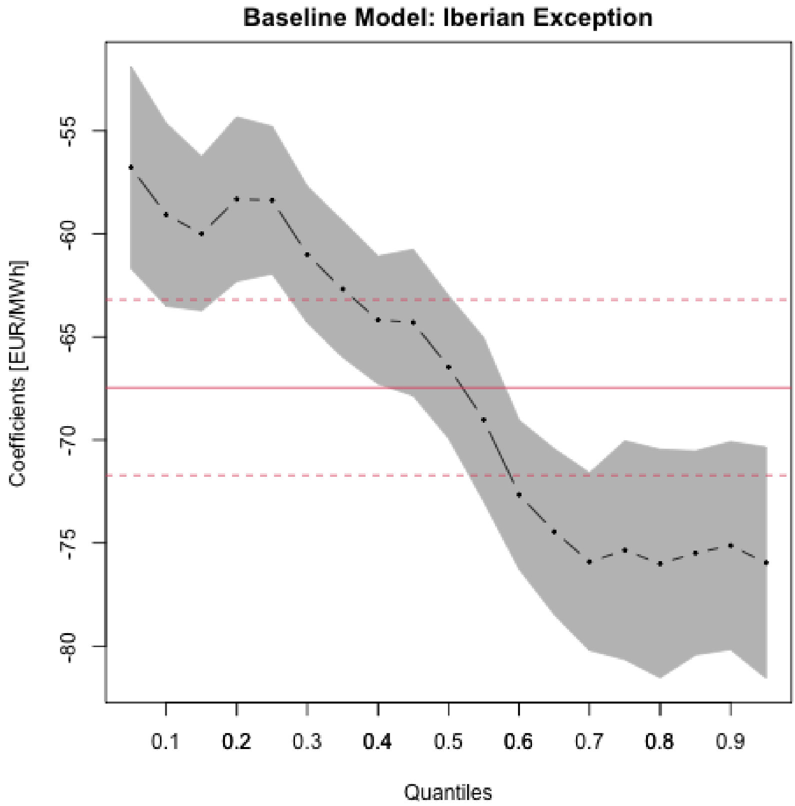



**Figure 5.4:** Quantile regression coefficient estimates of the Iberian Exception dummy using the baseline model specification.

In accordance with the former models, the Iberian exception variable is negative and significant at 1% level of significance in all quantiles. The coefficient estimates decrease from -57 €/MWh in the 5th quantile to -76 €/MWh in the 70th quantile where the estimates stabilize. We observe a decreasing pattern across the price distribution. Furthermore, most of the coefficient estimates of the Iberian exception are significantly different from the OLS estimates, represented by the red line, except in the 40th – 55th quantiles. These results suggests that the price effect is different across quantiles. Moreover, the results indicate that the Iberian exception reduces the electricity prices in all quantiles, with the price effect having a larger magnitude for the highest price levels.

As the Iberian exception coefficient estimates are negative across quantiles, the hypothesis from Section 4.2.2 expressing a price reduction effect from the gas cap is confirmed. In addition to observing negative coefficient around the median, we observe negative coefficient estimates in all quantiles, implying that the gas cap has a downward pressure on electricity prices in all parts of the distribution. Thus, these results support the findings from the difference in difference model.

Moreover, we expect the Iberian exception to have a reducing effect on price volatility. As explained above, the Iberian exception coefficient estimates are decreasing across quantiles, although the decrease is less than expected. A possible reason for this is that the market gas price has been higher than the reference price in the time period of our dataset. However, overall, we do observe that the gas cap has had a volatility reducing effect on the electricity price confirming the hypothesis.

Furthermore, the hypothesis that the Iberian exception would have a peak shaving effect on electricity prices is confirmed. The results from Figure 5.4 show that the coefficient estimates of the Iberian exception are both negative and relatively larger in the higher quantiles. However, it is surprising that the estimates stabilize from the 70th quantile and above, indicating that the Iberian exception has the same downward pressure on prices above the 70th quantile. While we overall observe a peak shaving effect, the effect would have been stronger if the decreasing pattern continued above the 70th quantile.

## 5.3 Mechanisms Quantile Regression

In this chapter we analyze our baseline model results in further detail by examining whether the effect from control variables on the electricity price have changed following the implementation of the gas cap. This gives us further insight into the potential underlying drivers of price and volatility reduction. These effects can be understood as the mechanisms that cause the results from the Iberian exception.

As such, we add interaction terms to our baseline model. Adding interaction terms can expand our understanding of the relationships between the variables in our model (Hansen, 2022). Thus, we can assess whether the effect of control variables on electricity prices is different before than after the Iberian exception. The unique interpretation of the control variables is not limited to the coefficient estimate of the control variable and depends on the coefficient estimate of the interaction term as well. Moreover, the unique interpretation of the Iberian exception is the coefficient estimate of the Iberian exception added to the coefficient estimate of the interaction term.

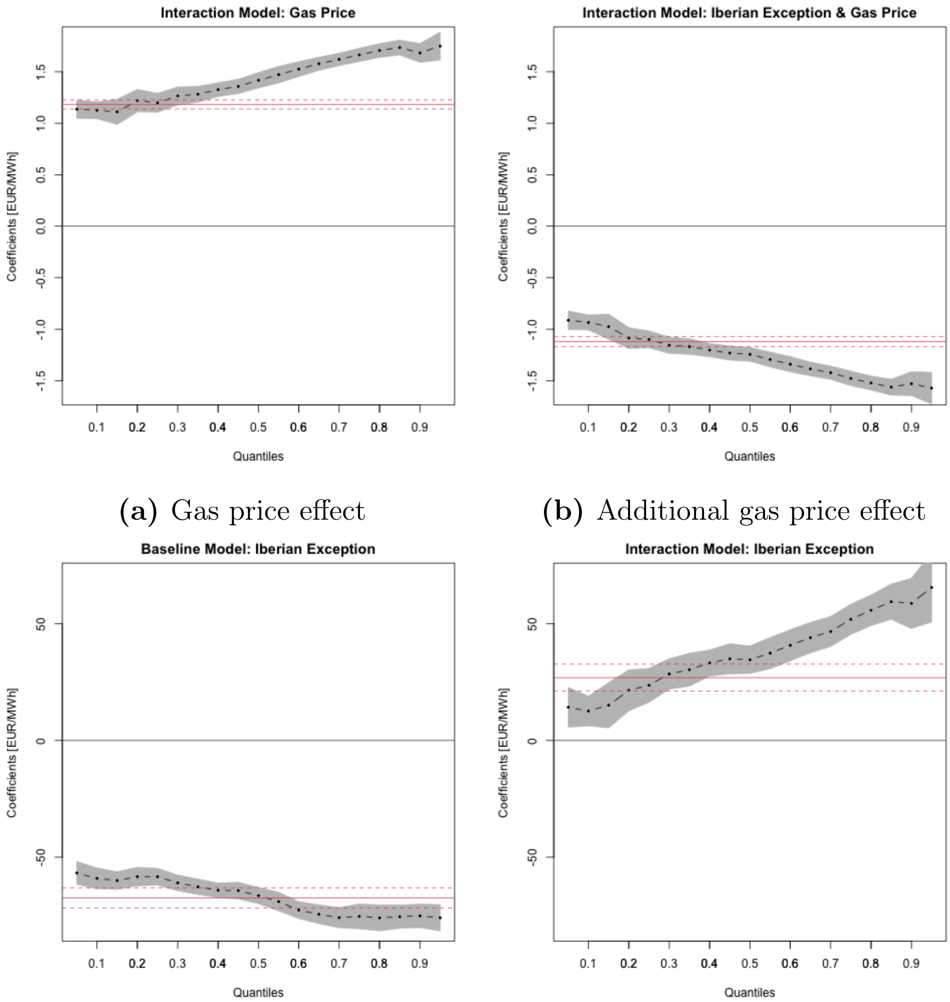
When adding the interaction term to the model, the effect of a control variable on prices vary depending on whether or not the Iberian exception is adopted. The coefficient estimates of the interaction term represents how different the slopes of the regression lines are before and after the adoption of the Iberian exception. Thus, we can interpret the coefficient estimates of the interaction terms as the additional effect of the control variable on prices after the adoption.

### 5.3.1 Electricity Price's Exposure to Natural Gas and EUA Prices

As illustrated with the merit order curve in Section 2.4.2, the Iberian exception has led to a structural change in how the marginal cost of gas is priced in the electricity market. The bids from gas-fired power plants used to include the entire marginal cost of natural gas. However, from June 15th the bids in the market could only include a maximum of 40 €/MWh of the current market price for gas, disregarding the actual market price. This indicates that the relationship between gas and electricity prices has changed. Therefore, it is interesting to examine whether the effect of natural gas prices on electricity prices have changed after the implementation of the price cap.

Moreover, because the EUA price is strongly connected to fossil fuel generation, we will additionally study how the EUA price has impacted electricity prices before and after the gas cap. While coal-fired power plants are also included in the Iberian exception reform, we will not examine the mechanisms behind the coal price. This is largely because in 2022, coal-fired power only accounted for 3% of the electricity mix in Spain (IEA, 2023a).

### Natural Gas Price




**(a)** Gas price effect **(b)** Additional gas price effect

**(c)** Baseline results **(d)** Interactions results

**Figure 5.5:** Interaction terms between gas and Iberian exception dummy.
*Note: Y-axis for Iberian exception's baseline result (shown in Section 5.2.3) are adjusted for comparability to Iberian exception results from interaction model including gas.*

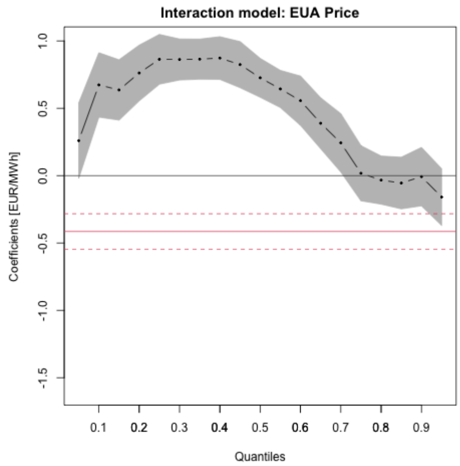
The coefficient estimates for natural gas price are shown in Figure 5.5a. All coefficient estimates are positive and significant at the 1% level. The increasing pattern of the coefficient estimates across quantiles suggests that the effect of gas prices on electricity prices is larger at the higher tale of the distribution. The strictly positive coefficient estimates and their increasing pattern is as expected, as higher gas prices generally increase electricity prices, especially in Spain where the electricity mix consists of approximately 25% gas generation.

Figure 5.5b shows the coefficient estimates of the interaction term of gas prices and the Iberian exception dummy. We initially observe a substantial difference between the coefficient estimates in Figure 5.5a and 5.5b. The estimates for the interacted term are negative and significant at the 1% level in all quantiles. This suggests that the positive effect from gas prices on electricity prices are weakened after the adoption of the Iberian exception. The additional effect from gas prices on electricity prices after the implementation has a strong downwards pressure on electricity prices. Moreover, the estimates have a decreasing pattern across quantiles, indicating that the positive effect has been weakened the most at the highest quantiles.

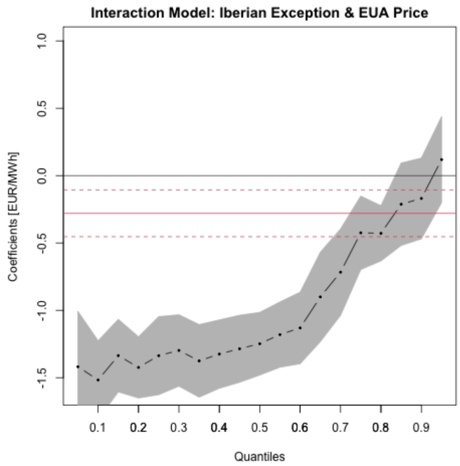
Furthermore, Figure 5.5d shows the coefficient estimates of the Iberian exception dummy in the model with the interacted term for gas price. Again, we notice the distinct difference between the coefficient estimates in Figure 5.5c and Figure 5.5d. The coefficient estimates are positive and significant at the 1% level for all quantiles. The 5th quantile coefficient estimate is 14 €/MWh, and the coefficient estimates are increasing up to 95th quantile coefficient estimate of 76 €/MWh. The coefficient estimates of the Iberian exception have changed from negative to positive values when controlling for the additional effect of the gas price. This suggests that the changed relationship between gas and electricity prices explains the entire downward pressure from the Iberian exception. This is because when we control for the additional effect, the dummy coefficient estimates become positive. This means that we only find the price reducing effect of the Iberian exception in conjunction with the gas price. Furthermore, the dummy coefficient estimates increase across quantiles, indicating that when controlling for the additional effect, the Iberian exception dummy has the strongest effect on higher quantiles pushing electricity prices upwards.

The results overall are as expected. We anticipated seeing a significant change in the effect gas prices have on electricity prices given the configuration of the Iberian exception. Furthermore, the decreasing pattern of the interaction term is rational since the effect of the gas cap should in theory be stronger for higher price levels, where the difference between the reference gas price and the market gas price is greater. However, what is more surprising is the effect on the dummy variable. For the Iberian exception dummy coefficient estimate to become positive, the upwards pressure from the interaction term must be stronger than the downwards pressure from the dummy variable. Meaning the model suggests that not only does the additional effect of gas explain the downward pressure from the dummy, but it explains more than the effect of the dummy.

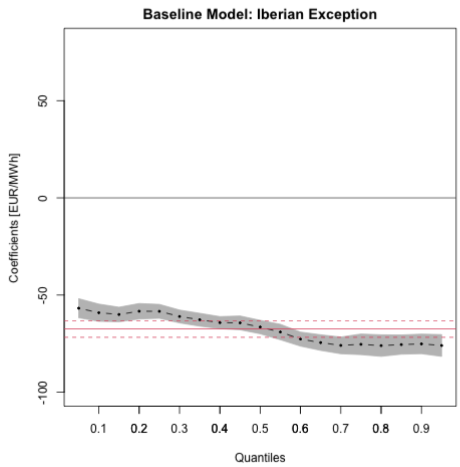
### EUA Prices



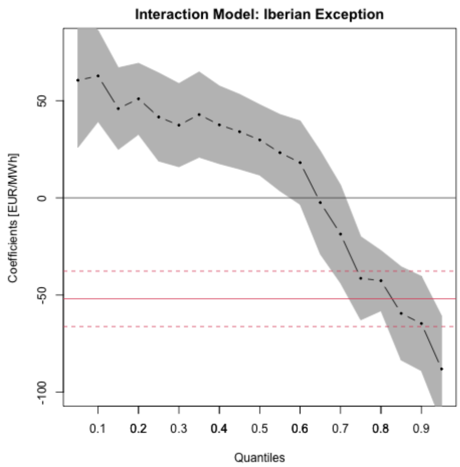

**(a)** EUA price effect




**(b)** Additional EUA price effect




**(c)** Baseline results




**(d)** Interactions results

**Figure 5.6:** Interaction terms between EUA and Iberian exception dummy.
*Note: Y-axis for Iberian exception's baseline result (shown in Section 5.2.3) are adjusted for comparability to Iberian exception results from interaction model including EUA.*

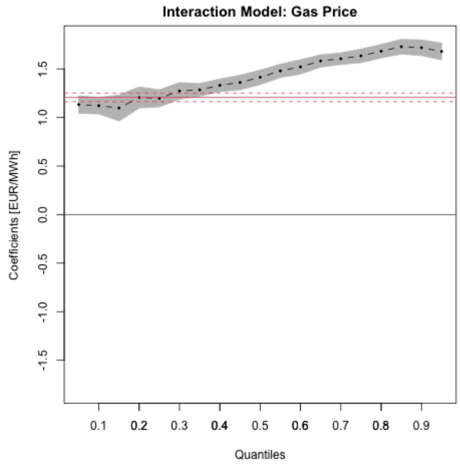
In figure 5.6a we observe the coefficient estimates of the EUA price. The estimates are positive and significant at the 5% level in all quantiles except for the 75th quantile and above. The pattern of the quantile estimates are concave, indicating that EUA exerts the most upwards pressure on electricity prices around the median. The results are as anticipated, as EUA is an additional cost for generating electricity from fossil fuels, it should have an upwards pressure on electricity prices.

Figure 5.6b shows the coefficient estimates of the interaction term between the EUA price and the Iberian exception dummy. The coefficient estimates are negative and significant at the 5% level up to the 80th quantile. This suggests that the effect of EUA prices on electricity prices are reduced after the adoption of the price cap for the price distribution below the 80th quantile, while above they are unchanged. Furthermore, the estimates increase across quantiles which suggests that the additional effect from EUA prices on electricity prices have been strongest for the lowest price levels.

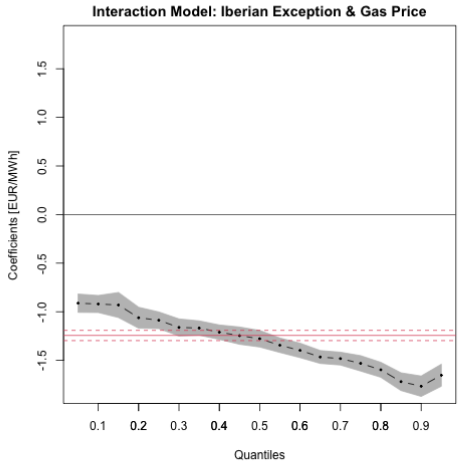
Moreover, Figure 5.6d shows the coefficient estimates of the Iberian exception dummy in the model with the interacted term for the EUA price. Compared to the Iberian exception coefficient estimates in the baseline model shown in Figure 5.6c, we initially notice that the coefficient estimates in Figure 5.6d vary considerably more across quantiles. The coefficient estimates below the 60th quantile are positive, while quantiles above have negative coefficient estimates. The coefficient estimates are significant at the 5% level in all quantiles, except for the 60th, 65th and 70th quantile. The coefficient estimates have a decreasing pattern across quantiles, with the 5th quantile at 60 €/MWh and the 95th quantile at -88 €/MWh. Compared to the baseline model, we observe that for the highest quantiles the difference in the magnitudes are minimal, indicating that the Iberian exception has a similar downwards effect on electricity prices on the highest price levels when we control for the additional effect of EUA prices. However, for lower quantiles the model suggests that the additional effect of EUA explains the downward pressure from the Iberian exception.

Overall, the results are surprising as the Iberian exception was not intended to affect how EUA prices impact electricity prices. Despite that gas-fired power plants can only bid in the market with a cost of gas at maximum 40 €/MWh, they must take into account the market price for EUA. It is therefore not obvious why the EUA price effect on electricity prices should decrease following the cap. However, the price of EUA is strongly connected to fossil fuels. Therefore, we should control for the additional effect of both gas and EUA price and see if we get different results.

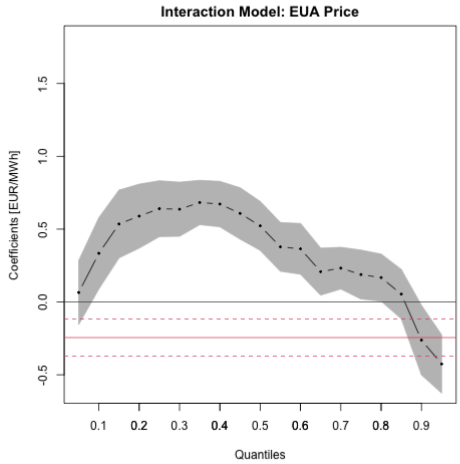
### Gas and EUA Prices



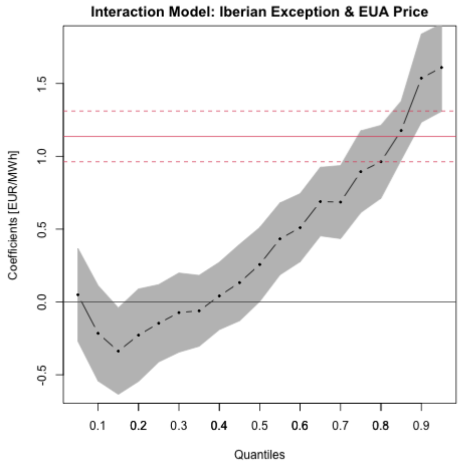

**(a)** Gas price effect



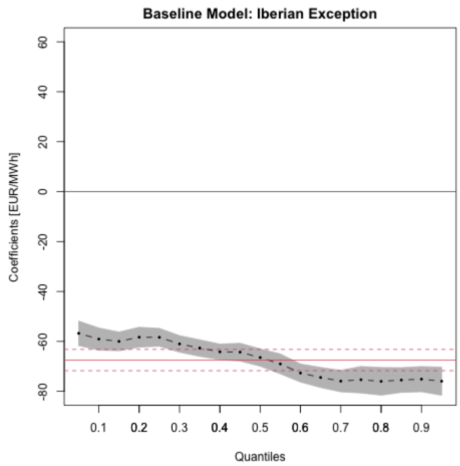

**(b)** Additional gas price effect



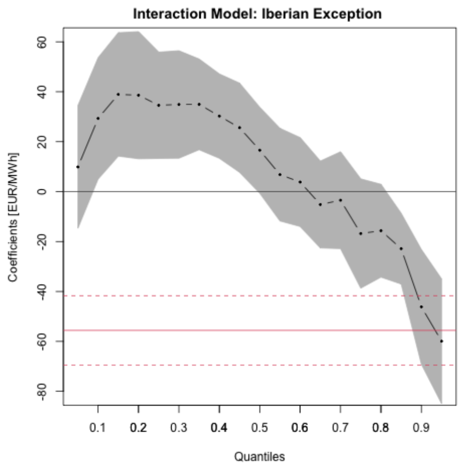

**(c)** EUA price effect




**(d)** Additional EUA price effect




**(e)** Baseline results




**(f)** Interactions results

**Figure 5.7:** Interaction terms between gas, EUA and Iberian exception dummy.
*Note: Y-axis for Iberian exception's baseline result (shown in Section 5.2.3) are adjusted for comparability to Iberian exception results from interaction model including gas and EUA.*

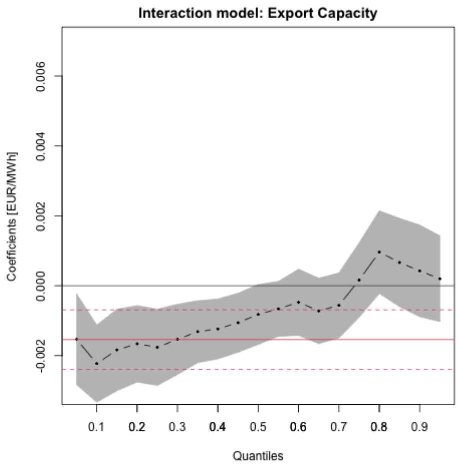
Figure 5.7a and Figure 5.7b show the coefficient estimates of gas price and the interaction term of gas price. Compared to the model with only the gas price there are only small changes, and the effects are overall the same even though we have included the EUA interaction term in the model. Furthermore, Figure 5.7c shows the coefficient estimates from EUA prices, which are not considerably different from the model with only the interacted term for EUA.

However, the coefficient estimates of the interaction term of EUA price are different compared to the model without gas interaction, shown in Figure 5.7d. While the pattern of the coefficient estimates is similar, the coeafficient estimates have changed from negative to positive. The coefficient estimates are positive and significant from the 50th quantile and increasing in magnitude towards the highest quantiles. In contrast to the former model, these results suggest that the effect of EUA prices on electricity prices are strengthened above the 50th quantile, while they are unchanged below.

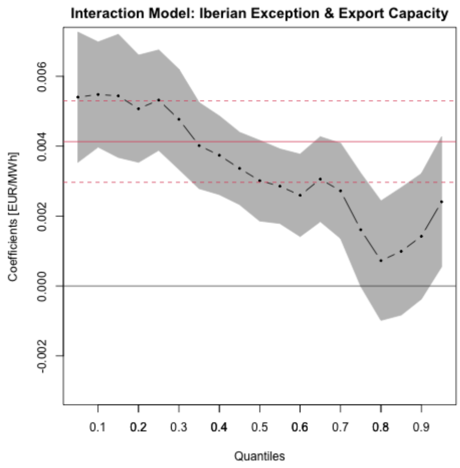
Lastly, in Figure 5.7f, we have the coefficient estimates of the Iberian exception dummy in the model with interaction terms. The pattern and the coefficient estimates are similar to the model with only the EUA interaction term, but the coefficient estimates have converged closer to zero. The estimates below the 80th quantile are either positive or not significant, which suggests that for these quantiles, we only find the price reducing effect of Iberian exception in conjunction with gas and EUA prices. From the 80th quantile and above, the coefficient estimates are significant and negative. This allows us to conclude that the additional effect from gas and EUA prices does not alone explain the Iberian exception's downward pressure on electricity prices at the highest part of the price distribution.

### 5.3.2 Increased Exposure to Export Capacity

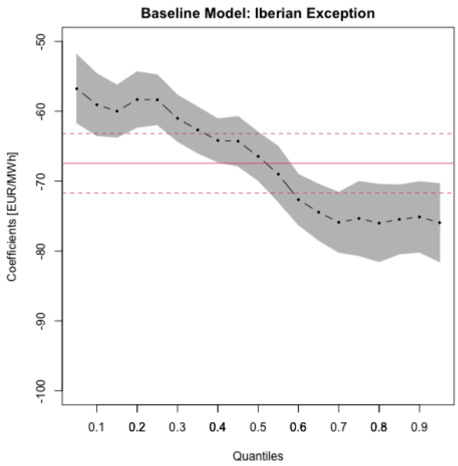
We recall prior research on the Iberian exception discussed in Section 2, where the findings suggests that the exports from Spain, in particular to France, increased considerably following the implementation of the gas cap. Therefore, we see it appropriate to examine whether the impact of export capacity on electricity prices has changed after the implementation.



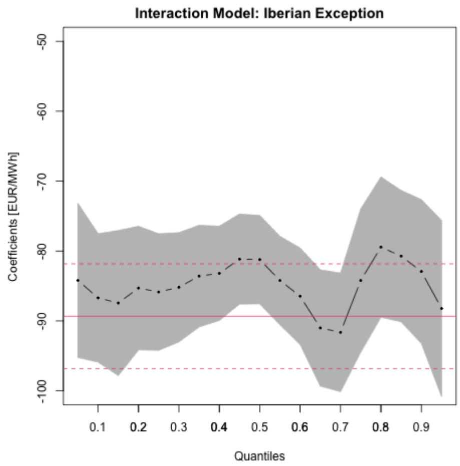

**(a)** Export capacity effect




**(b)** Additional export capacity effect




**(c)** Baseline results




**(d)** Interactions results

**Figure 5.8:** Interaction terms between EUA and Iberian exception dummy.
*Note: Y-axis for Iberian exception's baseline result (shown in Section 5.2.3) are adjusted for comparability to Iberian exception results from interaction model including Export capacity.*

Figure 5.8a shows the coefficient estimates for export capacity. The estimates up to the 55th quantile and the 65th quantile are negative and significant at the 5% level. The coefficient estimates from the 70th quantile and upwards are not significant except for the 80th quantile, which is positive. Moreover, the estimates below the 75th quantile are not significantly different from the OLS estimate, while from the 75th quantile and upwards they are. This indicates a weak upwards trend in quantiles above the 75th.. We expected positive coefficient estimates in all quantiles as higher capacity for exports should lead to higher demand for electricity from neighboring countries. Thus, these results are somewhat surprising.

Furthermore, Figure 5.8b shows the interaction term of export capacity and the Iberian exception dummy. The coefficient estimates up to the 75th quantile are positive and significant at the 5% level and are decreasing across quantiles. The results indicate that the effect from export capacity on electricity prices is positively strengthened after the implementation of the Iberian exception for most quantiles. This is expected, as export is generally higher when electricity prices are lower. With higher exports, the capacity for exports becomes a more important factor for electricity prices, thereby pushing prices upwards.

Moreover, Figure 5.8d shows the coefficient estimates of the Iberian exception dummy in the model with the interacted term of export capacity. We see that the coefficient estimates exhibit minimal variation across quantiles. In fact, none of the coefficient estimates are significantly different from the OLS estimates. The results imply that the Iberian exception pushes electricity prices downwards by 89 €/MWh on average in all quantiles.

All aforementioned results indicate that the additional effect of export capacity has pushed prices upwards in quantiles below the 80th quantile. In other words, the additional effect from export capacity has moderated the Iberian exception's downward pressure on these quantiles, while having minimal impact on the highest quantiles. Furthermore, since the Iberian exception coefficient estimates in the interacted model are equal across quantiles, this suggests that when controlling for the additional effect of export capacity, we do not find that the gas cap has reduced price volatility. For the interacted model, the Iberian exception coefficient estimates are lower than the coefficient estimates from the baseline model in all quantiles. However, the results suggest that the additional upwards pressure from export capacity below the 80th quantile causes some of the volatility reduction we observe in the baseline model, which is surprising.

# 6 Discussion

The main finding from the difference in difference model and the quantile regression model is the significant reduction of electricity prices caused by the Iberian exception. Furthermore, we find evidence of volatility reduction and peak shaving, in addition to an altered relationship between electricity and gas prices. In this chapter, the results will be set in context and discussed to give a better understanding of the effects of the Iberian exception.

## 6.1 Price and Volatility Reduction

We used the difference in difference model to evaluate the causal effect of the Iberian exception on the day-ahead electricity price in Spain. The results from our analysis suggests that the electricity price reduces on average by approximately 190 €/MWh in Spain after the adoption of the Iberian exception. Furthermore, from the quantile regression analysis we found a price reduction on day-ahead prices of 67 €/MWh on the median. Despite that quantile regression models are not primarily used for finding causal effects, the results from our quantile regression analysis supports the findings from our difference in difference analysis. Comparing our results to prior research on the Iberian exception, we can settle that the Iberian exception has significantly reduced day-ahead electricity prices in Spain.

Furthermore, when including the compensation cost paid to the fossil-fuel generators in the difference in difference model, we found a price reducing effect of 107 €/MWh from the Iberian exception. The effect confirms that the gas cap has reduced the electricity price for consumers on the PVPC. Reducing electricity price for consumers, in addition to the wholesale price, was the main objective of the legislation, and the results show that this was accomplished. The Iberian exception can therefore, before looking at possible adverse effects, be considered a success.

Regarding price volatility, the results from the quantile regression analysis shows that the Iberian exception had a downward pressure on prices across the price distribution with the estimate ranging from 57 €/MWh on the 5th quantile to 77 €/MWh on the 95th quantile. While the decreasing coefficient estimates across quantiles, which correspond to volatility reduction, were expected, we did expect a larger difference between the lowest and highest quantiles. A likely reason for this is that the MIBGAS benchmark price, shown in Figure 2.4, has been higher than the reference price each day after the cap was implemented. If the gas price would have been lower than the reference price for the lowest quantiles of the electricity price, we would likely see a weaker, and perhaps negligible, effect of the Iberian exception for these quantiles. This would in turn give a stronger volatility reducing effect overall.

Furthermore, the results from the interaction model with export capacity indicated that the additional upwards pressure on prices could explain the volatility reduction from the Iberian exception. It is reasonable that export capacity increases prices more for the lower part of the price distribution, as that is the price range when exports usually occur. However, the large magnitude of the additional effect was surprising. While it may seem positive that export capacity reduces volatility, the reduction comes at the expense of higher electricity prices for the quantiles below the 80th.

Moreover, the peak shaving effect in the results were weaker than expected, with the coefficient estimates for the Iberian exception from the 70th quantile and above stabilizing. Due to the combination of the cap on marginal cost of gas and the correlation between gas and electricity prices, we expected to observe the strongest downward pressure for the highest quantiles of the electricity price. It is not obvious why we do not witness a stronger peak shaving effect, but it likely linked with the results from the interacted model with export capacity. The results suggest that the additional effect from export capacity has pushed prices upwards below the 80th quantile, which coincides with the stabilizing of the coefficient estimates in the baseline model.

We might see a weak peak shaving effect from the Iberian exception because the effect of additional export capacity is not significant for the highest quantiles. In other words, without the additional effect from export capacity, we would not see a volatility reduction or a peak shaving effect. Moreover, the results from the interacted model with gas and EUA prices found a downwards pressure from the Iberian exception at the highest quantiles, even when controlling for the additional effect from these variables. This indicates that there is another factor besides gas, EUA and export capacity that pushes prices downwards in the highest quantiles. Overall, the results with a weak peak shaving effect and the drivers behind the price volatility are intriguing and it is something that should be researched further.

## 6.2 Gas and EUA Prices

In line with our hypothesis, the interacted model with gas prices showed that the positive effect from gas prices on electricity prices are weakened after the implementation of the Iberian exception. This means that increased gas prices do not increase electricity prices as much as they did prior to the implementation of the Iberian exception. This was the intended effect of the cap, essentially decoupling electricity prices from volatility gas prices. However, this fundamental change to the electricity market has not come without consequences. The gas price's positive impact on electricity prices is reduced after the cap, incentivizing gas-driven electricity generation. A cap on the marginal cost of gas in the electricity market increases the competitiveness of gas-driven generators compared to other technologies, since the full marginal cost of gas is not reflected in the market. Consequently, the increased incentives for gas-fired generation have led to increased gas-power following the Iberian exception. In fact, IEA (2023a) found that gas-fired generation increased by 25% or 18 TWh in 2022 compared to 2021 levels.

Prior research on the Iberian exception also highlighted that gas-fired generation had increased after the implementation. Eicke et al. (2022) found a 42% increase in gas-power for the two first months of the reform. Further, Hidalgo-Pérez et al. (2022) emphasized that the reform may reduce the incentives for transitioning to clear energy sources because it incentivizes increased gas generation. In the context of the European energy crisis and the shortages of natural gas, increased gas consumption in the power sector is unfavorable, despite the fact that Spain should have a low risk of supply shortages due to their LNG-terminals. Moreover, in the long term with decarbonization targets, it is also counterproductive to incentives gas generation. Overall, the increased gas consumption following the reform is a substantial adverse effect.

The increased gas generation in Spain may have impacted the electricity prices indirectly through EUA prices. The model with interacted terms for gas and EUA price showed that from the 50th quantile the EUA price has had an additional positive effect on electricity prices. The additional positive effect could be due to the increased gas generation, as more gas power requires more EUAs. Since the cost of gas is capped in the market, this can make the cost of EUA a larger part of the marginal costs. When EUA cost constitutes a larger part of the marginal costs, the EUA price additionally affects the electricity price positively. In particular, that is the case in the higher areas of the price distribution.

## 6.3 Electricity Exports

In the quantile regression model with the interaction term for export capacity, we found that the effect of export capacity on electricity prices was positively strengthened after the implementation of the Iberian exception. This effect was the case for the price distribution up to the highest quantiles. Export capacity impact electricity prices when the capacity is a limiting factor for electricity transmission between two markets. Therefore, when export capacity has an increased upwards pressure on prices after the Iberian exception, it is likely because exports have increased which makes capacity a more constraining and important factor.

Exports from Spain to its neighboring countries have increased following the cap, which comes as no surprise since the instrument have reduced electricity prices in Spain. According to OMIE (2023), the total exports from Spain doubled from 2021 to 2022, switching Spain from a net importer to a net exporter. Figure 6.1 show the interconnection flow between Spain and France, where the grey lines are net flow and the green and blue are capacities. The figure illustrates that from June 15th until November, the exports towards France persistently reached the maximum levels. With these levels of exports towards France, it is logical that export capacity's effect on electricity prices were positively strengthen, contributing to the volatility reducing effect of the Iberian exception.

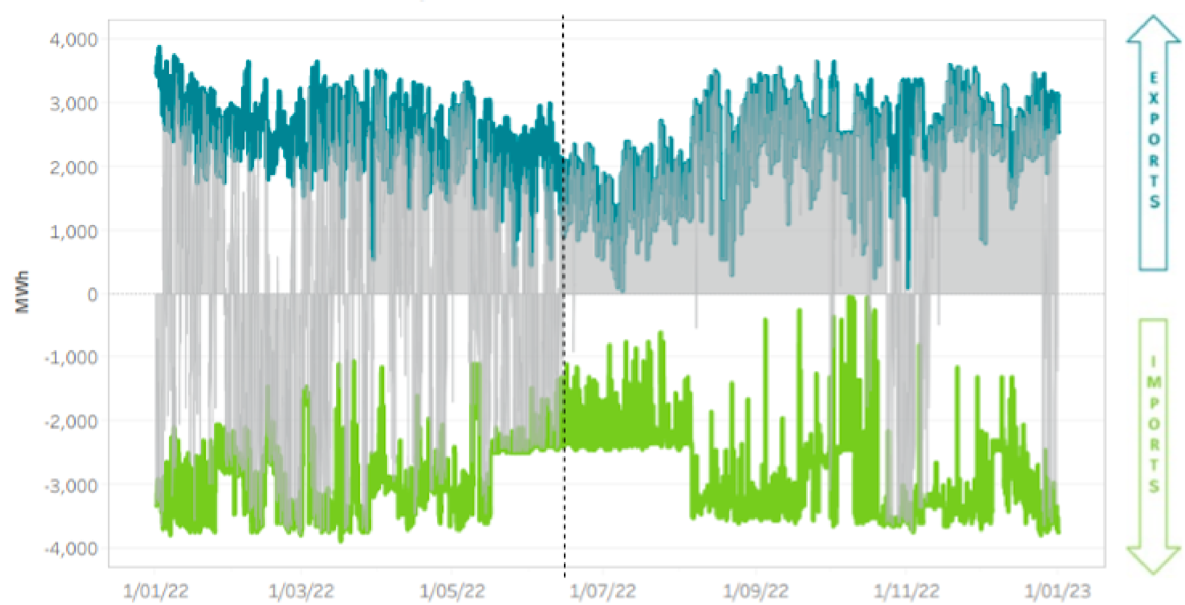



**Figure 6.1:** Interconnection flow and capacities between Spain and France in the day-ahead operations program in 2022 (OMIE, 2023).

It is important to highlight that the increased exports from Spain to France is not necessarily due to the Iberian exception. Coinciding with the Iberian exception were several factors which increased the electricity price in France, particularly nuclear maintenance struggles and drought. Therefore, it is possible that the prices in France might have been higher than in Spain even if the gas cap was not implemented. Hidalgo-Pérez et al. (2022) found that out of the 78 days they analyzed, French day-ahead prices would have been higher than the Spanish for 55 days even without the Iberian exception. On the other side, the instrument is designed to reduce electricity prices, hence it is natural that net exports increase to neighboring countries which do not intervene in the same manner (Eicke et al., 2022). Even with the nuclear struggles, it is likely that the Iberian exception has led to more exports to France (Rystad Energy, 2022).

Regardless of the reason behind the increased exports, the Iberian exception has benefited French consumers because the French market buys electricity at a subsidized price, without having to pay for the subsidy (Fuster, 2022). In other words, part of the subsidy is leaking, which is problematic, yet an important adverse effect of the Iberian exception. The problem would however be considerably worse if Spain and France were more interconnected

## 6.4 Limitations of the Thesis

Due to limitations on the available data, we have made some assumptions in order to formulate meaningful models. We chose to use data from October 1st,, 2021, when the gas prices started to surge, until December 15th, 2022, when the first period of the gas cap concluded. That is, we have chosen a period characterized by exceptionally high electricity prices. As such, prices can exhibit more extreme price levels than previous long run levels. Additionally, the short time range of our dataset can make controlling for seasonal dynamics difficult. However, electricity prices present stochastic behavior and we have hourly data for six months post the implementation of the price cap. As such, we assume the same price formation dynamics in the state of crisis.

Further, in our quantile regression models we are focusing on the day-head wholesale market, which does not include the compensation to fossil-fuel generators. For consumers, especially the ones on the PVPC tariff, the compensation is a substantial part of their electricity costs. Because we have chosen to examine day-ahead prices, the true cost for consumers is not reflected in our quantile regression model. It is important to have in mind that the price reduction in our model does not necessarily reflect savings for consumers, since they would have to pay eventual compensation on top of the wholesale price.

Lastly, the control variables in our quantile regression models are mainly based on research in the German and Italian electricity market. The electricity market in Spain follows the same price setting model agreed upon and approved by all the European markets. As such, we assume that Spanish electricity price formation is homogenous to German and Italian price formation. However, we cannot rule out additional factors that influences the electricity price formation in Spain.

## 6.5 European Exception?

In light of the energy crisis in Europe, the Iberian exception raises the question of whether a gas cap is a solution for other countries. Our difference in difference and quantile regression models showed statistically significant reductions in the wholesale electricity price. Moreover, the difference in difference model which included the compensation also showed a significant reduction in the electricity price. Could other European countries experience similar price reductions? Would for instance an Italian exception provide the same results?

It is important to highlight that this thesis has not evaluated every effect of the Iberian exception reform. Additionally, we have not intended to quantify social welfare made by the reform. Still, our results provide new information about the subject, and confirm what earlier research has found. Furthermore, our analysis may be a valuable tool in discussions on whether the Iberian exception was in fact a success or not, and how one potentially can introduce it to other markets.

Other markets where gas power sets the electricity price should in theory experience lower wholesale prices if they implemented the cap. However, they are likely dependent on having a considerable share of renewables for consumers to benefit when considering the compensation. As mentioned, the savings comes from inframarginal technologies, like renewables because their windfall profits are reduced. In a fossil-fuel dominated power system, the savings would be less, and consumers would likely not receive a net benefit (Gambau, 2022).

Furthermore, the adverse effects with increased gas generation and increased exports would be an issue. We recall that Spain has been granted an exception due to the country having limited interconnection to the rest of Europe and because they have good access to natural gas through their LNG-terminals and pipelines. As Eicke et al. (2022) explains, most other European countries are considerably more interconnected, which would greatly increase the leakage problems. Even with an EU-wide implementation, the leakage problem would occur to non-member countries. Additionally, the increased gas generation, which the gas cap incentivizes, would likely be a bigger problem in other European countries. Most European countries do not have the same infrastructure for LNG-shipments. Hence, an implementation would likely lead to higher gas prices which would have further consequences for consumers and industry, creating extensive distortions (Gambau, 2022). In particular, for those who might not have any subsidies, which is the case for most of the industry. Overall, in a shortage of natural gas, measures that incentivize increased gas consumption have substantial drawbacks.

Despite the likely adverse effects with an implementation outside of the Iberian Peninsula, the Commission President Ursala von der Leyen said “It really merits to be considered at EU level,” during a debate on the October 20th (Gambau, 2022). However, when the European Commission proposed a reform to the EU’s electricity market design in March 2023, there were no measures regarding caps such as the Iberian exception. Instead, the Commission emphasized that marginal pricing should be upheld and the proposals included no fundamental changes to the price forming in the day-ahead market (Vercammen, 2023). Hence, it appears that the EU has concluded that despite the prospects of lower wholesale electricity prices, the adverse effects of a European exception pose too big of a problem. Overall, such a reform of the electricity market is not beneficial.

# 7 Conclusion

The soaring energy prices experienced in 2021 and 2022 have plunged Europe into its biggest energy crisis since the 1970s. To combat the shortage of energy and the sky-high prices several countries and the EU have adopted drastic measures. The most extreme measure came from the Iberian Peninsula with the introduction of the Iberian exception reform. In the context of the crisis, it is crucial to evaluate whether implemented measures have accomplished their objectives, as well as studying the possible adverse effects. Therefore, empirically analyzing the Iberian exception's impact on electricity prices could provide valuable insights for future decision-making. This thesis has focused primarily on the day-ahead wholesale market in Spain. A difference in difference model has been used for identifying causal effects, in addition to a quantile regression model based on relevant research to examine price effects across the electricity price distribution. Based on the goal of the reform and prior research, hypothesis for price and volatility reductions were made prior to the analysis. In addition, we have analyzed and discussed possible underlying drivers of our results.

Our results show a significant price reducing effect from the Iberian exception on day-ahead electricity prices in Spain, even when including the compensation to fossil-fuel generators. These results provide evidence that the Iberian exception has accomplished its target of reducing electricity prices. The results also indicate a decrease in price volatility and a weak peak shaving effect following the cap. Furthermore, when controlling for possible underlying drivers of the results, we find that gas prices' positive impact on electricity prices have been reduced, providing evidence for a partial decoupling of gas and electricity prices. The price reducing effect of the Iberian exception is only evident in conjunction with the gas price. Moreover, the additional effect from export capacity pushes electricity prices upwards in all quantiles except for the highest. Thus, indicating that increased exposure to export capacity is a key underlying driver for the experience volatility reduction from the Iberian exception.

Prior research on the topic found that after the implementation of the Iberian exception, gas-fired generation and exports increased substantially. Since gas and electricity prices were partially decoupled, the gas cap incentivized gas-fired generation making it more competitive compared to other technologies. Exports likely increased due to the gas cap and nuclear troubles in France, leading to leakage of the subsidy with French consumers. Increased gas generation and increased exports are key adverse effects of the Iberian exception.

The Spanish government is confident the reform has been a success. In March 2023, the government extended the cap until December 2023 (Bronte, 2023). Though with 2023 gas prices the instrument is primarily a safeguard. The government did however emphasize that the measure gives a safety net for consumers, and that it has saved more than EUR 5.1 billion for Spanish consumers. While this thesis has not evaluated every effect of the Iberian exception reform, our results still evidently show that the Iberian exception did accomplish its goal of reducing electricity prices. Furthermore, because of its LNG infrastructure and limited interconnectors, the adverse effects were constrained to some degree. The reform could therefore be considered a success on the Iberian Peninsula. However, more research on the benefits and drawbacks is needed before a conclusion can be made. Overall, there is limited research on price caps and other controversial measurements in electricity markets, topics we would recommend for future research.

The effectiveness of the Iberian exception in lowering electricity prices raises the question of whether a gas cap is a solution for other countries. However, the adverse effects identified from the Iberian exception would likely pose a bigger problem in other countries compared to the Iberian Peninsula. Conclusively, a similar solution would not be beneficial for the rest of Europe.

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# Appendix

## A1 Data

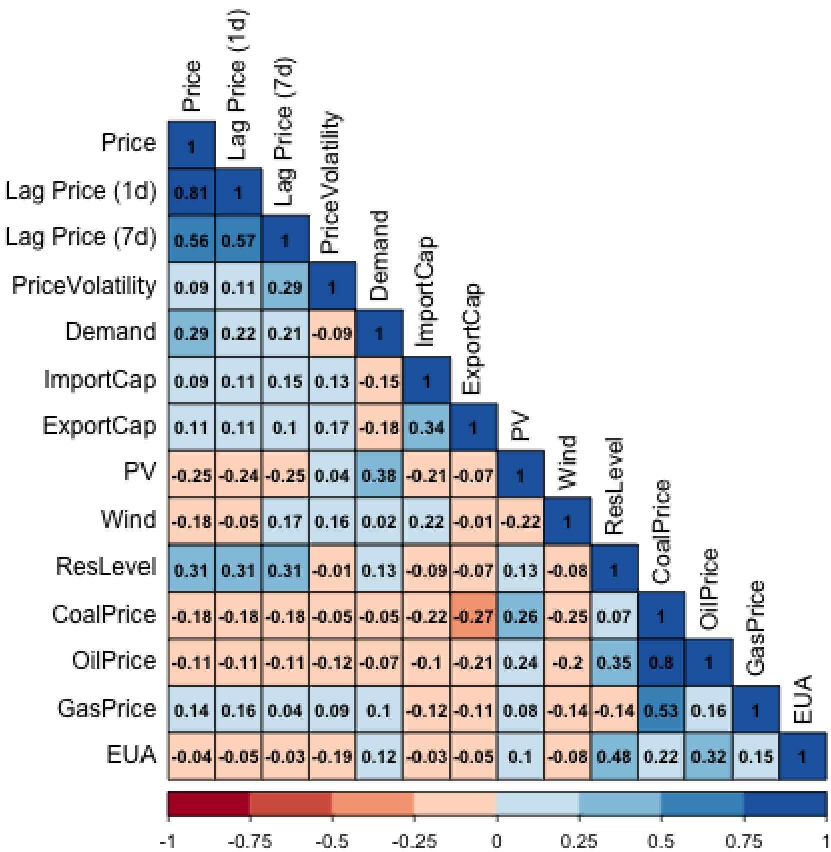
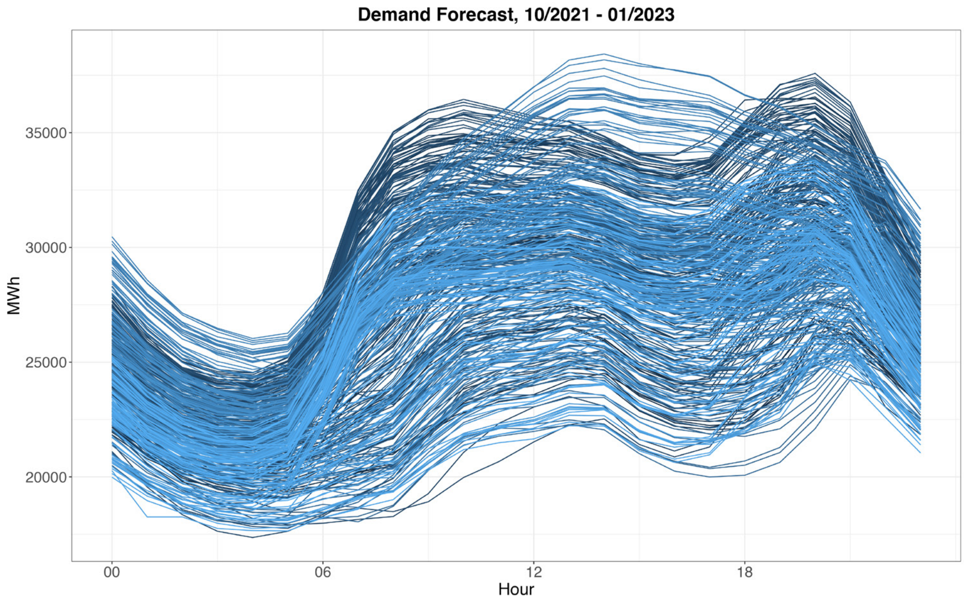
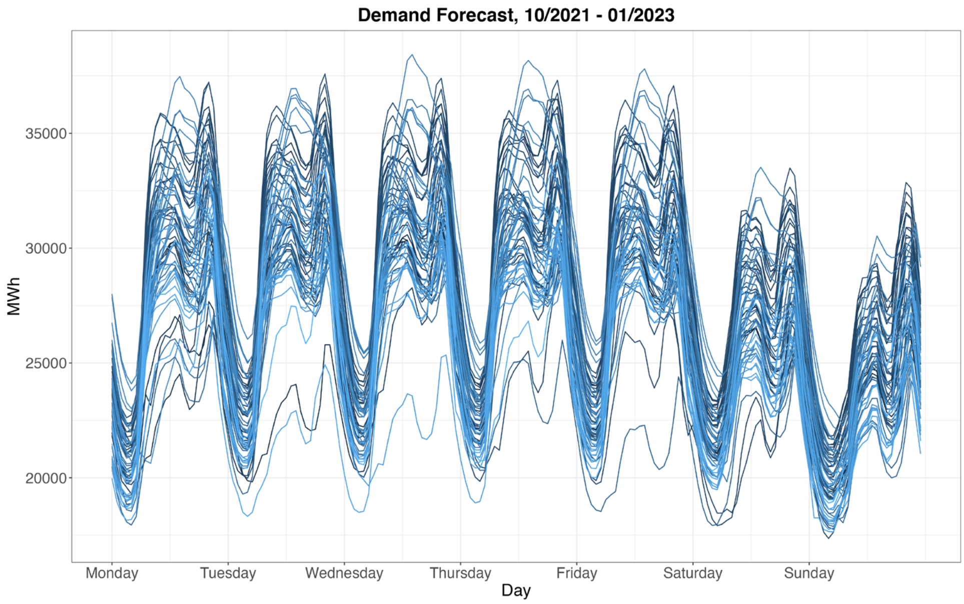



**Figure A1.1:** Pairwise correlation between explanatory variables.

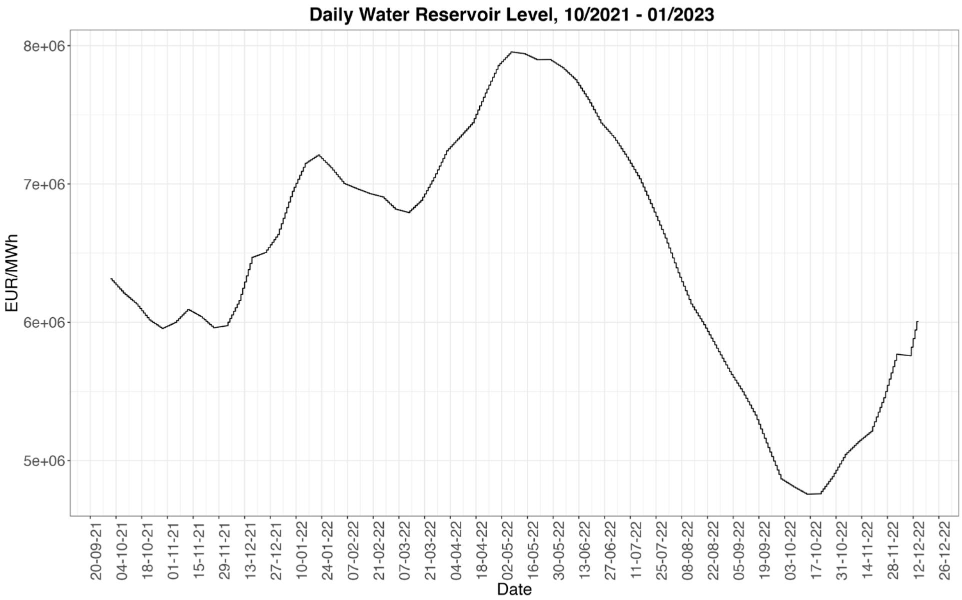



**(a)** Seasonal plot showing daily seasonal patterns for Spanish demand forecast.

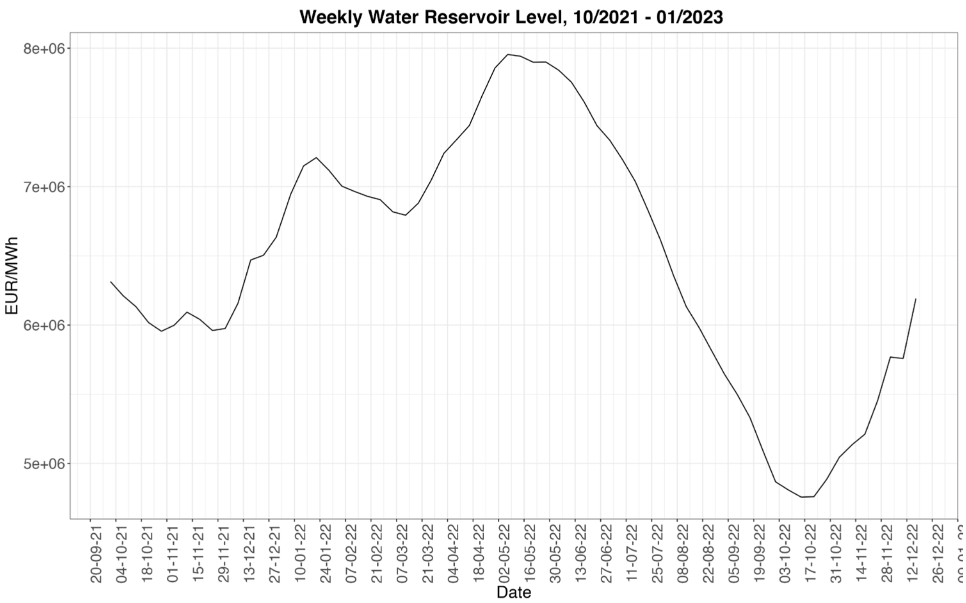



**(b)** Seasonal plot showing weekly seasonal patterns for Spanish demand forecast.

**Figure A1.2:** Seasonal plots for the period 10/2021 - 01/2023.




**(a)** Daily linearly interpolated data.




**(b)** Weekly original data.

**Figure A1.3:** Water reservoir level for the period 10/2021 - 01/2023.

| **Date** | **Holiday** |
|---|---|
| 12.10.2021 | Spain's National Day |
| 01.11.2021 | All Saints' Day |
| 06.12.2021 | Spanish Constitution Day |
| 08.12.2021 | Immaculate Conception |
| 25.12.2021 | Christmas |
| 26.12.2021 | Christmas Holiday |
| 01.01.2022 | New Year's Day |
| 15.04.2022 | Good Friday |
| 01.05.2022 | Labor Day |
| 15.08.2022 | Assumption of Mary |
| 12.10.2022 | Spain's National Day |
| 01.11.2022 | All Saints' Day |
| 06.12.2022 | Spanish Constitution Day |
| 08.12.2022 | Immaculate Conception |

**Table A1.1:** Spanish holidays in the period 01.10.2021-15.12.2022.

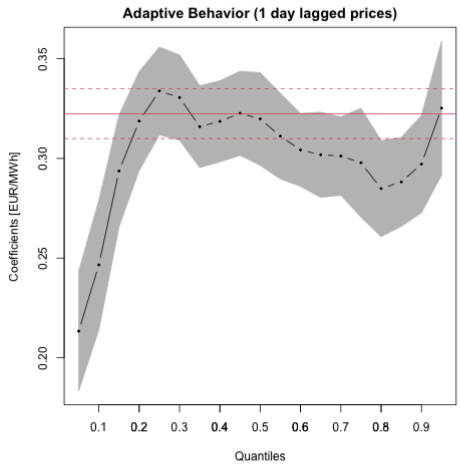
# A2 Results

In this section we display by plots the estimation results for the explanatory variables in the baseline model. Each plot includes the quantile regression profile for the set of coefficient estimates for each variable, along with their respective bootstrapped confidence intervals. Additionally, the plots include the OLS estimates, which are constant in quantiles, with their confidence intervals.

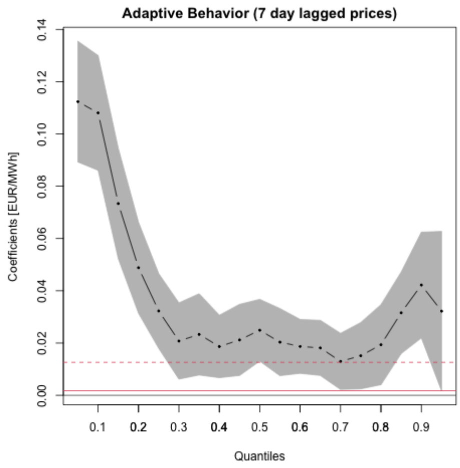
| | *Dependent variable:* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Day-ahead Spot Price [EUR/MWh] | | | | | | | | |
| | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% |
| Iberian Exception Dummy | −56.776*** | −59.071*** | −59.989*** | −58.319*** | −58.364*** | −61.010*** | −62.678*** | −64.180*** | −64.302*** |
| | (1.601) | (2.044) | (1.358) | (1.435) | (1.496) | (1.393) | (1.322) | (1.059) | (1.186) |
| Forecasted Demand | 0.005*** | 0.005*** | 0.005*** | 0.005*** | 0.005*** | 0.004*** | 0.004*** | 0.004*** | 0.004*** |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| Import Capacity | 0.001*** | −0.001* | −0.001*** | −0.001*** | −0.001*** | −0.001*** | −0.001*** | −0.001*** | −0.001*** |
| | (0.0003) | (0.0004) | (0.0003) | (0.0002) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) |
| Export Capacity | 0.001*** | 0.001* | 0.001* | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** |
| | (0.0004) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0002) |
| Forecasted Wind Production | −0.005*** | −0.005*** | −0.005*** | −0.005*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| Forecasted Solar Production | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** |
| | (0.0002) | (0.0002) | (0.0001) | (0.0001) | (0.0002) | (0.0002) | (0.0001) | (0.0001) | (0.0001) |
| Reservoir Level | −0.00001*** | −0.00002*** | −0.00002*** | −0.00002*** | −0.00002*** | −0.00001*** | −0.00002*** | −0.00001*** | −0.00001*** |
| | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) |
| Gas Price | 0.416*** | 0.400*** | 0.349*** | 0.312*** | 0.311*** | 0.323*** | 0.352*** | 0.396*** | 0.434*** |
| | (0.026) | (0.019) | (0.019) | (0.016) | (0.021) | (0.023) | (0.021) | (0.021) | (0.022) |
| Oil Price | −0.014 | −0.120* | −0.043 | −0.005 | 0.037 | 0.024 | −0.041 | 0.004 | 0.045 |
| | (0.072) | (0.065) | (0.052) | (0.059) | (0.063) | (0.055) | (0.063) | (0.056) | (0.059) |
| Coal Price | −0.002 | 0.016 | 0.058*** | 0.074*** | 0.081*** | 0.085*** | 0.077*** | 0.073*** | 0.068*** |
| | (0.013) | (0.013) | (0.011) | (0.011) | (0.012) | (0.012) | (0.011) | (0.011) | (0.011) |
| EUA | −0.256*** | 0.104 | 0.296*** | 0.396*** | 0.526*** | 0.569*** | 0.581*** | 0.528*** | 0.476*** |
| | (0.077) | (0.084) | (0.076) | (0.075) | (0.078) | (0.068) | (0.066) | (0.059) | (0.062) |
| Price Volatility | −0.992*** | −0.798*** | −0.595*** | −0.445*** | −0.340*** | −0.263*** | −0.204*** | −0.146*** | −0.115*** |
| | (0.035) | (0.037) | (0.032) | (0.031) | (0.027) | (0.026) | (0.025) | (0.022) | (0.023) |
| Weekend Dummy | −4.987*** | −2.644*** | −2.696*** | −2.597*** | −2.075*** | −1.219* | −0.176 | −0.544 | 0.057 |
| | (0.660) | (0.478) | (0.386) | (0.513) | (0.687) | (0.679) | (0.602) | (0.493) | (0.538) |
| Holiday Dummy | −8.340*** | 16.758 | 6.416 | 0.142 | −2.967 | −5.991 | −7.367 | −11.317*** | −16.692 |
| | (2.890) | (15.357) | (6.440) | (2.645) | (3.776) | (6.593) | (7.776) | (1.746) | (68.265) |
| Time Trend | 0.028*** | 0.012 | −0.008 | −0.030*** | −0.033*** | −0.030*** | −0.026*** | −0.020*** | −0.015** |
| | (0.009) | (0.009) | (0.007) | (0.007) | (0.009) | (0.007) | (0.007) | (0.006) | (0.006) |
| Day-ahead Spot Price Lagged (1 day) [EUR/MWh] | 0.213*** | 0.247*** | 0.294*** | 0.319*** | 0.334*** | 0.331*** | 0.316*** | 0.319*** | 0.323*** |
| | (0.011) | (0.010) | (0.010) | (0.010) | (0.009) | (0.009) | (0.009) | (0.008) | (0.009) |
| Day-ahead Spot Price Lagged (7 days) [EUR/MWh] | 0.112*** | 0.108*** | 0.073*** | 0.049*** | 0.032*** | 0.021*** | 0.023*** | 0.019*** | 0.021*** |
| | (0.010) | (0.009) | (0.008) | (0.007) | (0.008) | (0.007) | (0.008) | (0.007) | (0.007) |

| | *Dependent variable:* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day-ahead Spot Price [EUR/MWh] | | | | | | | | | |
| | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% |
| Iberian Exception Dummy | −66.456*** | −69.012*** | −72.652*** | −74.450*** | −75.898*** | −75.346*** | −75.995*** | −75.477*** | −75.122*** | −75.948*** |
| | (1.266) | (1.412) | (1.235) | (1.232) | (2.276) | (2.964) | (2.910) | (1.603) | (2.745) | (2.039) |
| Forecasted Demand | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.003*** | 0.003*** | 0.003*** |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| Import Capacity | −0.001*** | −0.001*** | −0.001*** | −0.001*** | −0.001*** | −0.002*** | −0.002*** | −0.002*** | −0.002*** | −0.002*** |
| | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0004) |
| Export Capacity | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.0005* | 0.001** | 0.001*** | 0.001*** | 0.001*** | 0.001*** |
| | (0.0002) | (0.0002) | (0.0002) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0004) | (0.0003) | (0.0003) |
| Forecasted Wind Production | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| Forecasted Solar Production | −0.004*** | −0.005*** | −0.005*** | −0.005*** | −0.005*** | −0.005*** | −0.005*** | −0.005*** | −0.005*** | −0.005*** |
| | (0.0001) | (0.0001) | (0.0002) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0002) | (0.0002) | (0.0002) |
| Reservoir Level | −0.00001*** | −0.00001*** | −0.00001*** | −0.00001*** | −0.00001*** | −0.00002*** | −0.00002*** | −0.00002*** | −0.00002*** | −0.00002*** |
| | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) | (0.00000) |
| Gas Price | 0.482*** | 0.518*** | 0.562*** | 0.625*** | 0.692*** | 0.769*** | 0.822*** | 0.845*** | 0.892*** | 0.921*** |
| | (0.023) | (0.023) | (0.024) | (0.025) | (0.026) | (0.029) | (0.027) | (0.027) | (0.029) | (0.029) |
| Oil Price | 0.064 | 0.155*** | 0.158*** | 0.241*** | 0.396*** | 0.493*** | 0.601*** | 0.731*** | 0.973*** | 1.260*** |
| | (0.053) | (0.055) | (0.059) | (0.065) | (0.063) | (0.070) | (0.073) | (0.067) | (0.075) | (0.075) |
| Coal Price | 0.072*** | 0.079*** | 0.092*** | 0.104*** | 0.109*** | 0.110*** | 0.115*** | 0.134*** | 0.159*** | 0.177*** |
| | (0.011) | (0.011) | (0.012) | (0.013) | (0.012) | (0.015) | (0.014) | (0.014) | (0.017) | (0.014) |
| EUA | 0.430*** | 0.314*** | 0.213*** | 0.095 | 0.004 | −0.118 | −0.180** | −0.089 | −0.036 | −0.072 |
| | (0.062) | (0.060) | (0.063) | (0.069) | (0.067) | (0.073) | (0.084) | (0.085) | (0.089) | (0.086) |
| Price Volatility | −0.049** | −0.004 | 0.016 | 0.034 | 0.064*** | 0.106*** | 0.191*** | 0.303*** | 0.476*** | 0.743*** |
| | (0.023) | (0.020) | (0.020) | (0.021) | (0.021) | (0.026) | (0.031) | (0.029) | (0.035) | (0.038) |
| Weekend Dummy | 0.216 | −0.154 | −0.249 | −0.237 | −1.368*** | −2.293*** | −3.405*** | −4.400*** | −6.112*** | −6.612*** |
| | (0.461) | (0.405) | (0.442) | (0.442) | (0.387) | (0.469) | (0.470) | (0.450) | (0.482) | (0.583) |
| Holiday Dummy | −22.114* | −16.963 | −18.579 | −14.540 | −5.571 | −7.435 | −10.068 | −12.571** | −15.136** | −8.983 |
| | (13.024) | (14.521) | (14.410) | (14.969) | (27.574) | (7.573) | (7.313) | (5.704) | (7.333) | (7.936) |
| Time Trend | −0.008 | −0.006 | 0.002 | 0.005 | 0.003 | 0.001 | −0.003 | −0.013* | −0.032*** | −0.037*** |
| | (0.006) | (0.007) | (0.007) | (0.008) | (0.009) | (0.010) | (0.010) | (0.007) | (0.009) | (0.009) |
| Day-ahead Spot Price Lagged (1 day) [EUR/MWh] | 0.320*** | 0.311*** | 0.304*** | 0.302*** | 0.301*** | 0.298*** | 0.285*** | 0.288*** | 0.297*** | 0.325*** |
| | (0.009) | (0.008) | (0.008) | (0.009) | (0.009) | (0.011) | (0.011) | (0.010) | (0.012) | (0.012) |
| Day-ahead Spot Price Lagged (7 days) [EUR/MWh] | 0.025*** | 0.020*** | 0.019*** | 0.018*** | 0.013** | 0.015** | 0.019** | 0.032*** | 0.042*** | 0.032*** |
| | (0.007) | (0.006) | (0.007) | (0.007) | (0.006) | (0.008) | (0.008) | (0.006) | (0.007) | (0.008) |
| *Note:* | | | | | | | | | | *p<0.1; **p<0.05; ***p<0.01<br>Month and hour dummies are omitted. |

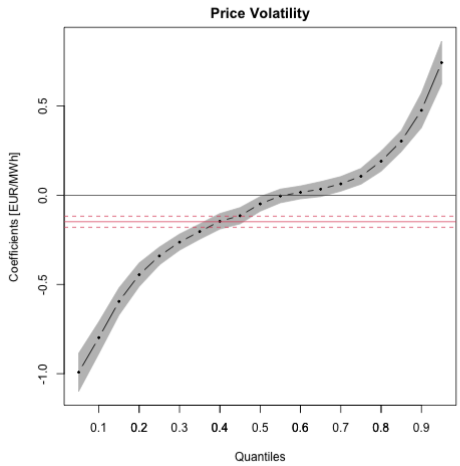
**Table A2.1:** Quantile regression baseline model output.



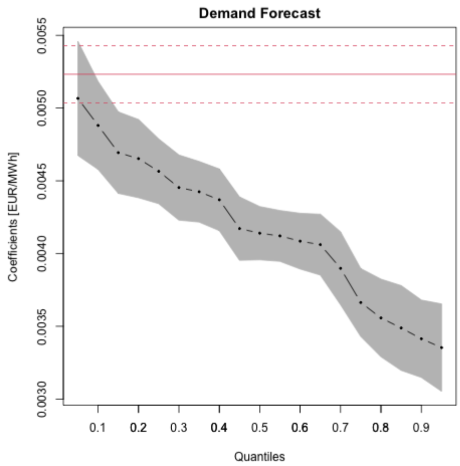

**(a)** Adaptive behavior



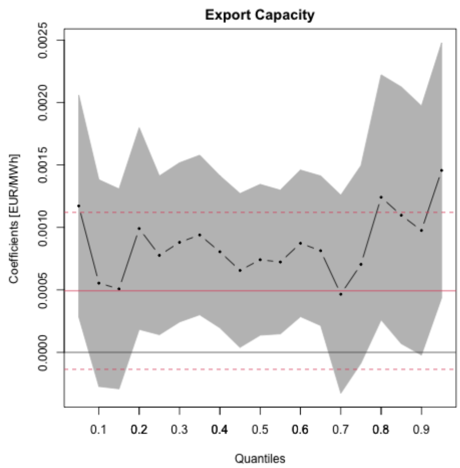

**(b)** Adaptive behavior



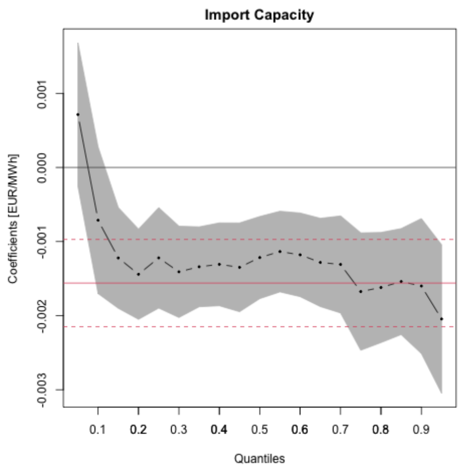

**(c)** Price Volatility




**(d)** Demand




**(e)** Export capacity




**(f)** Import capacity

**Figure A2.1:** Coefficient estimates for control variables.

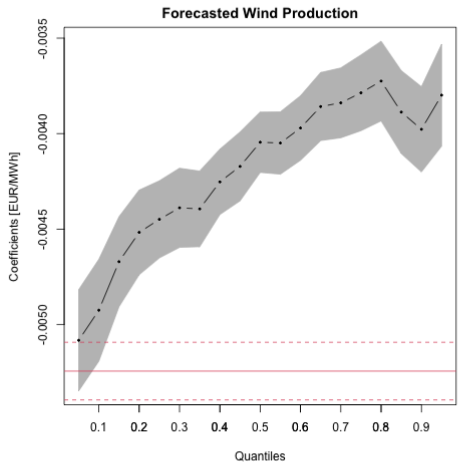
Figure A2.1 shows the coefficient estimates of the control variables. The coefficient estimates of the 1- day lagged spot price are positive and significant at 1% level of significance in all quantiles, shown in Figure A2.1a. Further, coefficient estimates of the 7-day lagged spot price are positive and significant at 1% in all quantiles, as seen in Figure A2.1b. These results indicate the adaptive behavior of actors in the market. Additionally, the results indicate the mean reverting of prices.

The results for price volatility are shown in Figure A2.1c. The coefficient estimates are negative and significant in all quantiles bellow the median, while the coefficient estimates are positive and in all quantiles above the median. Meaning that when prices are low (high), and increase in volatility tends to drive the prices even lower (higher). Indicating that price volatility amplifies both low and high prices.

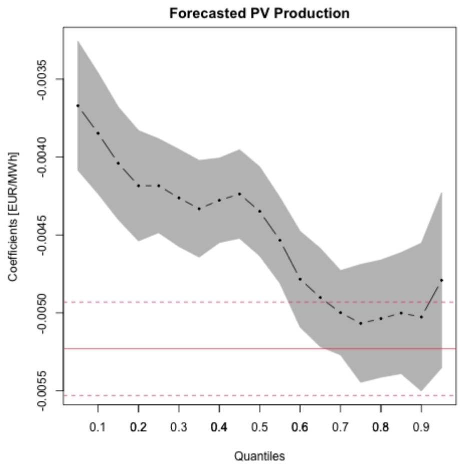
Figure A2.1d shows the coefficient estimates for forecasted demand, which are positive and significant at 1% level of significance in all quantiles. However, the decreasing pattern of the coefficients with quantiles contradicts both the expected results in our thesis and the findings of Bunn et al. (2016), anticipating the effect of demand to increase with higher quantiles.

From Figure A2.1e we can see that the coefficient estimates for export capacity is positive and significant in all quantiles. This suggests that export capacity has a positive effect on electricity prices, which coincide with our expectations. The coefficient estimates for import capacity, shown in Figure A2.1f, are negative and significant in all quantiles, suggesting a negative effect on electricity prices.

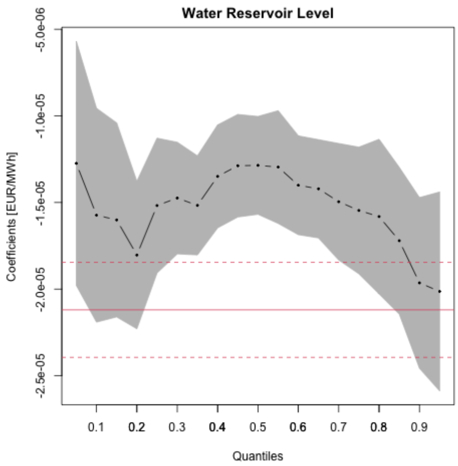
Figure A2.2 shows the coefficient estimates for the renewable energies, that is wind production, PV production and water reservoir level.




**(a)** Wind production




**(b)** PV production

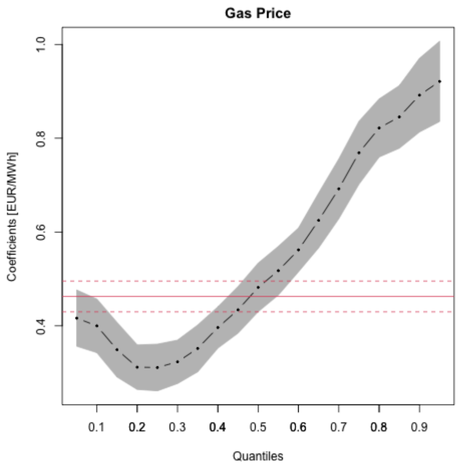



**(c)** Water reservoir level

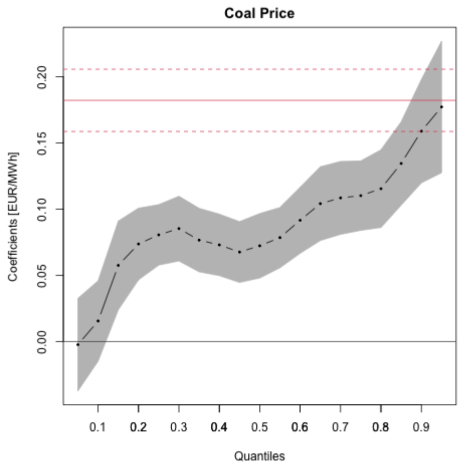
**Figure A2.2:** Coefficient estimates for control variables.

The coefficient estimates of wind production are negative and significant in all quantiles, indicating that wind exerts a downward pressure on electricity prices, which is consistent with our expectations. These results are shown in Figure A2.2a. Figure A2.2b shows the coefficient estimates of PV production, which are negative and significant in all quantiles. This is in line with our expectations. The results for water reservoir levels are shown in Figure A2.2c. The coefficient estimates are negative and significant in all quantiles, which is consistent with our previous proposition about the potential negative effects due to the reservedness of hydropower producers when reservoir levels are low.

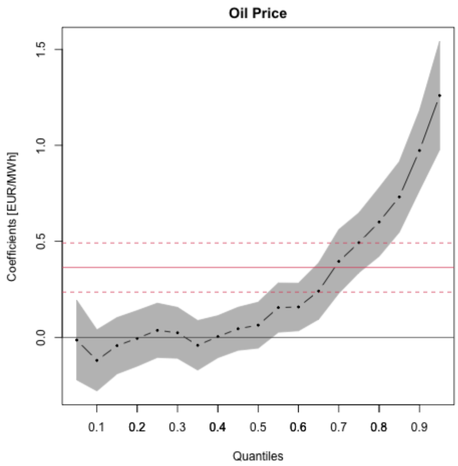
Figure A2.3 show the coefficient estimates of fossil fuels and EUA prices.



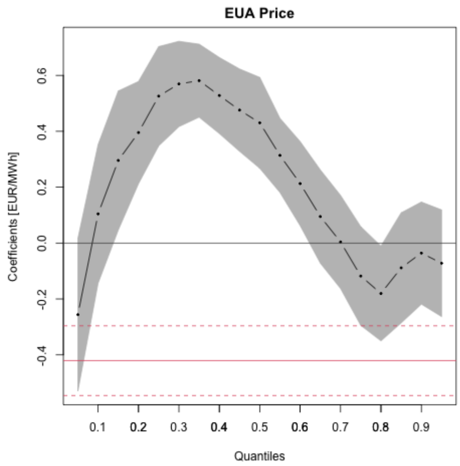

**(a)** Gas price




**(b)** Coal Price




**(c)** Oil price

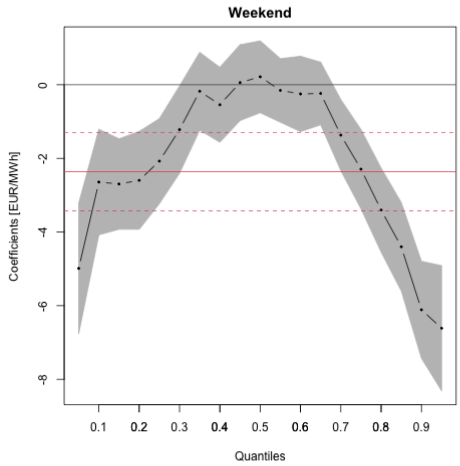



**(d)** EUA price

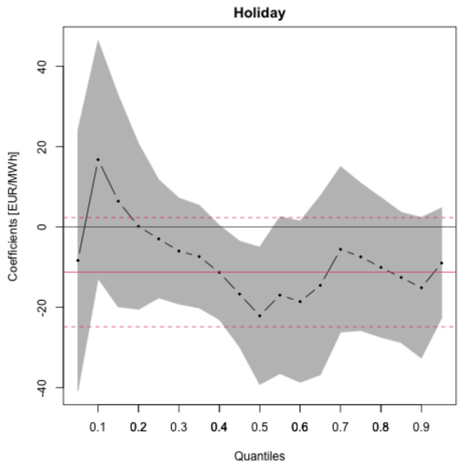
**Figure A2.3:** Coefficient estimates for control variables.

The gas price coefficients are positive and significant in all quantiles. The results can be seen in Figure A2.3a. This is consistent with our expectation about the effect of gas prices. The coefficients of the coal price are shown in Figure A2.3b. They are positive and significant in all quantiles, which is consistent with the proposition in the discussion of supply fundamentals. Figure A2.3c shows the oil price coefficients, which are positive and significant in all quantiles above the median. The results suggest that the oil prices positively effect electricity prices, which are in line with our expectation, however, they do not suggest a price effect in quantiles below the median. For the carbon emissions price coefficients, they are positive and significant, suggesting a positive effect on electricity prices. These results can be seen in Figure A2.3d.

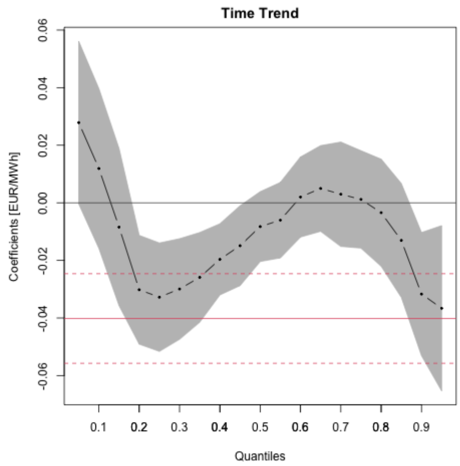
The results for the time variables are presented in Figure A2.4. We exclude the results for hourly and monthly dummy variables from the presented results due to brevity.




**(a)** Weekend dummy




**(b)** Holiday dummy




**(c)** Time trend

**Figure A2.4:** Coefficient estimates for fixed variables.

In Figure A2.4a we see that the coefficient estimates for the weekend dummy are negative and significant in all quantiles except the 35th-65th quantiles. This negative coefficient suggests that during the weekend the electricity prices are pressured down. For the holiday dummy coefficient estimates, we see in Figure A2.4b that they are negative in all quantiles, though occasionally being significant in the 5th, 40th, 50th, 85th, and 90th quantiles. The negative and significant coefficients suggest that during holidays, electricity prices are pressured down. The time trend coefficients are shown in Figure A2.4c. The coefficients are mostly negative and are significant for all quantiles except the 10th, and 50th-80th quantiles. This indicates that the electricity prices have decreased with time, which contradicts our expectation about the positive price effect of the time trend.