**OIL PRICE INFLUENCE ON SPANISH GAS PRICES. FUNDAMENTALS
AND VOLATILITY**

PhD THESIS

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Resumen

A pesar de la rápida evolución de los mercados organizados nacionales de gas en el mundo, la contratación de gas a largo plazo sigue siendo el proceso principal de determinación de precios de referencia, al menos en Europa continental y Asia Oriental. El caso de España es un ejemplo de mercado local, donde las condiciones de suministro de gas están condicionadas por la existencia de una cantidad sustancial de contratos de largo plazo, que junto con la limitada interconexión gasista con Francia, explican en gran medida la lenta evolución hacia un mercado líquido. En este contexto, parece conveniente profundizar con más empeño en la relación subyacente entre el precio del crudo y el precio del gas de largo plazo y así determinar pruebas evidentes que demuestren de forma cuantificable el nivel de los efectos, aspectos que serán tratados en esta tesis. En este sentido y aunque los mecanismos de transmisión de precios entre productos energéticos son complejos, esta tesis intenta abordar tanto efectos relacionados con los niveles de precios como otros efectos más sutiles como son aquellos asociados con la posibilidad de que variables exógenas puedan tener una influencia significativa en la volatilidad intrínseca. En consecuencia, la tesis se centra en dos áreas clave con el fin de obtener los mejores resultados.

Dentro del primer eje, dos aspectos específicos son investigados. Por un lado, se realiza un análisis preliminar de las influencias sobre los precios del gas mediante correlación y regresión optimizada y por otro lado, se realiza una investigación detallada para determinar las propiedades de largo plazo de las series temporales incluyendo el análisis de cointegración. En esta fase, nuestra principal contribución tiene un doble aspecto: en primer lugar, desarrollar una estrategia definida para evaluar la existencia de raíz unitaria en las variables seleccionadas incluyendo la posibilidad de rupturas estructurales y en segundo lugar, la determinación tanto endógena como exógena de las características del impacto y su distribución temporal. Las pruebas de raíz unitaria convencionales indican que ninguna de las variables analizadas es estacionaria. Sin embargo, los resultados de nuestra investigación incluyendo hasta dos rupturas estructurales durante el periodo analizado, revelan que al menos el precio del gas en UK presenta características claramente estacionarias. Asimismo, los resultados muestran el diferente comportamiento de las variables analizadas. Por un lado, el conjunto de variables relacionadas estrechamente con el crudo y por otro las dos variables más representativas de mercados independientes como el National Balancing Point (NBP) y el carbón. Por ejemplo, durante el periodo investigado se demuestra que la situación de caída progresiva de precios de crudo desde el año 2012 conjuntamente con la situación de exceso de oferta de GNL global produjo en los albores de 2013 un cambio de tendencia significativa en los precios del gas en España incluso más brusco que el cambio de tendencia correspondiente en los precios de Brent. Por otro lado, los precios de gas NBP solo reflejan un cambio de tendencia en nivel significativo a finales del 2005 mientras que el carbón demuestra principalmente reacción en tendencia significativa a la crisis financiera de 2008.

Con respecto a la segunda parte, la tesis examina en detalle la naturaleza de la volatilidad tanto del gas en España como del crudo desde dos ángulos distintos. Por un lado se

evalúan características particulares relacionadas con la volatilidad como por ejemplo la asimetría de los impactos, la volatilidad de larga persistencia o el comportamiento de colas. Para ello, varias especificaciones de modelización son consideradas. Como resultados más interesantes, encontramos que la volatilidad condicional de los precios del gas es ligeramente persistente frente a la evidencia contrastada de una mayor persistencia de la volatilidad en los mercados petrolíferos. Dentro de la segunda fase, se efectúa un análisis de agrupación de volatilidad específica, un fenómeno no vinculado intrínsecamente a ninguna especificación de modelo econométrico. De acuerdo con la información disponible, nuestra investigación supone el primer intento de analizar la relación entre el petróleo y los precios del gas de largo plazo de forma cuantitativa hasta el punto de poder proporcionar una evaluación objetiva de la penetración de mercados líquidos de gas en España. A la luz de los resultados, concluimos que desde 2013 hasta 2016, sólo alrededor del 33% del valor incremental de volatilidad agrupada en los precios del Brent se refleja en los precios del gas en España, medidos por la tasa de indexación incremental (R_n). Ciertamente, una de las consideraciones más relevantes para nuestra investigación es el hecho de que los valores del parámetro R_n fluctúan entre diferentes periodos en función de la respuesta de los precios de gas a la volatilidad del precio del Brent, reflejando al mismo tiempo la interacción con otros factores estabilizadores. A pesar de la complejidad resultante de las fuerzas del mercado del gas en España, las futuras actualizaciones de la evolución del índice R_n podrían servir como referencia inmediata para cuantificar los avances de las medidas de liberalización y evaluar la resiliencia de las estructuras indexadas en los contratos a largo plazo.

Dada la importancia de las estructuras contractuales de suministro de gas indexadas al petróleo para entender mejor el grado de penetración del precio del hub líquido en España, nuestra investigación proporciona evidencia que nos permite entender mejor cómo las fuerzas que interactúan para determinar los precios del gas en España producen efectos independientes. En última instancia, nuestra tesis debe facilitar una evaluación precisa del grado de liberalización de los mercados nacionales de gas y mejorar el nivel de transparencia, cuestiones de gran interés tanto para los responsables de la política energética como para legisladores y reguladores, así como para las comercializadoras de gas que operan en el sector.

Abstract

In spite of the rapid evolution of national gas hubs worldwide, long-term gas contracts remain the dominant pricing process at least in mainland Europe and the Far East. The case of Spain is a good example, where gas supply conditions comprising a substantial amount of long-term contracts together with limited connectivity with France, may explain the slower pace of implementation of a liquid gas hub in the country. Within this context, it seems necessary to explore more deeply the underlying relationship between crude oil with long-term gas and provide more reliable, quantifiable evidence as to the overall impact, aspects which will be covered in this thesis. In this sense, although price transmission mechanisms are complex, this thesis covers both cross-commodity price movements feeding into gas prices for example through switching as well as other more subtle impacts as those associated with price volatility. In this regard, our thesis breaks down into two related areas of research leading to enhanced results.

Within the first area, two particular pieces of research are undertaken. On the one side, a preliminary analysis of energy commodities influences on gas prices based on correlation and optimized regression principles is performed. On the other hand, research is conducted to determine long-term properties of time series analysed related to nonstationarity including cointegration analysis. In this sense, our most important contribution at this stage is twofold: firstly to evaluate the unit root hypothesis of the selected variables using advanced econometric techniques allowing for the possibility of structural breaks and secondly, to assess the impact and timing of those breaks on the changing patterns of time series. The approach taken in that context is being developed through the evaluation of a series of statistics over a range of possible break dates to analyse more closely the distribution of these statistics for each possible break date. Conventional unit root tests indicate that all variables are nonstationary. However, results from our research suggest that gas prices in the UK are clearly stationary, i.e., price series data have a tendency to return to a constant mean. Finally, the results show the different behaviour of the variables analysed. On the one hand the set of variables closely related to crude oil and on the other hand National Balancing Point (NBP) price and coal prices representing traded markets to some extent not directly connected with crude oil. As an example of this, during our investigation, it is shown that a significant shift in slope affected Spanish gas prices as a result of both the progressive fall in crude oil prices since 2012 in combination with the oversupply situation regarding global LNG produced at the dawn of 2013. This change in trend was not significant for Brent prices. On the contrary, NBP gas prices only reflect a significant shift in the level at the end of 2005 reflecting tight gas market supply conditions in the UK while coal mainly shows a significant trend reaction on the slope to the 2008 financial crisis.

With regard to the second part, the thesis examines the time-varying volatility of long-term gas contract prices using a novel integrated approach to assessing the degree of crude oil interaction. Among the properties investigated, we focus on volatility clustering a phenomenon that has intrigued many researchers as it is not intrinsically linked to a model specification. To the best of our knowledge, this is the first attempt to analyse the relationship between oil and

long-term gas prices to such an extent that it can ultimately provide an objective assessment of liquid gas hub penetration away from oil price dominance. The study evaluates in the first place, volatility behaviour of long-term gas prices particularly in the stylized empirical facts such as the asymmetric news impact, long-persistence volatility, and tail behaviour. Several specifications of GARCH models are considered (Bollerslev, 1988) to identify the referred stylized facts, and they are compared with the results of the existing research on oil price volatility to derive meaningful conclusions. As a result, we find conditional volatility of gas prices to be modestly persistent against evidence found for higher volatility persistence in the Brent market. Supported by modelling results, we introduce novel research strategies to evaluate how volatility clustering characteristics of crude oil and long-term gas prices compare using proven methodology in the field of finance. In the light of these results, we conclude that since 2013 until 2016, only about 33% of incremental volatility clustering embedded in Brent prices is reflected in gas prices, measured by incremental clustering indexation rates (R_n). Certainly most relevant to our investigation is the fact that R_n values fluctuate along different periods in response to Brent prices while they are also affected by other stabilizing factors. Despite the complexity of market forces and gas price interaction, future updates on the evolution of the R_n index could serve as a reference to quantify progress made by liberalization measures and evaluate the resilience of oil indexed structures in long-term gas contracts.

Given the importance of oil-indexed contract structures in understanding the degree of penetration of liquid hub pricing, our research provides evidence to enable us to understand better how the interacting forces determining price dynamics have yielded certain outcomes and effects. Ultimately, our thesis should facilitate an accurate assessment of the degree of liberalization of national gas markets and improve the level of transparency, these matters of great interest to both energy policy makers enacting new legislation and regulatory arrangements but also for market traders.

KEYWORDS/PALABRAS CLAVE

Long-term gas price, oil price, crude oil, natural gas, energy commodities, Spanish coal price, unit root, structural breaks, cointegration, persistence, volatility clustering, autocorrelation, EGARCH, volatility modelling.

Precio de largo plazo de gas, precio petróleo, crudo, gas natural, materias primas energéticas, precio del carbón en España, raíz unitaria, rupturas estructurales, cointegración, persistencia, agrupamiento de volatilidad, autocorrelación, EGARCH, modelado de volatilidad.

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CHAPTER 1. INTRODUCTION AND METHODOLOGY

This doctoral thesis work builds on previous research that looked into the dynamics of Spanish wholesale gas prices with a view to extend current understanding of the driving forces underlying those prices. In this sense, this thesis is conceived as a much more comprehensive piece of research aiming to develop a structured framework that incorporates a broad range of econometric and quantitative methods to significantly improve knowledge about the intrinsic characteristics of Spanish gas prices in regards to Brent crude oil influence. Ultimately, this study seeks practical applicability by providing assistance to energy policy-making and competitive environment monitoring of the Spanish gas market. In this sense, our work aims to bridge a gap between traditional research on energy prices and practical evaluation of the level of market liberalization. Last but not least, the scope of applicability of this research could be extended to other regional or local gas markets with similar gas supply characteristics than Spain such as Asia Pacific or Continental Europe.

This introductory piece gives the background and context regarding the detailed purpose for which this research is developed, and the goals and objectives set out. The background and current situation are followed by the subject, providing an insight view on the central issue of this research. This chapter also illustrates the structure and the methodology that has been followed.

1.1 Background and current situation

In competitive markets, with multiple sellers and buyers, prices are mostly driven by supply and demand with price itself providing signals to ensure market equilibrium. In the case of gas markets and due to the nature of gas trade typically organized around regional markets, gas prices are not set everywhere under the same competitive conditions. Furthermore, the firm push from Governments for liberalization will continue to change the shape of competition and to influence pricing structures. One common example of this is the process of gas markets deregulation in Europe, opening up scope for the development of mature local gas hubs as well as increasing market integration. In spite of the progress made and the rapid evolution of national markets, long-term gas contracts remain the dominant pricing process at least in Continental Europe, which does, in turn, lead to an interesting debate about the level of independence of gas prices in respect of other energy commodities like crude oil or coal. The case of Spain is a example of this, where gas supply conditions comprising a substantial amount of long-term contracts together with limited connectivity with France, may explain the slower pace of implementation of a liquid gas hub in the country. Moreover, the fact that globally the relationship between natural gas and energy commodities is not certainly transparent, not only because the latter are rivals in production but also because gas markets are regionally segmented, raises questions about the view of steady state growth of natural gas prices.

In this context, oil-gas indexation¹ continues to play a crucial role² given the fact that it is mainly the part of demand not covered in long-term contracts for which prices are set freely by supply and demand. As a matter of fact, the principle behind oil-gas indexation is well-rooted in the gas market with standards for valuing and pricing gas in Europe being established in the early 1960s when gas was first introduced as a substitute fuel. In a similar manner, in East Asia, the largest and more influential gas market linked to oil and oil derivatives³, while LNG was first introduced as an alternative source of energy to reduce the high dependence on oil, the oil-price linkage guaranteed that gas was competitive with oil.

Globally, the fact that gas market fundamentals have significantly changed in recent years with substantial gaps arising between hub-based spot prices and oil-indexed long-term contract prices may have led to inappropriate pricing structures and restrictions for gas markets development. Furthermore, the paradox inherent in using a price benchmark related to global crude oil markets rather than to gas market fundamentals seems in itself a compelling reason to believe that traditional gas pricing mechanisms will be strongly challenged in the years to come.

In this sense, the first question we have to address naturally concerns to the evidence of the inherent connection between Spanish natural gas prices⁴ and those variables making up those prices, being crude oil the most important. The logic is self-evident as it can be seen in Figure 1 that shows the significant similarities between Spanish gas prices (SGP), oil prices (Brent) and other crude oil-related variables like gasoil (GO), low sulphur fuel oil (LSFO) but also with coal (all in normalized prices for better clarity).

¹ Although we refer along the research to oil-gas indexation, technically speaking we follow recommended definition by the International Gas Union (IGU) for OPE (Oil Price Escalation) formation mechanism where gas price is linked, usually through a base price and an escalation clause, to competing fuels, typically crude oil but also gas oil and/or fuel oil. In some cases coal prices can be used as can electricity prices.

² Oil-gas indexation share worldwide totals around 663 bcm and is predominantly Asia Pacific (231 bcm), Asia (180 bcm) and Europe (146 bcm). It is widespread being found in some 60 countries, including virtually every country in Europe, and in all regions except North America (Aguilera et al., 2014).

³ The share of oil indexed imports (including both LNG and pipeline gas) in East Asia was 83.7% of the total imports, against the global average of 48.7% in 2015. IGU (2016).

⁴ As it will be explained in the following section, we use average gas import prices released by the Comisión Nacional de la Energía (CNMC), the Spanish regulator.

Figure 1_ Oil, oil products, and coal prices vs. Spanish gas price

As it can be seen and in spite of the price lag effect, the relationship shown in energy commodities and Spanish gas prices is impressive. Interestingly and although coal appears countercyclical concerning Spanish gas and crude oil, possibly due to the substitution effect, price patterns in the long-run are rather similar. As one would expect, long-term relationships seem to be at the heart of the pricing process not only because those are sought after producers and buyers but also because of the natural links among energy variables. Thus, issues such as whether the selected time series are piecewise trend stationary rather than truly nonstationary or the persistence properties, need to be tackled at an early stage. Furthermore, the far-reaching implications of this analysis may allow us to address core economic issues as whether market fundamentals dominate or on the contrary exogenous shocks, like the financial crisis in 2008, may have played a prominent role. Interestingly, Figure 1 also shows the significant smoothing effect of the monthly average oil price indexation in the SGP formula, which also explains why gas prices have dropped less sharply than oil prices in the past.

In this environment of different pricing dynamics, there are compelling reasons to rely on Spanish gas import prices as an ideal reference to assess relationships between crude oil and long-term gas globally (Neumann, 2009). Firstly, the characteristics of Spanish gas traders' portfolio with a majority of long-term contracts indexed to oil and oil products similarly to Asia

Pacific natural gas importers (IEA⁵, 2017; Aguilera et al. 2014; IGU⁶, 2016). Secondly, since Spain imports most of the gas it consumes, a key factor that also influences gas prices in Spain is the importance of LNG⁷ in gas procurement. In this sense, the ability to arbitrate in the global LNG market, makes the Spanish gas importer dynamically interconnected with other LNG markets, this influence resulting in higher exposure. Thirdly, the fact that Spain is the largest LNG importer in Europe (see Figure 2) with a high level of secure gas supplies from a diversified range of supply sources, reveals a similar pattern than other large LNG importers particularly in Asia where aside from Japan, Korea or Taiwan⁸, LNG imports are growing overall (IEA, 2017).

Figure 2_LNG imports in Europe in 2016 (thousand tonnes/percentage over total). Source: CNMC⁹.

Within this context, further research into the current relationship between oil and long-term gas contract prices seems especially desirable at times when stable oil-gas relative pricing is under pressure in Asia and Europe (Aguilera et al., 2014; Erdos, 2012). In this sense

⁵ International Energy Agency (IEA)

⁶ International Gas Union (IGU)

⁷ Liquefied Natural Gas (LNG).

⁸ Percentage of LNG over total gas imported in Asia Pacific, i.e. about 49% is similar to that of Spain, i.e. about 42% (2015). Source: IGU/Enagas.

⁹ Comisión Nacional de Mercados y Competencia

and in spite of the significant amount of work analyzing volatility of crude oil prices solely (Sadorsky, 2006; Kang and Yoon, 2009; Cheung, 2009; Sevi, 2014; Serletis and Xu, 2016), work related to long-term gas prices fluctuations and potential for an appropriate assessment of liberalization measures in gas markets is scarcer. This thesis attempts to fill this gap by answering two fundamental questions: First, whether shocks to Spanish gas prices and underlying commodities more closely resemble the permanent shocks of a random walk more than the transitory shocks consistent with a time trend decomposition. Secondly, supported by the fact that oil prices are the determining factor behind long-term gas prices¹⁰, to quantify the degree of variability exercised by oil prices that is reflected in the gas price, using proven methodology in the field of finance. In line with this and to the best of our knowledge, this thesis is the first that addresses a systematic review of long-term gas prices fundamentals and volatility in a quantitative manner seeking to make results directly applicable to energy policy.

1.2 Subject, research questions and scope of the Ph.D. Thesis

The central question in this thesis is how to measure and evaluate oil price influence on Spanish natural gas prices. This influence we here refer to is two-sided: on the one hand, it concerns the way in which oil prices characterize the long-term evolution of Spanish gas prices. On the other hand, it is intimately related to measuring and examining medium-term variability exercised by oil prices on gas prices to provide an indicator of its degree of influence finally. Towards this end, we investigate into a multifaceted environment not only links between crude oil and Spanish gas but also among other influential variables over time. Specifically, the key research question can be formulated as follows: ‘how can this influence be measured in a manner that the current trends towards open gas trade in Spain can be assessed?. In order to respond this question, a set of relevant questions will also be raised: which is the long-run behaviour of Spanish gas prices in respect of shocks to those prices?, is there evidence about similar intrinsic behaviour for crude oil and Spanish gas?, if yes, how does the influence manifest and ultimately, since crude oil prices historically reveal themselves as the most influential factor determining Spanish long-term gas prices, is there information by means of quantitative indicators that can help to understand potential for a successful development of a gas hub in Spain?.

Since trend dynamics, stochastic or deterministic, exhibited by the price of energy resources help to understand empirical verification of economic theories better and to explain long-term behaviour, our aim is also to assess the sound fundamentals underpinning Spanish gas prices. To this end, we contribute an approach that is not limited to a single framework or methodology but to present a wide set of econometric procedures to benefit from comparability of results. The scope is enlarged in this sense by including extra variables into the analysis not

¹⁰ As discussed, the leading role of oil arises through oil price indexation in the contract price formula

only to convey valuable information into our main questions but also to bring the debate about the nature of energy commodities forward. Although ambitious, this approach provides a natural and desirable extension of our most important piece of research focused on Spanish gas and crude oil prices.

As it is well known and although commodity price behaviour has been largely debated, it seems that there are no certain elements that can generally be applied. In the case of non-agricultural commodities, views on the subject vary from the classical Hotelling model, predicting that resource prices are trend stationary to other views suggesting that uncertainty largely drives energy pricing events and generated by a random walk process. In the case of oil prices permanent shocks are likely to produce the high instability observed, supporting the view that crude oil would not revert to a long-marginal cost as it could be expected from structural fundamentals forces. Moreover, our focus on the effects of exogenous shocks which might be dominating future trends may add additional elements to help to understand commodity prices stationarity conditions. Overall, we believe that the selected period, 2002-2016 is a highly representative time window that will facilitate the proposed assessments and will help to improve the understanding of commodity prices behaviour.

1.3 Goals and objectives

In order to perform our investigation the thesis is structured around specific goals, building up support to resolve our most important research question, namely:

- (i) Goal 1. Assess the current situation of natural energy resources in Spain, Spanish natural gas role and potential for market-based relationships of Spanish gas prices with other energy sources.
- (ii) Goal 2. Establish a clear benchmark for coal prices in Spain that can be used in the thesis to assess current gas-coal relationships in a consistent manner. The importance of coal-gas switching as a transmission mechanism for coal prices feeding into gas prices in traded markets reveals the need for a clear understanding of this particular issue moving forward.
- (iii) Goal 3. Estimate prior to using more advanced techniques, the strength and direction of the relationships between Spanish gas prices, Brent price and other variables analysed using regression tools. This analysis leads to quantitative support for ulterior judgment, pointing out flaws and providing insights that can help decision-making process at a later time.
- (iv) Goal 4. Investigate thoroughly whether shocks to gas prices and underlying commodities more closely resemble the permanent shocks of a random walk more

than the transitory shocks consistent with a time trend decomposition. This goal can be divided into two areas:

- Provide evidence about the true nature of the series within an integrated unit root testing framework allowing for level breaks both in the intercept but also including both trend and intercept breaks.
 - Examine whether there have been any significant changes - upwards or downwards - in the long run path of selected energy variables as a result of important events, mainly the financial crisis in 2008 and the oil price drop in 2014.
- (v) Goal 5. Investigate into cointegrating relationships connecting crude oil price and Spanish gas prices mainly as a means of ensuring that the connection between the two is not bias even if both are non-stationary variables.
- (vi) Goal 6. Assess the resilience of traditional oil-indexed structures and as a consequence advance the degree of penetration of liquid hub pricing into Spain over the referred period. This goal concentrates on three key areas:
- Analyse whether long-term gas prices and crude oil volatility stylized facts share similar characteristics using a comprehensive GARCH framework.
 - Examine the changing patterns of volatility in crude oil and Spanish natural gas prices. This property often manifests as volatility clustering and suggests that the conditional variance of the return series may not be constant. Knowledge about the persistence of volatility enables us to obtain more efficient parameter estimates, as persistence suggests that current volatility can be predicted.
 - Quantify the degree of variability exercised by oil prices that is reflected in the gas price, using proven methodology in the field of finance.

1.4 Contributions

Regarding the benefits provided by the Ph.D., we contribute in the first place, to a better understanding of the nature of Spanish natural gas prices both in relation to crude oil effects but also related to forecasting and risk management in the gas sector industry in Spain. Moreover, and as result of the close rapport between crude oil and Spanish gas, the thesis also aims to contribute to better understand the gas market liberalization process in Europe and Spain in particular, advancing potential effects of Government intervention towards increased competition based on quantitative factors. More generally, we contribute to the debate about

long-term dynamics of energy variables by incorporating in our research a broad framework including other commodities into the equation especially regarding the proposed methodology to test the unit root hypothesis in the presence of up to two structural breaks. As it is well known the effects of major historical events find the balance of evidence in favour of the trend stationary hypothesis more often (Perron, 1989). In this sense, our research will help agents to understand the repercussions of major events on commodity prices better and especially on Spanish gas prices. At a local level it will help participants in regional gas markets, like the case of Spain, to operate in a more comfortable environment. Specifically, our research makes three major contributions:

- (i) To unravel the nature of long-term gas supply in a quantitative manner, facilitating a more precise assessment of the degree of liberalization of national gas pricing structures away from oil price indexation. In parallel, this analysis leads to improve clarity and understanding regarding the assessment of the level of transparency and competition, these matters of great interest to both policy makers and gas market agents substantially.
- (ii) To provide evidence about the true nature of the series analysed including Spanish gas prices within an integrated unit root testing framework. Previous studies which have investigated persistence properties of non-renewable resource prices have intensively analysed unit root tests results, allowing only in some cases for structural breaks in the trend function. In this paper, we contribute to the debate by incorporating results from a set of representative models to tests the unit root hypothesis in the presence of up to two structural breaks. The fact that exogenous shocks which might be more influential for some commodities than for others, may introduce another set of far reaching implications about price stationarity conditions.
- (iii) To measure the extent to which crude oil volatility is displayed in long-term gas prices making available useful reference information for the countries and regions where a majority of long-term gas contracts are oil-indexed.

1.5 Structure of the Ph.D. thesis

Providing a structured approach is essential to accomplish an adequate and consistent framework to support valid conclusions. The research process starts with the definition of a broad area of interest as already discussed in Section 1.2 that focuses on the theme. Following on this, a narrower scope is developed through specific goals and objectives nailing down exactly which issues need to be resolved (See Section 1.3 for details). Within this setting Chapter 2 provides a profound review of literature relevant to our research as necessary introduction to advance previous lines of research on related matters. Chapter 3 starts building up a business case including the necessary description of the Spanish energy environment, the role of gas and

of its closest competitor, i.e., coal. Subsequently, Chapter 4 still part of the initial supporting phase, extends preliminary foundation pillars of the research by developing detailed investigation on the Spanish coal market to provide support for the use of the most relevant coal price benchmark, this element perhaps the more questionable regarding sources of data used in this thesis.

At the narrower point of granularity in our research, the different approaches to the analysis of crude oil-Spanish gas relationship research stand at the core of our efforts. Following on this, we use different theoretical approaches, the majority of them advanced in the past, to address the problem. It is important to highlight that in addition to academic interest in the results obtained from each theoretical process, we are interested in the way these results compare with previous experiences especially those related to crude oil dynamics. More importantly, and hence the novelty of our research, we aim at composing a comprehensive but nonetheless accurate view of the issue in which we focus from different angles. Within this framework, Chapter 5 presents preliminary correlation and regression analysis of the variables analysed to understand better how they manifest in reality. Chapter 6 develops the long-term evaluation of energy price dynamics using unit root testing methodology and including the relative effects of structural breaks. In Chapter 7 a detailed cointegration analysis is performed, and finally, Chapter 8 develops the quantitative evaluation of the relationship between the main driver, i.e., crude oil and the dependent variable long-term gas prices based on volatility clustering patterns. In Chapter 9 we present main results from our investigation, and we try to compile those results within a theoretical perspective while attempting to address the original broad question of interest by generalizing from the results obtained. Figure 3 below shows an overview of the general framework of the doctoral thesis.

Figure 3_Notion of research summary. Source: Authors

1.6 Methodology

Although a wide variety of econometric methods have been applied to the analysis of energy commodity variables and related applications, possibly three main areas attract the interest of both researchers and practitioners. These three areas are generally: analysis of fundamental value¹¹, commodity market dynamics and commodities and the business cycle. In this sense, possibly the key issue to a better understanding of commodity markets lies in the need to shift away from the descriptive and purely statistical analysis to a more detailed and specialized econometric analysis of those markets. Moreover, it has to be admitted that the vast amount of information provided by market players makes absolutely necessary to place great emphasis on the quantitative treatment of that information. Therefore, before attempting to unveil complex interacting forces in commodity markets a careful selection of up-to-date financial economic and econometric methods is needed. Generally, strong focus has been given to energy econometrics tools in the first and second areas exposed. Regarding fundamental value analysis, a wide range of models have been specially developed for this purpose. Example of this are linear regression models, multivariate GARCH models and especially unit root testing and cointegration models. In the case of econometric techniques investigating commodity market dynamics, examples are found when analysing specific commodity prices features such as volatility, spillover effects, cross-asset linkages, common risk factors, and momentum. In parallel, some techniques can be considered to be overlapping those three categories, e.g., PCA¹² estimation.

Broadly speaking our intention on the methodological side has been to cover at least those two main areas of practice, i.e., fundamental value and market dynamics through the selection of tried and tested techniques at the most advanced level. Along the research the main elements of the methodological framework are summarized as follows:

1.6.1 Sources of data used

On the basis of the most reliable information available for Spanish gas prices, we examine along the thesis gas data publicly available in Spain for wholesale gas prices and in particular that provided by the regulatory body, the CNMC. Along the study, we will refer to this price as Spanish gas price or simply SGP. Although there are other relevant benchmarks for Spanish average gas prices like for example the price of the Last Resort Tariff (LRT) developed by the Ministry of Industry in 2008, we believe that CNMC's quoted price depicts a more realistic picture of imported gas prices than the LRT proxy. Moreover, it has to be noted that CNMC

¹¹ We refer here by fundamental analysis to a method of evaluating variables in an attempt to measure its intrinsic value, by examining related economic, financial and other qualitative and quantitative factors.

¹² Principal Component Analysis.

produces information based on price data gathered by the Agencia Estatal de Administracion Tributaria (AEAT)¹³, the Spanish administrative body that manages all fiscal related activities. AEAT controls all importation and exportation activities in the country with regards to the monetary value of the goods, and therefore the importation of natural gas in its gaseous form and as LNG is subject to AEAT's attention and procedures. All of this generates an obligation for the natural gas importer, i.e., the commercialicer or the customs agent on his behalf, to declare all the gas imported according to AEAT's requirements. Since the publication of Law 22/2005 transposing EU Directive 2003/92/CE, the entire fiscal regime for gas and electricity within Spain changed. The main effect on gas imports from the point of view of the gas commercialicer is that the obligation to pay VAT (IVA) and any import tariffs disappears. Furthermore, all taxes for gas imports are deferred until the final end-user's sale occurs. A new fiscal figure called 'Depósito Fiscal' is also created to allow only Enagas¹⁴ controlling and reporting to AEAT all tax related matters at the gas import terminal. Is for all these reasons that the use of AEAT's data base compiled by the CNMC seems the most suitable way forward.

It has to be said that, given the importance of imported LNG spot at the margin, we introduce at different stages, the NBP spot price benchmark as published by the CNMC to introduce also a global gas price reference fluctuating according to supply-demand conditions in the European zone. At this point and with the depressing effect of shale gas production significantly lowering US Henry Hub (HH) index, we understand that introducing HH prices in the study is not relevant. In regards to the rest of energy commodities analysed in the study, i.e., Brent crude oil, gasoil, fuel oil and coal, other reputed sources of information like CORES¹⁵ or Eurocoal have been used. Table 1 provides a detailed description of main energy variables used throughout the thesis.

¹³ AEAT comes under the umbrella of the Ministry of Economy.

¹⁴ Enagas is the main Spanish gas transmission system operator (TSO).

¹⁵ Corporación de Reservas Estratégicas de productos petrolíferos (CORES).

Sector	Variable	Description	Units
Oil and oil products	Brent	Average price of current month FOB	\$/ton
	GO	Average NWE Gasoil price of current month FOB	\$/ton
	LSFO	Average NWE Low Sulphur Fuel oil 0.1% S price of current month FOB	\$/ton
Gas market	SGP	CNMC monthly Spanish wholesale gas price	\$/MMBtu
	NBP	CNMC monthly average spot NBP	
Other markets	Coal	Monthly average MCIS Coal price	\$/ton

Table 1_ Summary of main energy variables used in the thesis

1.6.2 Preliminary tools: cross-correlation, linear regression, and PCA analysis

Due to the fact that the majority of Spanish long-term gas contracts are mostly indexed to oil and oil products in spite the fact that indexation to other indices like NBP, coal and even SMP¹⁶ can also be found, determining a simple measure of the relationship between variables takes a predominant role to start. In this sense, descriptive statistics for all the variables selected are analysed in order to initially advance similar patterns among the different variables and between crude oil and Spanish gas prices in particular. It is interesting to realize that despite a well-connected LNG market worldwide, Spanish gas prices might show an insufficient response to other than crude oil-related fundamentals. Following on this, price correlation, a relatively straightforward metric but extremely informative is used to formulate initial conclusions.

In order to determine in the best manner the existing relationship between each couple of commodity prices and the Spanish gas price, a pre-selection of best predictors is performed to evaluate when the correlation is highest over the specified period using regression techniques. It has to be noted that the process leading to the best set of predictors must not degrade the quality of the OLS¹⁷ regression estimates and therefore shall not lead to confusing results. Lastly, a PCA analysis performed to round preliminary findings.

¹⁶ System Marginal Price resulting from Electricity market daily activity.

¹⁷ Ordinary least squares.

1.6.3 Fundamental value: evaluation of the unit root hypothesis

Unit root testing is not only the most common method to study the persistence of time series, but it is also intimately related to advanced theoretical approaches to regression and cointegration analysis. Although the literature is vast probably two main drivers have led the significant developments seen on this field: the assessment of whether time series are affected by transitory or permanent shocks and also the need to understand the effects of structural breaks. In this sense methodological issues affecting unit root estimation, testing and validity of results in the context of structural change will be thoroughly analysed. Our focus will be not only placed on the conceptual issues but also on the different approaches to better understand potential applicability to our investigation.

Although the effort to systemize and expand knowledge on unit root tests allowing for structural breaks is vast, the task has proven not to be easy due to the uncertainty about the number, location, and nature of structural breaks, among other factors, leading to a reduction in the power of the tests. In this sense, we will need to devise a strategy for unit root testing that guarantees a sound result. Following the choice of a strategy, the particular conditions are essential. Issues such as the nature of the impact over time, i.e., how fast reaction is to the event, how to estimate the precise dating of the structural break or even whether the assumption that there is only a single break can be qualified, are at the heart of the process. A summary of different methodologies used and compared in the thesis are:

- ADF¹⁸ and KPSS¹⁹ tests in which the null hypothesis is nonstationarity and stationarity respectively
- Unit root with one structural break
 - Zivot and Andrews (1992)
 - Vogelsang and Perron (1992)
 - Lütkepohl, Muller, and Saikkonen (2001)
 - Kim and Perron (2009)
- Unit root with two structural breaks
 - Lumsdaine and Papell (1997)
 - Lee and Strazicich (2003/2004)

Finally, we provide a brief discussion of the major events that are likely to have impacted on the series analysed.

¹⁸ Augmented Dickey Fuller.

¹⁹ KwiatkowskiPhillipseSchmidteShin.

1.6.4 Fundamental value: cointegration analysis

Generally, in order to test the presence of linear cointegration between Spanish gas prices and selected energy prices, especially oil price, we will follow the important work on this concept performed by Engle and Granger (1987) but specially techniques developed by Johansen (1995) for testing for unit roots using the ML estimator (Johansen, 1988). This is mainly a test for cointegration restrictions in a VAR representation (Sims et al. 1990) where the estimator gives asymptotically efficient estimates of the cointegrating vectors and the adjustment parameters. It also permits hypothesis testing for parameters in the possible cointegration vector as well as exogeneity tests (Johansen and Juselius, 1990). The basic relationship that will be considered for testing market cointegration is the long-term Johannsen's VECM²⁰ model equation as follows,

$$SGP_{1t} = \delta + \beta_1 Brent_{1t} + \sum_{i=1}^n (\beta_{i1} P_{i1}) + \varepsilon_t \quad (1)$$

Where δ is a constant that captures differences in the levels of the prices and β^{21} establishes the long-term trend between both prices through a separate contribution of each explanatory variable i , determining Spanish gas prices values.

This equation describes a situation of both prices adjusting immediately what would not be realistic in the short-term. To avoid this, the intention will be to expand our investigations through dynamic cointegration analysis and the development of a vector autoregressive error correction model that will allow us to determine cointegration quality testing as well as exogeneity characteristics of the variables involved.

1.6.5 Market dynamics: modelling volatility characteristics for crude oil and natural gas

In spite of the wide variety of studies addressing the performance of crude oil volatility in modelling, there is a limited investigation into the differences and similarities in long-term gas contracts prices characteristics. Moreover, modelling crude oil volatility is challenging, and experience suggests that there is not a model that consistently dominates the other despite the fact that different authors have followed up very actively on the evaluation. For example, Kang et al. (2009) model superiority is assessed for both its ability to forecast and also to identify volatility stylized facts, but other considerations can be taken into account. The characteristics

²⁰ A vector autoregressive error correction model (VECM) is suitable to model macro and several financial data since it distinguishes between stationary variables with transitory (temporary) effects and nonstationary variables with permanent (persistent) effects.

²¹ β coefficients represent the long-run (cointegrating) vectors entering each of the VECM equations.

of the product being analysed are also essential. In this regard, Sadorsky (2006) for instance finds that the GJR model fits well for heating oil and natural gas volatilities, whereas the standard GARCH model fits are better for crude oil and unleaded gasoline volatilities. Regarding crude oil specifically, EGARCH model is favoured by Narayan and Narayan (2007) whereas Kang et al. (2009), take a view on CGARCH, and FIGARCH models fit better to capture persistence in the volatility of oil prices. More recent research by Wei et al. (2010) also concludes that none of the GARCH-class models, including the FIGARCH one, outperforms the others in all situations.

Modelling SGP returns, and their volatility is performed in three steps. The first step involves the specification of the ARMA (p, q) model for mean returns and diagnostic tests of their residuals. The second step is the specification of the GARCH (p, q) model for conditional volatility and its diagnostic tests. Thirdly we analyse asymmetric effects through extended GARCH models.

1.6.6 Market dynamics: measuring volatility clustering effects

In order to discuss the nature of volatility clustering quantitatively, we arrange for a structured methodology that can provide a consistent comparison of clustering effects over time. Following recent research (Tseng and Li, 2010) and former theory on volatility analysis of financial time series (Alexander, 2001; Dacorogna et al., 2001; Malsten and Teräsvirta, 2004; Zivot and Wang, 2006) we introduce an index as a quantitative measure of volatility clustering that can also be used to compare the degree of volatility clustering along Spanish gas prices and Brent time series. This index is calculated using a moving window reference to obtain valid rolling indicators related to volatility clustering effects.

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CHAPTER 2. LITERATURE REVIEW

The intention of this chapter is to present an overview of academic work on the fields related to this thesis. This review has been carried out with the help of academic staff with expert knowledge and experience assessing the quality of academic work in related areas. In this sense, this review is not merely a summary of prior research but a profound and critical examination of research related to the different topics under investigation. Reference materials are presented in a logical sequence within the methodological framework.

2.1 Literature related to stationarity properties of energy commodities

In the past three decades, intensive work has been put into unit root analysis given the importance of nonstationary processes to understand the nature of time series and its practical applicability to econometric models and forecasting. In this field, economic data sets remain probably the most popular time series analysed and in fact, whether some of these macroeconomic time series are unit root or not is still a debated topic. Since Nelson and Plosser (1982) sustaining the view that almost all macroeconomic time series have a unit root until today's broader approach including a detailed investigation of isolated events, it can be said that unit root research has significantly altered time series analysis over the last years. Although many of the studies mentioned in this section analyse a wide variety of time series, only findings relating to coal, gas, oil and oil products will draw comment.

A number of papers (Nelson and Plosser, 1982) have examined the persistence properties of energy resources prices altogether but also individually with crude oil prices to be possibly the most discussed and investigated to date. In this sense, Slade (1982) represents one of the first attempts to analyse the evolution of a number of resource prices and finds that prices for US commodities appear to follow a U-shaped time path. Slade (1988), using eleven sets of annual time series with data beginning in 1870 and ending in the mid-1970s, finds empirical support for those prices being nonstationary and concludes that uncertainty appears to be a strong determinant of price formation, as opposed to Hotelling (1931) type deterministic models. Berck and Roberts (1996) enlarging Slade (1988) series until 1991 and applying both Augmented Dickey-Fuller (ADF) and Lagrange Multiplier (LM) tests, find overwhelming support for non-stationary natural resource prices except for petroleum where events seem to dominate the price series over long time spans. However, the evidence for increasing prices remains unclear. Ahrens and Sharma (1997), re-examining Slade (1988) time series through 1990, only find clear evidence of a unit root for natural gas casting doubts on the research of Slade (1988), Berck and Roberts (1996) and Agbeyegbe (1993). Their research is somehow innovational at that time since it includes Perron's unit root test for break in, assuming one exogenously given structural break common to all commodity price series. Extending the period analysed by Slade (1988) up to 127 years of annual data and using ADF tests, Pindyck (1999) observes that even with 120 years of data, ADF unit root tests are unlikely to give much information about the stochastic processes that best represent long-run price evolution. He finds a bias towards non-

rejection resulting from shorter samples (it needs to be noted that the greater the estimated values of p , the longer time series would be necessary to reject) or from shifts in the slope of the trend line (see Perron, 1989). Other studies that have tested for unit root in the prices of West Texas Intermediate (WTI) crude oil and Brent oil applying generic²² test over shorter periods, e.g. ten years, could not reject the unit root for spot prices and future prices using daily data (Pyndyck, 1999; Sivapule and Moosa, 1999; Serletis and Rangel Ruiz, 2004). As it can be seen, providing evidence for the difference in results even using the closest data replication is difficult due to different trend specifications and test methods applied.

Possibly, of all the factors involved, the analysis of unit roots including the effects of structural breaks has been proved to be the most challenging. Serletis (1992) published the first study testing for a unit root with a single endogenous structural break using a sample of daily NYMEX energy futures prices including crude oil, heating oil, and unleaded gasoline, over the period July 1983 to July 1990. He finds that based on that test, the unit root null is rejected for all energy prices. Using the same data than Slade (1988) and applying the two-break LM test, Lee et al. (2006) find evidence against nonstationarity for gas and coal but fail to reject the unit root null of crude oil at 5 percent significance level. Their research provides valuable insights into unit root testing practice. In this regard, they show that LM tests are robust with or without quadratic trends and also that reduced power can be expected from including unnecessary breaks in the maintained regression, issues that are common to any investigation on unit roots, also to our research. Interestingly, Presno et al. (2014) using identical data than Ahrens and Sharma (1997) although applying a rather different methodology²³ conclude on stationarity of oil prices around a quadratic trend, this consistent with crude oil being sold in a competitive market where prices revert to long-run marginal cost which changes only slowly being determined by structural fundamentals. As a matter of fact, they only find nonstationarity for coal (just for the linear model) and natural gas. Their research confirms once more how important it is to adapt unit root tests to nonlinearities using information criteria or other relevant methodology to avoid the low power of the tests.

Aside from historical data series based on Slade (1988) sample, Postali and Picchetti (2006) considering a sample of oil prices from 1861 to 1999 and dividing it into several subsamples show that for the subperiods, generic tests reject nonstationarity (do not reject stationarity in the case of the KPSS test) only for the 139 years global sample at 5% significance. Interestingly, LM unit root tests performed allowing for two breaks in the intercept could not reject the unit root null whereas when including trend-breaks, a two-break unit root is rejected

²² By generic unit-root tests we refer to basically three tests: the Augmented Dickey Fuller (ADF) test, the Phillips-Perron (PP) test and the KwiatkowskiPhillipsSchmidtShin (KPSS).

²³ The analysis is carried out from the perspective of stationarity and incorporating the possibility of smooth changes. Moreover their analysis fall within proposed approaches to test for stability of the trend function prior to unit root testing.

for all samples which show how important is the structural break type in the testing regression. More recently, the results from Ghoshray (2011) when analyzing three types of crude oil (WTI, Dubai, and Brent) using free on board monthly prices over the period 1975 to 2009, hence more relevant to our study, show that the prices are difference stationary and shocks that occur to these prices are likely to be long lasting rather than short-term, transitory ones. Moreover, considering the long-term investment horizon in oil and gas fields, such persistence would imply that ignoring the mean reverting component is of little consequence. As a reflection of the difficulties to reach a consensus on the unit root properties of oil prices, Ghoshray (2014) analysis of the same three benchmark crude oils with monthly frequency over the period January 1985²⁴ to July 2013, using a unit root test that allows for nonstationary volatility, shows that in reality the global economy might experience shocks which have a transitory effect at least on both WTI and Brent prices. Contrasting results from both studies emphasize the importance of issues such as heteroscedasticity when applying unit root tests to energy prices (Mishra and Smyth, 2014) but also that using more sophisticated unit root tests the conclusions about persistence in crude oil prices can be different. It is worth noting at this point that when allowing for the existence and effects of structural breaks, the choice of the sample period and the frequency of data can have a bearing on the results. Serletis and Herbert (1999) investigate the dynamics of North American natural gas, fuel oil and power prices using daily data over the period 1996-1997 to show that there appear to be effective arbitraging mechanisms for the price of natural gas and fuel oil, but not for the price of electricity. Maslyuk and Smyth (2008), using weekly data for crude oil spot and future prices over the period 1991 to 2004 and allowing for up to two structural breaks, find evidence against stationarity for Brent oil price. Further, one could argue that to solve the low power of the unit root test; researchers should increase the number of observations. This can be possible by either considering a longer span or employing data recorded at a higher frequency. However, Shiller and Perron (1985) and Campbell and Perron (1991) have argued that increasing the frequency does not lead to higher power. They state that the power of the unit root test depends on the span of the data chosen rather than the frequency of the observations.

Although research on stationarity properties of other energy resources than crude oil is not so abundant, its focus might be particularly revealing. Existing literature on natural gas prices with particular focus on European gas prices agrees that NBP prices are nonstationary and first-order integrated when using generic tests, despite some uncertainty when including a trend in the test (Ashe et al., 2006; 2012; 2013; Panagiotidis and Rutledge, 2007). Of particular interest is the existing research on the US energy market where historically the scope of investigation has been much wider (Bachmeier and Griffin, 2006). As an example, Zaklan et al. (2011) including exogenous structural breaks in the tests, conclude that coal is predominantly stochastic whereas

²⁴ The intention was to include in the analysis the fact that during 1985 there was a marked shift in the OPEC pricing policy.

oil and natural gas prices are strongly affected by outliers. Unfortunately, in this case assuming one known structural break based on previous studies and without a pre-test examination invalidates the distribution theory for inference (Christiano, 1992).

In summary, the empirical evidence of unit root prices of energy commodities is still mixed although possibly weighted in favour of nonstationarity. In particular crude oil prices are found to display a significant level of persistence, and therefore shocks are perceived to be long lasting rather than being short-term transitory. Unfortunately, some problems related to loss of power of unit root tests remain to reach a consensus, e.g., unit root tests in small samples (Pyndyck, 1999) or samples with non-homogenous errors (Kim and Schmidt, 1993), using a wrong break date under the null hypothesis (Harvey et al., 2013; Harvey et al., 2014) and ultimately the presence of structural breaks. In this regard, although structural breaks reduce local persistence in oil prices, there appears to be still a high degree of persistence locally when structural breaks are not taken into account (Ozdemir et al., 2013).

2.2 Literature related to unit root testing methodology

Unit root testing methodology deserves a separate description since not only it is the most common method to study the persistence of time series, but it is also intimately related to advanced theoretical approaches to regression and cointegration analysis. This section is concerned with methodological issues affecting unit root estimation, testing, and validity of results in the context of structural change. Our focus is on the conceptual issues about the different approaches to better understand potential applicability to our investigation. It is important to highlight the impressive amount of research in the last few decades devoted to improve existing methodologies and to overcome potential problems. Although the literature is vast probably two main drivers have led the impressive developments seen on this field: the assessment of whether time series are affected by transitory or permanent shocks and also the need to understand the effects of structural breaks. The fact that unit root processes can sometimes be viewed as observationally equivalent to, or hardly distinguishable from, a trend stationary process with breaks lays at the heart of the debate. Intuitively speaking, it could be the case that a structural change may imply persistent effects similar to those in a unit root process (Durlauf and Philips, 1988).

The most recent surveys (Narayan and Smyth, 2007; Smyth, 2013), show the significant effort that has been made to systemize and expand knowledge on unit root tests allowing for structural breaks. The task has proven not to be easy due to the uncertainty about the number, location, and nature of structural breaks, among other factors, leading to a reduction in the power of the tests (Kejriwal and Lopez, 2011). Furthermore, correct inference for structural breaks depends on whether a unit root is present or not, given the fact that different limiting distributions exist, so different asymptotic critical values, depending on a unit root is present or not. Given this circular problem and looking toward the practical applicability of the various testing approaches, a joint inference strategy on the unit root and the break is a plausible

solution that we will consistently use in this research (Patterson, 2013). It has to be noted that since the seminal paper by Perron (1989) was published, several alternatives in addition to joint inference, have been developed and a complementary strand of literature is concerned with specific issues related to detection and estimation of structural changes. Accordingly, a wide variety of tests has been proposed to evaluate the null hypothesis of stable persistence against the alternative that there is at least a one-time shift in persistence. The proposed approach, in this case, is based on the assessment of the presence of a structural change without any prior knowledge as to whether the noise component is stationary or contains an autoregressive unit root. In this regard alternative routes developing sophisticated techniques to test for deterministic trend followed by unit root testing have been developed (Harvey et al., 2007; Perron and Yabu, 2009b; Harvey et al., 2010b; Perron and Yabu, 2009a; Kejriwal and Perron, 2010). Further, a set of new unit root tests allowing for structural breaks under both the null and alternative hypothesis is proposed by Harris et al. (2009) and Carrion et al. (2009). Unfortunately, asymptotic results are somewhat at odds with finite sample simulations using these tests. The reason behind this fact is that while the trend break pre-tests used are consistent against breaks of fixed (independent of the sample size) magnitude, in finite samples they may not provide perfect discrimination, i.e., some degree of uncertainty will necessarily exist in finite samples as to whether breaks are present or not (Harvey et al., 2013). Simulation results suggest that this problem becomes increasingly pronounced the greater the number of breaks in the series other things being equal. Unsurprisingly drawbacks using this framework may result in serious power and size distortions whereas uncertainty over whether or not trend break occurs remains. Although solutions have been proposed by Harvey et al. (2013), the debate about increasing finite sample power in the presence of plausibly-sized breaks remain.

Following the choice of a strategy, the particular conditions are essential. Issues such as the nature of the impact over time, i.e., how fast reaction is to the event, how to estimate the precise dating of the structural break or even whether the assumption that there is only a single break can be qualified, are at the heart of the process. In regards to the former question and as described by Vogelsang and Perron (1998), in practice since magnitudes of trend shifts are commonly not broad enough to cause substantial size distortions, the choice between the AO and IO models²⁵ should be based on the dynamics of the shift. The innovational outlier model (see Appendix 2) fits better the distributed lag response of commodities' prices to major events and therefore it is a more realistic approach to our case. The second and third issues will be considered almost in parallel during the investigation.

²⁵ This distinction gives rise to mainly two forms of structural break model based on Perron's (1989), i.e. additive outlier (AO) and the innovation outlier (IO) models allowing for an immediate or distributed over time impact respectively.

In this setting, the bulk of the existing literature has emphasized that testing for unit root using a framework whereby the break is treated as fixed is inappropriate (Christiano, 1992) mainly due to the incorrect use of critical values corresponding to a confused hypothesis. In response to this criticism, subsequent theoretical approaches have focused on the case where the possible break occurs at an unknown point in the sample. The most relevant research include Banerjee et al. (1992), Zivot and Andrews (1992) (ZA) and Perron and Vogelsang (1992) (VP). These unit root tests have in common that they endogenize the choice of the break point, either minimizing the Dickey-Fuller statistic or optimizing a statistic which tests the significance of one or more of the coefficients on the trend break dummy variables. Implementing such a process for testing the unit root hypothesis, including the possible presence of a structural break, has at least two advantages: first it prevents yielding a test result which is biased towards non-rejection, i.e., can have little power when the true generating process of a broken linear trend is stationary Perron (1989). Second, since this procedure can identify when the possible structural break has occurred, it can provide valuable information as to whether structural breaks have significantly contributed to a change in trend or not.

Interestingly except VP in all the above studies, the assumption is made that no break has occurred under the null hypothesis of unit root. In line with this, Nunes et al. (1997) own analysis extend ZAs by permitting a break under the null as well as the alternative hypothesis while allowing for the sequential nature of the testing. They probe that not allowing for breaks under the null hypothesis leads to size distortions²⁶ in the presence of a unit root with a break. As such, spurious rejections might occur and more so as the magnitude of the break increases.

Lumsdaine and Papell (1997) (LP) extend the ZA model to introduce a unit root testing procedure that allows for two structural breaks under the alternative hypothesis to resolve the trade-off involved due to the existence of additional events within a long-run context. Although the test identifies the break dates more accurately with increasing break size, rejection of the null converges to hundred percent more rapidly also with increasing break size (Narayan et al., 2010). Others who have considered multiple breaks are Clemente, Montañés, and Reyes (1998) who base their approach on VP developments and Ohara (1999) that utilizes an approach based on the ZA sequential t-tests to examine the case on a finite number of unknown breaks.

In a generalization of Perron's initial tests and following Leybourne et al. (1998) with known breaks, Saikkonen and Lütkepohl (2000), Lütkepohl et al. (2001), Lanne et al. (2000) and Perron and Rodriguez (2003) extend the tests of Elliot, Rothenberg and Stock (1996) which are based on estimating the deterministic term first by generalized least squares (GLS) and

²⁶ This problem arises only in the endogenous break unit root test. The asymptotic distribution of Perron's (1989) exogenous test does not depend on the magnitude of the break, even when a break occurs under the null. Thus, there is no size distortion in the exogenous break test, even when the magnitude of a break is very large.

subtracting it from the series. The estimation of the nuisance parameters of the data generating process (DGP) including the shift date in a first step is followed by a standard unit root test to the residuals. Interestingly, it is the behaviour of the breakpoint estimators used in these approaches when no break occurs which results in inference problems. In practice, since it will be unknown if a trend break occurs or not, this differing behaviour of the break fraction estimator also renders the true asymptotic critical values of the tests above dependent on whether a break occurs or not Cavaliere et al. (2011). It has to be noted that Saikkonen and Lütkepohl (2000), Lütkepohl et al., (2001) and Lanne et al. (2000) tests have the convenient feature that they allow for smooth transitions to a new state through more general structural shift functions, this feature improving the intervention characteristics of a traditional impulse-type outlier. Moreover, tests statistics are easy to compute for quite general shift functions and also allow the possibility to include seasonal dummies in addition to a constant or linear trend line. If the break date is unknown, Saikkonen and Lütkepohl (2002) and Lanne et al. (2001) (LLS) extend Saikkonen and Lütkepohl (2000) and Lanne et al. (2000) tests respectively to that situation, showing that for any estimator of the break date the tests have the same asymptotic distribution as the corresponding tests under the known break date assumption. Different estimators of the break date are compared in a Monte Carlo experiment and a recommendation to choose the break date in small samples is given. Surprisingly test versions which assume that there is no linear trend in the DGP do not necessarily have sizeable power advantages over tests which allow for a linear time trend.

In an effort to resolve some of the problems encountered, Lee and Strazicich (2003)(2004) (LS) propose a one and two breaks Lagrange Multiplier (LM) unit root test as an alternative to the ZA and LP tests respectively. In contrast to the ADF test type of tests that assume the absence of breaks under the null in order to eliminate the dependency of the test statistics on nuisance parameters, no such assumption is required in the LM framework, since the test statistic is free of this nuisance parameter (see Amsler and Lee, 1995, and Lee and Strazicich, 2003). The breakpoint estimation scheme is similar to that in the LP test, i.e., the breakpoints are determined to be where the test statistic is minimized. While the LS test offers an improvement over procedures that only allow for breaks under the trend stationary alternative, it is recognized to be substantially undersized for large breaks whereas it has difficulties in identifying the break dates (Narayan et al., 2010). These considerations will be taken into account at a later extent in the empirical analysis.

Included within the alternative approach that was initially discussed and using research on structural change by Perron and Zhu (2005) and Perron and Yabu (2009a), Kim and Perron (2009) (KP) developed new test procedures which allow a break in the trend function at an unknown time under both the null and alternative hypotheses. Also, when a break is present, the limit distribution of the test is the same as in the case of a known break date, thereby allowing increased power while maintaining the correct size. As discussed previously, following this strategy, when no break occurs, the asymptotic results do not hold so a pretest to assess

whether a break is present or not is mandatory before applying the proper unit root test procedure, thus allowing for a relative amount of uncertainty and potential loss of power for small samples (Harvey and Mill, 2000).

2.3 Literature on volatility characteristics and long-term relationships between crude oil and energy prices.

Many empirical studies have investigated on the long-term relationship between natural gas and oil prices, mostly in the US and the UK, by large the most liquid markets worldwide and therefore showing a less evident connection than gas markets in Continental Europe or Japan. Particular attention has been devoted to the degree of integration between natural gas and oil markets with a focus on whether was a separation between the two types of prices (Bachmeier and Griffin, 2006; Hartley et al., 2008) but also on the nature of volatility (Pyndyck, 2004a; 2004b, Elder and Serletis, 2009). Possibly one of the earliest research analysis applied to the US market is found in Serletis et al. (1994). They show through a multivariate framework, the presence of one common stochastic trend among crude oil, unleaded gasoline, and heating oil future prices. Adrangi et al. (2001) study the price dynamics of a specific crude (the Alaska North Slope) and its relation with US West Coast diesel fuel price using bivariate VAR and GARCH models. They find a unidirectional causal relationship going from the crude oil to the product. Bachmeier and Griffin (2006) evaluate the degree of market integration both within and between crude oil, coal, and natural gas markets to conclude that the world oil market is a single, highly integrated dynamic market. On the other hand, coal prices at five trading locations across the United States are cointegrated, but the degree of market integration is much weaker, particularly between Western and Eastern coals. Moreover, they show that crude oil, coal, and natural gas markets are only very weakly integrated. Brown and Yücel (2006) and Villar and Joutz (2006) find the prices of natural gas and crude to be cointegrated, and also reveal that the price of natural gas reacts to the price of crude oil but no vice versa. Mjelde and Bessler (2009) using prices from two diverse markets in the US (PJM and Mid-Columbia) and four major fuel sources: natural gas, crude oil, coal, and uranium find cointegration between the eight price series although they are not able to detect one single stochastic trend. Some recent studies in the US, show that a separation between natural gas prices and crude oil prices occurs sporadically or in outbreaks (Ramberg and Parsons, 2012). Adding insight into this question, Loungani and Matsumoto (2012) find that separation between US natural gas prices and oil prices may occur as a result of the oversupply of natural gas and the US shale gas revolution whereas Erdos (2012) finds that the existing long-term equilibrium relationship between US natural gas prices and oil prices disappeared after 2009. More recently Brigida (2013) deals very accurately with the cointegrating relationship between natural gas and crude oil to find further evidence that both prices do not permanently 'decouple' but rather experience a temporary shift in regimes.

In Europe, Gjølborg and Johnsen (1999) analyse co-movements between the prices of crude oil and major refined products during the period 1992–1998. Specifically, they explore the

existence of long-run equilibrium price relationships, and whether deviations from the estimated equilibrium can be utilized to predict short-term price changes and risk management. Their results strongly support the hypothesis that crude and product prices are cointegrated. Asche et al. (2003) analyse the relationships between crude oil and refined product prices over the period 1992-2000 to conclude that there is a long-run relationship between oil, gasoil, kerosene and naphtha prices, implying that possibly demand changes for one of these products may influence operational needs at the refinery. However, no such relationship between the prices of any of these products and the price of heavy fuel oil is found. Panagiotidis and Rutledge (2006) investigate during the period 1996-2003 whether oil and gas decoupled. The existence of a cointegration relationship before the opening of the Interconnector indicates that despite the highly liberalized nature of UK gas market, gas prices and oil prices are moving together in the long-run. Panagiotidis and Rutledge (2007) study whether oil and gas decoupled during the post market deregulation period (1996-2003) in the UK to find that both prices are cointegrated before and after liberalization. In related work, Asche et al. (2006) also find cointegration between natural gas and crude oil prices in the UK market after natural gas deregulation, with crude oil prices leading those for natural gas. Relying on daily ICE futures prices of gas and Brent for five contracts, Westgaard et al. (2011) find that a long-term relationship exists between oil derivatives and crude oil prices depending on the length of the contracts, i.e., although cointegration is found for the one and two month contracts (1994-2009), no cointegration relationship arises for the three, six and twelve month contracts (2002-2009). They conclude that possibly the effects of high volatility during some periods of the financial crises might explain these results because in such volatile periods the spread between gasoil and crude oil is likely to deviate. For energy traders and hedgers, the implications of this might be far-reaching. Recent studies like Asche et al. (2012) indicate that the UK energy market is highly integrated with oil prices leading gas prices but also that European spot markets do also follow the same determination process as in the UK²⁷. Even more recently, Ji et al. (2014) using panel cointegration analysis conclude that oil price volatility has an adverse impact on gas price. The shock impact is weak in North America, lags in Europe and is significant in Asia. Also, they find that the response of natural gas import prices to increases and decreases in crude oil prices shows an asymmetrical mechanism, of which the decreasing impact is relatively stronger. The hypothesis that Brent oil prices play a leading role in European and Japanese gas price fluctuations is reiterated in research from Lin and Li (2015) using a VEC-MGARCH approach. As a very relevant finding to this investigation, they confirm that volatility in the oil market spillovers onto natural gas but not backward, this applies to both the US and European energy markets.

It has to be noted that in the last years, the nature of the nonlinear relationships between crude oil prices and regional natural gas prices has led to increased interest in

²⁷ However the effect of Brent oil price on day-ahead gas price like TTF is small.

multiscale modelling approaches interconnecting several gas markets simultaneously. In this regard, empirical mode decomposition techniques (EMD) are increasingly being used to capture the different fluctuation features of the original series at various scales. Using EMD and cross-correlation method, Geng et al. (2016b) confirm once more that oil prices play the leading role in affecting Asian and European natural gas prices, having advanced effects of one to three months and one to six months, respectively. Interestingly, Geng et al. (2016a) using EMD and the VAR model unveil that the effects of oil price shocks on the European gas market have become stronger since the shale gas revolution.

Not surprisingly, and since oil is one of the most important drivers of the economy, with an intriguing connection with other factors like inflation, stocks, bonds and economic growth, the amount of research on the relationship between oil price volatility and other aspects has been fluent and especially intense over the last few years in fields like macroeconomy and exchange rates (Lee et al., 1995; Federer, 1996; Huang et al., 2005; Chan and Chen, 2007; Mensi et al., 2015; Su et al., 2016; Tiwari and Albulescu, 2016; Sun et al., 2017) or stock markets (Sadorsky, 1999; 2003; 2012; Hayette, 2016; Huang et al., 2017). Interestingly, regarding the Spanish stock market, research has found the limited exposure of Spanish industries to crude oil price (Moya et al. 2013). In a category of its own, a fewer number of studies approach crude oil price and returns in relation to other commodities also including natural gas (Plourde and Watkins, 1998; Pindyck, 2004; Regnier, 2006; Rafiq and Bloch, 2016). Finally, and as for other traded commodities, a highly sophisticated category of research is available on both volatility modelling and forecasting evaluation (Kang and Yoon, 2009; Cheung, 2009; Sevi, 2014; Agnolucci, 2009; Narayan and Narayan, 2007; Mohammadi and Su, 2010; Wei et al., 2010; Haugom et al., 2014; Baumeister and Lutz, 2015; Lux et al., 2016; Balaban and Lu, 2016; Barunik and Malinska, 2016; Wang et al., 2016), both perhaps the most relevant areas for our research.

CHAPTER 3. OVERALL ASSESSMENT OF NATURAL GAS AND COAL RESOURCES

As discussed in the previous chapter a vast body of literature has sought to explain how natural resources develop and in which ways the different theories outlined may well represent energy commodities price paths, this subject clearly at the heart of our research. In this chapter, we provide a solid understanding of how natural resources have contributed to the energy mix in Spain with particular attention to natural gas. More importantly, we show the nature and purpose of market trends which are likely to spread and possibly have an effect on energy price developments. The objective of this chapter is to facilitate diagnosis of the overall context and the specific interacting forces related to fossil fuels industries but also renewable resources.

3.1 Fossil fuel market structure

As in most OECD countries fossil fuels make up the lion's share of the energy mix in Spain with a total of 72.2% of total primary energy supply (TPES)²⁸ in 2014, including oil (41.2%), natural gas (20.8%) and coal (10.3%), this is in spite of impressive growth in renewable energy, accounting for 14.9% of the total. However, TPES consumption has been decreasing since 2007 as a result of the economic slowdown showing no clear indications for recovery in the medium-term. As a matter of fact in 2014 TPES was lower by around 18.1% than in 2004²⁹ with total energy demand decreasing by 17.7% since 2007³⁰ (see Figure 4 below). The steady decline in total primary energy supply has been caused not only by lower economic growth but also by structural changes in the energy mix favouring renewable resources integration. In general, fossil fuel share has remained stable with oil decline in electricity generation largely compensated by natural gas growth with coal largely maintaining its share. Interestingly Spain's fossil fuels share in TPES was twelfth-lowest among IEA member countries in 2014, similar to Hungary's and the Czech Republic's while the share of solar in TPES was the highest.

²⁸ TPES is made up of production + imports - exports - international marine bunkers - international aviation bunkers ± stock changes. This equals the total supply of energy that is consumed domestically, either in transformation (for example refining) or in final use. International Energy Agency (IEA)

²⁹ IEA.

³⁰ Ministry of Industry Energy and Tourism. (Minetur) 2015.

Figure 4_Total Primary Energy Supply Spain. Source: IEA/Carbunion.

3.2 Key energy policies

Spain's main energy policy goals are derived from the EU directives³¹ stretching over five areas that will be shaping all Member states policies in the coming years 'to bring about the transition to a low-carbon, secure and competitive economy'. These five policy areas are:

- Security of supply
- A fully-integrated internal energy market
- Energy efficiency
- Climate action - emission reduction, and

³¹ Energy Union strategy 5th February 2015.

- Research and innovation on climate

At the moment public commitments to deliver 20% of final energy consumption from renewable sources by 2020³², translated into the electricity sector to reach a 40% of total electricity production from renewable sources by 2020, seem less stringent. As the monitoring figures show, Spain has met the timeline for objectives in the area of electricity and heating/cooling although is behind schedule in achieving the objective on transportation³³ that cannot be compensated by above-target renewable energy consumption in the other areas.

In terms of air emissions and air quality overall, emissions of air pollutants have significantly decreased since 2000 due to a combination of factors, including changes in Spain's energy mix (increased use of natural gas and renewable energy sources), better quality fuel (especially lower sulphur content), abatement measures in industry and the power sector, reduced solvent use and improved vehicle emission standards. Similarly to Greenhouse Gas (GHG) emissions, air emissions reduction accelerated in Spain following the rapid slow down after 2007. In particular substantial progress has been made on reducing emissions of SO_x, which declined by more than 70% over 2000 -2012, faster than the OECD average. Such a significant reduction has been due to the change in the structure of the electricity sector, including the installation of combined cycle power stations but also to high desulphurization standards implemented by large combustion plants (LCPs). Emissions of NO_x, mostly from road transport but also from fuel combustion in power plants and industry, were reduced by about 34%, in line with the OECD average. Emissions per capita are below the OECD average for both SO_x and NO_x and slightly higher than the OECD average for NO_x/GDP³⁴.

Within this context of slow recovery, low energy demand conditions and therefore poor prospects for new investment in the medium term, current infrastructure utilization seems a priority for most of the energy producers. Furthermore since a substantial review of the current regulation on air pollution limits applicable after 2020 cannot be ruled-out, power generation assets and especially coal plants are under enormous pressure to perform most efficiently.

3.3 Electricity security

Although in Spain dependence on energy imports has decreased from around 80% in 2009 to 57% in 2016, this success is mostly attributed to the rapid increase in renewable energy

³² Directive 2009/28/EC.

³³ Transport is the largest GHG emitter in the non-ETS sector and, therefore, is the natural focus area of Roadmap 2020.

³⁴ IEA 2015.

supply. In the case of the electricity sector, security of power supply will remain the single most important driver of both natural gas and coal supplies in the future.

In this sense, the Spanish Government takes overall responsibility for ensuring that the required electricity infrastructure is available on time to be able to anticipate and satisfy energy demand needs. In general, it can be said that Spain has succeeded in integrating a wide range of diversified sources resulting in a large generating capacity and a very reliable power system. Moreover, total electricity generation installed capacity is high, and reserve margins are expected to remain high until 2020³⁵.

Table 2 shows how the decline in electricity demand, a 1.5% CAGR³⁶ between 2008 and 2016, follows a different path than installed capacity still trending upwards in 2014 maintaining the situation of fleet overcapacity.

MW	2006	2008	2010	2012	2014	2016
Hydro	17.018	17.087	17.107	17.338	17.348	20.353
Nuclear	7.456	7.456	7.515	7.573	7.573	7.573
Coal	11.393	11.325	11.342	11.064	10.936	9.536
Fuel/gas	8.900	6.659	4.698	3.106	2.996	0
Combined cycle	16.358	22.653	26.573	26.670	26.670	24.948
Ordinary regime	61.125	65.179	67.236	65.750	65.522	62.410
Special regime	20.390	29.017	34.184	39.574	40.270	37.798
Total Installed capacity	81.515	94.197	101.420	105.325	105.792	100.208
GWh						
Total demand	254.981	281.072	275.693	267.159	258.131	250.131

Table 2_Installed generation capacity and electricity demand evolution. Source: REE 2017

The referred change in macroeconomic variables has prompted the Ministry to revise scenarios for growth in energy consumption and to reflect new levels of electricity demand, i.e., in 2013 electricity consumption in Spain was already below 2006 levels. Specific for the electricity sector the recent publication of the 2015-2020 Planning document³⁷ reveals Ministry's intentions for the coming years after a period of over-optimistic forecasts and strong acceleration of investment in regulated assets, including subsidies to renewable generation. The

³⁵ IEA 2015.

³⁶ Cumulative Average Growth Rate.

³⁷ Environmental Sustainability Report (ESR) and Electricity Sector 2015-2020 Planning document. *Informe de sostenibilidad ambiental de la Planificación del Sector eléctrico*. May 2015.

document includes an extensive review of new macroeconomic conditions and corresponding expectations until 2020, basically anticipating low energy consumption growth (1% CAGR until 2020) in spite of positive GDP growth expectations, this coming about as a result of successful efficiency measures and saturation in some markets.

Regarding expected energy generation mix it is anticipated that renewables will continue to grow its share in total energy supply increasing at a rate of 4.7% CAGR in the period 2013- 2020, this including thermic biomass, thermic solar, biofuels, and even hydrogen given its positive expectations as discussed by Rodríguez-Monroy and Hernández-Sobrino, 2010. Quite remarkably, as included in the Planning document, Ministry's expectations on coal generation infrastructure reveals that 'existing units will be maintained except those that had notified will not continue to be under operation after 2015 and those that due to environmental legislation will not continue in service after 31st December 2020' statement that does not anticipate a drastic decrease of capacity in the coming years unless 'for environmental reasons'. Interestingly the new Planning document includes an equivalent of 6.000 MW of Combined cycle gas turbine (CCGT) capacity allowed for mothballing, this probably not a priority in the Ministry's agenda today, and nuclear capacity fully maintained excluding S.M. de Garoña 466 MW group as the Ministry decided to close it at the end of July 2017 permanently. Table 3 and Figure 5 show the foreseeable evolution of the power generation mix according to the Ministry's energy balance 2015-2020.

Energy source GWh	2013	2016	2020
Coal	41,166	47,190	47,548
Mainland Spain	38,734	44,690	45,048
Non-mainland	2,432	2,500	2,500
Natural gas	57,094	65,926	85,222
CCGTs	26,501	32,638	51,903
CHP/Other	30,593	33,288	33,319
Nuclear	56,731	59,670	59,670
Oil products	13,854	15,298	11,319
Renewables	110,949	108,866	121,475
Other	5,058	5,003	5,822
Total	284,852	301,953	331,056

Table 3_Spanish electricity balance 2013-2020 (GWh). Source: Ministry's planning document 2015

Figure 5_Spanish power generation balance 2013-2020. Ministry's planning document. Source: Ministry

As it can be seen, coal generation exceeds CCGTs production until 2020 providing about 15% of total electricity generated in 2020. This could be an indication of Government's intentions to support coal generation technology in the future. Regarding thermic gap share and not including pumped hydro, coal generation would cover almost 48% of total available in 2020.

3.4 Power market dynamics

The energy mix used for electricity generation has significantly changed since 2001 when coal and nuclear accounted for more than 60% of the total production. In 2016, renewable sources³⁸ generated 27% of electricity, higher than the contribution of 25% from coal and CCGTs together (Figure 6). As is well-known, overcapacity in the generation sector along with the asymmetric effects of renewables preferential dispatching reduces not only opportunities to run thermic plants but also brings down wholesale prices. This, in turn, drives out producers who are not competitive.

³⁸ Cogeneration production not included but included in the Especial Regime category.

Figure 6_Energy balance by technology. Source: Ministry/Carbunion/REE

Figure 7 shows from 2002 to 2016 the trend in the relative cost advantage of imported coal³⁹ against imported natural gas prices on comparable energy cost basis to generate electricity⁴⁰ (yellow and blue bars, these only since 2008 for more clarity, without and with emissions rights respectively). It also indicates the percentage of the thermic gap⁴¹ being served by either coal or gas-fired generation units over the period (solid lines).

³⁹ In this manner the effects of RD RGS 2010 are reduced.

⁴⁰ It basically compares contribution to fixed costs and including efficiencies, CO2 emissions rights, etc.

⁴¹ Thermic gap refers here to generation provided by coal, gas, oil and pumped hydro to satisfy the remaining chunk of the demand available at the highest tranche of the supply-demand merit order.

Figure 7_Coal vs. gas electricity market competition. Source: Ministry/Carbunion/REE

As it can be seen between 2006 and until 2010 gas-fired generation had the highest percentage of operating hours, these supported by gas price advantages overall (yellow bar below zero). However, it is apparent that since 2010 coal generation has increased substantially overcoming the limitations imposed by low gas prices. Figure 8 shows the evolution of total coal generation, increasing since 2010 despite reduced scope for thermic generation, this in part due to growing renewable capacity since then.

Figure 8_Coal/gas competitive position vs. available thermic gap. Source: Ministry/Carbunion/REE

Figure 9 shows in more detail, on a monthly basis, the relative cost advantage of coal generation units against gas-fired plants since 2011 (also called monthly average dark and clean spark spreads) showing the trend of coal-gas relative price attractiveness to produce electricity. In addition to price competitiveness, however, the significant increase in the use of coal in Spain since 2009 has been due to a combination of factors including low carbon emissions prices and Ministry's support to domestic coal production.

Figure 9_Clean/Dark monthly average spread. Source: Ministry/Carbunion/REE

It needs to be highlighted that the picture of monthly average spreads does not reveal real power operators' strategies during the day. Typically, coal plants would be willing to operate during low demand hours whereas gas-fired plants would most likely operate for a limited number of peak hours and within secondary 'fast response' electricity markets.

In relation to domestic-imported coal competition, Figure 10 shows the tendency in the use of each product and total coal in the power sector since 2002 as a share of electricity demand. It also indicates the percentage of domestic coal over total coal used for power on the secondary axis (dash).

Figure 10_Domestic – Imported coal competition dynamics. Source: REE

As it can be seen, the share of domestic coal declined more steeply than imported coal between 2006 and 2010 as a result of more challenging market conditions and the absence of a regulated plan to operate (notice a sudden drop in domestic coal supply in 2010, dash line). It is also worth noting that the contribution from domestic coal gradually decreases since 2002, possibly anticipating a more stable pattern of supply in the medium term at the level of 'no Government support.' Interestingly and despite the disappearance of Ministry's support⁴² at the end of 2014, the activity of so called 'RGS Plants' using domestic coal increases in 2015.

3.5 Current picture of the gas industry

3.5.1 Natural gas sector

The strong development of the natural gas industry in Spain started in the early 1990s. At that time, domestic production accounted for about 20% of total gas consumption in the country, with the remaining imported in the form of LNG from Algeria and Libya. Imports from Norway through pipelines started 1993, and in 1996 a new gas pipeline interconnection with Algeria was activated. In 1998, the Spanish Government approved the Hydrocarbons Sector

⁴² Mainly through publication of Royal Decree 134/2010 de Restricciones por Garantía de Suministro (RD RGS)

Law⁴³ that introduced unbundling provisions and the progressive liberalization of the gas sector. In 2001, the first CCGT unit was commissioned, starting an investment cycle that has resulted in about 25 GW CCGT installed capacity at the end of 2015.

The following table reports the evolution of gas demand in Spain.

GWh	2008	2009	2010	2011	2012	2013	2014	2015	2016
Residential-Comercial	59.617	55.945	64.328	52.433	56.776	56.597	49.162	51.774	53.510
Industrial	197.256	180.264	194.089	203.626	216.923	213.733	195.327	196.503	202.844
Conventional demand	261.906	241.083	263.292	260.935	278.038	276.590	249.835	253.560	261.844
CCGTs demand	187.534	160.793	135.617	109.920	84.634	56.844	51.772	61.238	59.643
Usos no energeticos	5.033	4.874	4.875	4.876	4.339	6.260	5.346	5.283	5.490
Total	454.473	406.750	403.784	375.731	367.011	339.694	306.953	320.081	321.487
% Power generation	41%	40%	34%	29%	23%	17%	17%	19%	19%

Table 4_Gas demand in Spain. Source: Sedigas/Enagas.

The table highlights that electricity generation has been the major determinant of the dynamics of natural gas demand. The combined effect of the economic crisis, the growth of renewable electricity production and low coal prices have dramatically reduced natural gas demand between 2008 and 2016.

Gas can be imported in Spain through ten entry points into the system, i.e. pipelines connecting Spain with France, Portugal, Morocco and Algeria and seven LNG terminals located on the Atlantic coast (Bilbao, Mugaros and Gijón⁴⁴ in the north and Huelva in the south) and on the Mediterranean (Cartagena, Sagunto and Barcelona). Figure 11 shows the infrastructure map and also evolution of both LNG and pipeline import capacity since 2004.

⁴³ Ley 34/1998, de 7 de octubre, del sector de hidrocarburos.

⁴⁴ This plant is currently mothballed.

Figure 11_ Gas infrastructure in Spain, 2015. Source: CNMC

Total import capacity is around 88 bcm/year, this not including mothballed LNG terminal at El Musel⁴⁵ in the north that could provide additional 7 bcm/year of import capacity in a matter of months. Such level of import capacity compares with less than 30 bcm total demand in 2013 and with forecasted demand never above 35 bcm/year. Based on that evidence it seems that excess import capacity will be relevant characteristics of the Spanish market for the foreseeable future. Planned upgrades are expected to increase interconnection capacity between France and Spain through Irún by up to 2 bcm/year in both directions, although this project was postponed from initial plans to implement it by 2012. In case also the Midcat project is realised, further additional exporting capacity from Spain to France of about 7.2 bcm/year would result⁴⁶. Finally, a third pipeline connecting Portugal and Spain through the northern border in Zamora is being currently considered.

⁴⁵ Real Decreto-Ley 13/2012.

⁴⁶ The Midcat project has been discarded in 2010 due to lack of subscription in the open season stage. However, it might be resumed in the context of the measures to increase European security of supply. Source: CNMC. *Spanish energy regulator's national report to the European Commission 2013*.

3.5.2 Historical and current wholesale gas prices

Historical data on wholesale prices is available from some sources, but on an aggregated basis, Spanish import prices published by the CNMC (CNMC_AT GN + GNL line on the chart below) are the most reliable. As seen, Spanish prices have followed crude oil patterns, with a peak at the end of 2008, followed by a period of relative stability since 2012, this caused by the crude oil oversupply situation and lower prices. Figure 12 shows landed prices into Spain representing the historical weighted average of LNG from both long-term contractual sources and versus TTF benchmark expressing the opportunity cost of choosing a traded alternative. It is interesting to see that average import price in Spain are consistently below European average import prices except at times where hub prices remain below long-term oil supply levels.

Figure 12_Historical long-term import prices of gas into Spain

Within aggregated import figures there is a broad range of dynamic prices, reflecting the range of contracts including both long-term agreements but also LNG purchase on the spot. It should be emphasized that there is substantial uncertainty over gas prices in Spain owing to the confidential nature of contractual agreements and the opaque structure of the market. Possibly, pipeline inflows into the country from Norway and Algeria set a benchmark for competitors eager to download LNG cargos on a long-term basis. In recent years both sources of supply, i.e., oil-indexed prices have become increasingly competitive with hub prices, contributing to maintaining a strong push of Norwegian and Algerian imports also against spot LNG cargos. Nonetheless, supply-demand dynamics in Spain continue to be driven by local gas shortage-oversupply conditions which in turn might open up divergence versus North West Europe's prices.

LNG comes into the country from a significant number of different sources as discussed. As a result of our broad experience on LNG long-term contracts into Spain and the extensive research done on this subject in the past, a large number of long-term contracts belonging to more than 15 companies, with Spain as intended destination, have been analysed. Interestingly, LNG spot imports and pipeline gas become competitive products given the inherent flexibilities of both supply sources. Figure 13 shows a brief comparison of LNG benchmarks at the margin with reloads average true price AEAT representing the reloading export price.

Figure 13_LNG spot import price band since 2013

As it can be seen, reloading export prices follow a different pattern in the short term as they chase Asian LNG spot prices. However, at times of abnormal internal demand in Spain, those can be regarded as an indication of alternative opportunity cost for Spanish LNG spot imports choking-off reloading activity.

3.5.3 Evolution of wholesale gas prices drivers in Spain

In general it can be said that Spanish wholesale prices are difficult to explore given the fact that there is not a transparent gas market yet and, in spite of price visibility shown by the new organized MIBGAS market, most of the gas imported in the country is negotiated and purchased by private companies at confidential terms of reference. Moreover, in highly competitive markets also called traded markets, conditions are met to allow prices to evolve in light of supply and demand considerations. For this to happen the traded market needs to be

able to demonstrate that two key features are met: firstly it has to be liquid, i.e., the traded asset can be sold or bought on the spot without hesitations or loss of value and secondly the market has to be deep, i.e., no single player can impact on prices by placing larger orders. It is important to notice that price changes in turn feedback on supply and demand by providing signals that in principle ensure market equilibrium. However, although supply and demand are endogenous variables in this sense they also depend on more factors than price, many of them moving abruptly and implying that the supply and demand vs. price adjustments never stop.

Although in Spain, liberalization of the gas market and competitive conditions have improved the range of supply options available, the fact that gas imported is delivered through long-term agreements, covering at least 94%⁴⁷ of the total expected annual demand, creates an excellent reference to assess the Spanish gas contracting structure. In this sense and according to our experience, the vast majority of indexation terms found in Spanish gas contracts remain linked to oil or oil products. Aside, gas-to-gas competition⁴⁸ pricing may develop temporarily through pipeline-traded volumes across the French interconnection or as LNG spot trade. In the first case, gas trade is still limited due to poor connectivity at the French border resulting in restricted influence of liquid price references in North-West Europe. Regarding LNG spot trade, dynamics are more complex, and although the price for spot cargoes in the LNG market is not necessarily set through gas-to-gas competition, there are certain aspects of the competitive wholesale gas market in LNG spot transactions. Last but not least, existing indications of crude oil price leading gas price formation in even more liquid markets in Western Europe (Asche, 2006), this independently of whether the gas price is determined in a spot or in a contract, reinforces the idea that trends and behaviour of crude oil prices can provide very useful insights into future modelling of SGP.

As a result of all this, the wholesale price of gas in Spain is still opaque, in spite of the newly developed MIBGAS organized market able to quote a marginal price, i.e. the price at which one could physically buy a marginal kWh of gas, this price fluctuating in between open traded market prices and oil-indexed benchmarks. Moreover, establishing a reference for the end-user price of gas to a consumer is also difficult. Not only are most transactions confidential, but contracts are often limited to one year in length and have been struck at very different prices. As a result, the imported gas price quoted as a reference may differ from the current contracts available in the market.

Finally, even assuming a perfect knowledge of a supplier's contract details, they might still sell gas at an unrelated price given the arbitrage (and hence value) of selling that gas

⁴⁷ Source: CNMC

⁴⁸ Gas-to-gas competition indicating an indexation to spot prices that reflect supply and demand in a liquid market.

elsewhere. Gas arbitrage opportunities tend to arise on a seasonal basis when the market matches supply with end-users' peak demand to allow for market price differentials.

3.5.3.1. Long-term contracts and oil-gas indexation

Oil-gas indexation has been a feature of most gas delivered into Spain since the first LNG was delivered to Barcelona in the 1970s and the first gas pipeline through the Maghreb (North-West Africa) in 1996. Typical contracts are linked to a basket of oil-products, often representing the share of competing oil products.

The principle behind valuing and pricing gas in Europe was established originally in the Netherlands in the early 1960s when gas was first introduced as a substitute fuel, mainly for oil products such as fuel oil and gasoil. Clearly, with no trading market in gas at that stage, valuing a product for both buyers and sellers was difficult. Comparing the price of gas with competing fuels offered both buyers and sellers a gas price that followed other markets that they were comfortable with, and gave a clear and straightforward price with hedging opportunities available through the liquid oil markets. The formula also allowed for recovery of the large capital costs involved in the construction of transportation networks. Subsequently as gas from various sources - Norway, Russia, and Algeria - was introduced more widely into Europe the same principle was followed. On the downstream side, most of the first pipeline gas and LNG buyers were regulated utilities such as Enagas, which enabled them to shift market risk to their end consumers (Jensen, 2004). In this regard, it is important to realize that oil indexation was and still is a tool to diversify risk in the gas value chain if accepted by both producers and consumers.

The underlying principle of all these oil-indexed contracts was that gas should be priced according to the market value of the fuels it replaced - mainly gas oil in heating and fuel oil, both High sulphur fuel oil (HSFO) and Low sulphur fuel oil (LSFO), in the industry. The formula would be weighted according to the relative size of the different markets in which gas competed.

For example, if in the industrial sector typically the market share of gas oil was 20%, LSFO 30%, and HSFO 30% then a simplified price formula would be:

$$P = P_0 + (20\% \times (GO - GO_0) + 30\% \times (LSFO - LSFO_0) + 30\% \times (HSFO - HSFO_0))$$

Where,

P₀, **GO₀**, **LSFO₀**, and **HSFO₀** are the gas contract price, the gas oil price and the fuel oil price at the date of contract signature; and

P, **GO**, **LSFO** and **HSFO** are the prices of the same products at covering 3, 6 or 9 months before the given date in question.

Although these contracts have formulas that are fixed at the time they are agreed, they typically allow reopeners to be carried out at regular intervals - often three to five years. These allow the contract terms to be changed if the market had substantially changed from the one envisaged when the contract was agreed. As a result, the composition and share of the LSFO, HSFO and gas oil components typically evolve over time. An example of the aforementioned were contracts that contained an HSFO component, as HSFO is now no longer able to be used as a fuel following the April 1999 second Sulphur in Liquid Fuels Directive (1999/32/EC) which imposed a ban on fuels with sulphur contents in excess of 1% (i.e., HSFO). As a result, contracts that were indexed based on competing fuels including HSFO have been re-opened to remove the HSFO component. In addition, often contracts, have an exchange rate and energy unit components to link the prices of oil in dollars and barrels to the delivered contract price in Euros per MWh in the case of Spain.

As a source of publicly available information on long-term contract prices, specialized publications like ICIS, Platts, and Argus among others, develop long-term contract assessments and a comparison of key spot gas prices and long-term contracts. According to these sources, Algerian LNG has a strong gas indexation to oil that may have maintained LNG gas prices from that country higher than LNG from other sources in the past. Another example of a typical long-term contract in Spain is the one between Gas Natural Fenosa (GNF) and Sonatrach for importing pipeline gas from Algeria through Morocco.

In respect of pricing policies at Ministry's level, and as it was to be expected, regulated benchmarks for wholesale base prices have been historically regarded as an indexation to oil products like the former 'Coste de Materia Prima' index (Cmp) serving as a reference in regulated business tariffs. Furthermore, we can say that this happens not only with regards to typical Spanish gas incumbents but also with regards to multinational gas traders importing gas into the country. Despite the significant amount of gas imported (Spain is still the largest LNG importer in Europe) and also the large size of the gas companies involved in that trade, the potential influence of more liquid price references like the NBP, TTF or even the French TRS⁴⁹ benchmark price is not still substantial and we believe that oil indexation in contracts will remain as the main feature in LNG gas pricing to Spain for some time.

Figure 14 shows the high influence of oil prices into the current, and potentially future, picture of LNG prices into Spain. It also illustrates how the characteristics of Spanish gas traders'

⁴⁹ As a reflection of the increasing linkages with France regarding spot price signals, during December 2016 greater demand from Spain from the TRS zone was able to push TRS prices upwards. Exports to Spain rose by 2mcm on average to 13mcm/day in week 50/2016, to meet higher Spanish demand and due to a widening spread between the TRS and Spanish MIBGAS price.

portfolio with a majority of long-term contracts indexed to oil and oil products are very similar to those of Asia Pacific LNG importers.

Figure 14 also illustrates that gas prices do not automatically reflect oil price rises due to the lagging effect of monthly average oil indexation formulas. Furthermore, it is also remarkable to see the significant smoothing effect of the monthly average oil price indexation in the LNG price formula, which also explains why gas prices have risen less rapidly than oil prices since 2000.

Figure 14_Brent vs. Spanish and Japanese import prices

Aside, figure 15 below shows the powerful correlation between long-term LNG gas contracts in Spain and Brent oil price evolution for the period analysed, i.e., 2002 to 2016. The typical absence of an S/curve, as in Asian contracts, to limit the upside with high Brent prices leads to a strong correlation with oil prices at all Brent oil price levels for all the long-term contracts in the country

Figure 15_Linear correlation Brent 601 vs. CNMC LNG

3.5.3.2. Gas and Power interaction

Influences on the gas price by Spanish electricity markets are complex since the electricity wholesale price (SMP⁵⁰), is affected itself by a large number of interacting forces such as government intervention or the market power of incumbents, sometimes with mixed effects on gas fundamentals. As discussed by Capitán-Herraiz and Rodríguez-Monroy, 2012, forward electricity prices are in turn influenced by power generation fuels, especially gas. Last, but not least, direct indexation of some existing LNG long-term contracts to the Spanish Electricity Wholesale Market⁵¹ implies an even larger level of integration between fundamentals of both gas and power markets.

Probably the most visible link between gas and electricity prices is found when analyzing operations by gas-fired power generation plants (CCGTs). In this respect, for a CCGT the decision to generate electricity or not, will depend on the spark spread, i.e., the difference between the cost of gas generating an extra MWh of electricity and the revenue obtained from the sale of electricity at the SMP. Therefore, price arbitrage between the gas and electricity markets is bound to happen. The high operational flexibility of CCGTs compared to other types of

⁵⁰ SMP stands for System Marginal Price, i.e. the marginal price of electricity, established a day-ahead through a matching of supply- and demand-side price and quantity bids in the wholesale electricity market.

⁵¹ Usually indexation to electricity prices in these contracts is done through direct indexation to the System Marginal Price (SMP).

generation plants like coal or nuclear, puts them in an optimal situation to obtain the benefits of spark spread price arbitrage. Moreover, to gain the most out of the power market opportunities, CCGTs have to adapt to the existing price merit order procedure for final dispatching allocation. In this respect, gas generating plants will be typically serving middle and peak demand hours due to the relatively high price for other generation sources like coal. This, however, makes gas operations more difficult and therefore tends to entail an additional risk premium to the price of gas supplies (Sadeghi and Shavvalpour, 2006).

The most important issue, however, related to CCGTs' gas supply operations is the additional flexibility created with regards to supply optimization that can provide potentially useful LNG short-term and spot deals. On the one hand and unless there is a reasonable market price of electricity to cover at least the variable production costs in the short-term, power generators will be willing to shut the plant down and sell the gas instead. On the other hand, if wholesale electricity prices are high enough to run the CCGTs, a specific LNG spot purchase can be justified. To what extent, wholesale electricity prices can affect international prices is not evident. Obviously larger players with diverse portfolios of gas supplies are in a much better position to optimize their supply portfolios and negotiate better deals when needed.

In this scenario of the interaction of gas-power markets, we can say that gas prices could affect (although not always) electricity prices at the marginal level. The fact that the existing gas market in Spain does not incorporate enough liquidity of trade may also reduce desired OMIP⁵² price efficiency (see Capitán-Herraiz and Rodríguez-Monroy, 2009).

Although ultimately regression is a backward-looking analysis which projects the past into the future and therefore does not account for market changes, (for example hydro becoming less dominant with the advent of a vast number of new CCGTs and more wind), historically the influence of gas on SMP has been significant.

Figure 16 shows how the evolution of the Spanish gas price follows a similar long-term trend to the SMP evolution although less steep. It has to be noted that values for the SGP are in euros per MWh to compare easily with the SMP price evolution. It is also important to note that SMP prices correspond to monthly average daily marginal prices and therefore they are not an indication of daily opportunities to run operations.

As a reflection of the potential effects of gas prices on the SMP, in Figure 16 it can be seen that there is some delay in the CNMC_AT GN+GNL reported prices when compared to the

⁵² Operador del Mercado Ibérico de Energía - Polo Português, SA (OMIP) is the derivatives exchange market for Iberian and non-Iberian products, that ensures the management of the market jointly with OMIClear, a company constituted and totally owned by OMIP, which executes the role of Clearing House and Central Counterparty of operations carried out on the market. www.omip.pt.

SMP pattern; this is possibly due to the lagging effect of gas prices reflecting oil prices and the SMP that are much more responsive to spot gas prices at any time.

Figure 16_Spanish gas prices and SMP

Figure 17_Correlation between Spanish gas prices and SMP

3.5.4 Developing gas market in Spain

Despite traditional gas markets contractual arrangements in favour of long-term contracts and oil-linkage terms, generating a competitive price has been a clear aspiration for most Governments, also in Spain. In this sense, the oil price linkage is evidently one of the primary influences determining paths for gas supply/demand equilibrium. Even if the push to unbundle infrastructure services is a success, rigid pricing terms at procurement level may be a barrier to generate true competitive conditions at the margin. This section provides an overview of the status of the wholesale natural gas market in Spain and real competition. Figure 18 shows the logic behind local gas markets, as in Spain, evolving towards competition between suppliers and consumers. Ultimately a wholesale functioning market evolves into a gas exchange including a spot and futures market.

Figure 18_Evolution of local gas markets. Source: IEA

3.5.4.1. Moving from physical balancing to virtual gas supply

As a result of limited competition in the past, ownership exchange in Spain is still mostly arranged in a bilateral (or OTC) fashion between suppliers and traders. As a result of this, a wide range of customized products to accommodate timing and volume flexibility are at the heart of operations in the gas system incorporating lower transaction costs and diminished requirements for risk management and trading structures. However, the downside of this practices is that,

despite an increasing number of short-term and medium-term deals, in many instances done for gas balancing purposes, price visibility remains very limited. As a result of this situation, gas trades do not incorporate adequate transparency which in turn has had a depressing effect on liquidity. There is a growing demand, especially amongst medium-sized shippers, to increase the scope for a more liquid and transparent operating environment. To what extent dominant players will be willing to back the emergence of a Spanish hub and of real spot trading activity, remains to be seen. A combination of regulatory measures and a global market approach seem to be needed to find a feasible way forward. Figure 19 shows the different forces pushing for increased flexibility of operations in a typical Spanish gas company trading environment.

Figure 19_Dynamics of current gas operations in Spain. Source: Authors

Figure 20 shows a snapshot of different balancing points (eight in total) allowing independently different short-term trading operations.

Figure 20_Spanish gas map of balancing points. Source: Authors

Relative to prices, most of the transactions are carried out by an estimated purchase price that might not be in line with any comparable market price. Only for transactions involving more than five or six months, there are some costs of working capital and storage to be negotiated between the parties. In the case of LNG swaps, the most significant part of the trading market activity, LNG storage costs are also being charged just in case the total volumes being traded are in excess of the free storage limit allowed within the system. The intrinsic value of gas, but not intrinsic seasonality, is considered in the final economics of deals. Moreover, the trading platform MS-ATR developed under Enagas requirements does not provide an open release of bilateral price deals, further constraining the flow of information to understand how traded gas is priced.

Curiously, the main reason for the relatively high current volumes of trading is the strict regulation of gas operations in Spain. Since the liberalization started in 1998, legislation has tightened up the balancing regime, increasingly linking defaults in operational limits with major extra charges and penalties. LNG storage limits and obligations have been reduced to allow for easier system operations, or at least as similar as possible to real day-to-day constraints in LNG terminals. The new rules mean that Enagas will not store gas free of charge anymore (charge for

those five days were previously included in the regasification tariff) at the linepack (now PVB⁵³). These limitations lay the foundation for current PVB arrangements that can be considered as an early version of a future virtual hub that centralizes wholesale activity. Moreover, the MIBGAS organized market is expected to set the stage for a common Iberian market trading activity with the serious possibility of France joining which would evidently add more liquidity to the system. Given the fact that the regulated market formally disappeared on 1 July 2008, only volumes of freely traded gas are now being incorporated into the market.

3.5.4.2. MIBGAS organized gas hub

As an alternative to OTC operations, the Organized Gas Market on the Iberian Peninsula began operating in December 2015 implementing Law 8/2015 that amended Law 34/1998 on the Hydrocarbons Sector. It also comes as a result of Spanish and Portuguese Governments' decision to design and implement a unified operating model for the Iberian gas market following the guidelines of the European Gas Target Model. Within this framework, MIBGAS S.A. is the company mandated as an operator⁵⁴. The MIBGAS trading platform is used for the purchase and sale of natural gas with physical delivery at the Virtual Balancing Point (PVB) for Within-Day, Day-Ahead, Balance of Month and Month-Ahead products.

The creation and development of the Iberian Organized Gas Market are of particular relevance to consumers and suppliers as it is intended as an alternative benchmark price for short-term operations. Also, it should be able to provide an increased level of transparency and liquidity in line with the trend in other European gas markets.

The creation of MIBGAS has the following objectives⁵⁵:

- Increase the security of supply through market integration and coordination of both systems of the natural gas sector and strengthening of interconnections.
- Raise the level of competition, reflecting the larger size of the market and the growth in the number of participants.
- Simplify and harmonize the regulatory framework in both countries.
- Encourage the efficiency of regulated and liberalized activities as well as market transparency.

⁵³ Punto Virtual de Balance

⁵⁴ Spanish and Portuguese market operators are respectively entitled to 20% and 10% of MIBGAS SA's share capital, and the technical manager of the Spanish gas system and the global technical manager of the Portuguese gas system are respectively entitled to approximately 13.3 % and 6.6% of the company's share capital.

⁵⁵ Source: Entidade Reguladora dos Serviços Energéticos (ERSE). Portuguese regulator.

It has to be highlighted that the volume traded at MIBGAS has been increasing since 2015 with products similarly negotiated as an auction or in the daily market.

Figure 21 below shows yearly volume traded in MIBGAS by negotiation type and product during 2016. As it can be seen, intraday and MIBGAS D+1 products account for about 75% of the total traded volume, confirming the spot predominance of MIBGAS operations.

Figure 21_MIBGAS traded volume in 2016. Source: MIBGAS

Unfortunately and despite regulatory support for the MIBGAS market, it will not be possibly be considered a real alternative unless the level of liquidity and volumes traded increase significantly. In this respect, the limited capacity in Spain through the French border is and will be one of the main limiting factors delaying the successful implementation of the MIBGAS platform. Furthermore, stretched tradability adds the risk of being exposed to a market with different fundamentals and time exposure. Figure 22 shows the extreme variability of the MIBGAS price in January 2017 reflecting intrinsic limitations to attend demand surge in the South of France, exacerbated by low send out from the Fos LNG terminal while gas from Spanish generators was soaring due to low wind conditions and drained storage levels in Spain.

Figure 22_MIBGAS price evolution versus European benchmarks

3.6 Current picture of the coal industry

3.6.1 Coal supply and demand

In 2015, coal consumption by the power sector was 12.7 Mtep. A further 1.44 Mtep of coal was used in the heavy industry of which 1.1 Mtep was coking coal for steel production; the remainder was used in cement manufacture, paper production, and other domestic uses. In recent years the demand for coal has been affected by some factors especially the decline in electricity demand and the more difficult operating conditions for coal-fired power plants as renewable and gas-fired power capacity has risen.

Domestic coal supply, only 1.3 million tonnes of oil-equivalent (Mtoe) (approx. 3.5 Mt) in 2015, has been steadily decreasing since 1990 being severely affected by EU decisive stand in phasing-out protection to uncompetitive energy sources and by the depletion of existing resources. As a consequence of this challenging environment with reduced domestic coal supplies, the use of imported coal has been gradually increasing also as a result of a combination of market factors mainly a significant loss of competitiveness of gas against coal and the low prices of carbon emission permits. Figure 23 shows the decreasing trend of domestic coal supply (by type), under enormous pressure by political phase-out measures, and the relative increase in coal imports since 2010.

Figure 23_Breakdown of total coal supply in Spain. Source: Carbuni3n

Total imports in 2015 amounted to about 16.2 Mt reaching a record figure of 82% of the total coal. These imports were sourced from various countries, mainly Indonesia, Colombia, and Russia. In addition, coking coal imports amounted to 2 Mt coming primarily from the United States and Australia the two largest exporters. Imported coal supply is mainly sub-bituminous coal for power generation effectively blended with domestic coal when needed.

It is interesting to note that although in essence, domestic and imported coal can be complementary products mostly tracking power plants demand needs; both follow slightly different logistics patterns this aside from pricing issues. While domestic coal supply allows for a significant amount of storage capacity at the mining premises, resulting in added flexibility, imported coal operations are limited by power plant storage capacity. This feature results in the more efficient use of the existing infrastructure at plants using imported coal.

3.6.2 Coal mining sector

The evolution of the coal mining industry until today has resulted in a restructured sector through downsizing with production falling in 2014 by 60% from 2004 levels. As a result in 2014, only 13 coal mining companies operate (down from 234 in 1990 with production reduced from 19.2 Mt to 3.9 Mt). Seven of these companies produced almost 95% of total coal production.

Annual production capacity (Kt)	Number of companies	Total production (kt/y)	Share in total production (%)
< 25	3	31	0.8
25-100	3	215	5.5
>100	7	3,657	93.7
Total	13	3,904	100

Table 5_Coal producers in Spain 2014. Source: Ministry 2014

In general, the exploitation of the national coal reserve has been historically associated with the development of the fleet of coal-fired power plants highly encouraged by the first oil crisis in the 70s and the great diversity of coals found, i.e., from anthracite and bituminous to all types of sub-bituminous coals (lignites). As of 2015 coal-fired generation capacity originally designed to run on domestic coal nearby still, represents almost half of current coal power generation capacity in the country. However, today domestic coal resources play a less significant role not only because of ongoing depletion but also because of EU efforts to facilitate the closure of uncompetitive coal mines by 2018. In line with this, the sector is undergoing a major restructuring process that started in the 90s, and that is formally implemented through Ministry's four-year work plans. These sector-based plans set out the priorities and actions to be undertaken with the objective to accelerate a downward adjustment and the end of state-aid subsidies⁵⁶.

The fact that domestic coal production depends almost entirely on electricity demand⁵⁷ has also had a bearing on the electricity sector dynamics sometimes involving a complex political dimension. This situation has resulted in frequent disagreements among the three parties involved, i.e., coal producers, power plants, and Ministry, creating a difficult context to the operation of coal-fired plants using domestic coal. Other factors, such as deteriorating business conditions, a worsening of coal quality due to more difficult mining operations, the phase-out of subsidies or the air pollution controls, have only increased over time. This has resulted in power plants, since the liberalization of the Spanish energy sector in 1998, seeking external coal supplies with reduced dependency on domestic coal. One recent example of this ongoing tensions has been the obligation dictated by the Ministry⁵⁸ for ten power plants to use domestic

⁵⁶ National Plans for Strategic Coal Reserves (Plan Nacional de Reserva Estratégica de Carbón) in 1990-1994, 1995-1997, 1998-2005, 2006-2012 and 2012-2018.

⁵⁷ Coke for the iron and steel industry (about a 10% of total coal products consumption) is not included in the analysis.

⁵⁸ Royal Decree 134/2010 de Restricciones por Garantía de Suministro (RD RGS)

coal from 2011 to 2014 and giving priority to the dispatch of these plants over other more competitive ones.

Bituminous coal mines are located in the region of Castilla y León, in particular, León and Palencia provinces, producing about 0.95 Mt in 2013. Also in northern Spain, another 0.97 Mt were produced in Asturias. Mining is very important at Puertollano in the Ciudad Real province south of Madrid with an output of 0.65 Mt and in the eastern part of the country in the Teruel province of Aragon where 1.8 Mt of sub-bituminous coal were produced in 2013.

Figure 24 shows main coal mining areas and major resource base. Note that in % it indicates the share of regional capacity burning domestic coal in 2016 and circles coal production per region (as per latest data available in 2013).

Figure 24_Geographical distribution of coal generation and coal mining production. Source: Ministry/ Carbuunion

Regarding resources available and according to the latest log created by the Ministry of Industry⁵⁹ total reserves (including possible reserves) in Spain are 3,356 Mtce⁶⁰ of which 2,810 Mtce are anthracite and bituminous and 546 Mtce are black lignite this mostly located in Teruel. However, only a small fraction is considered to be proven or probable⁶¹ having not discounted the total amount extracted to date what shows the limited scope for a reliable supply of indigenous coal resources in the long-term.

3.6.3 Coal mining Government support

Similarly to other countries in the EU, Spain has a long tradition of granting subsidies to domestic coal, justified regarding improved security of energy supply, and acknowledging the importance of indigenous sources of home-produced energy. However and in line with EU's principles discussed previously, the Spanish coal mining sector, similarly to other EU countries like Germany or the UK, has been forced to adapt to open market conditions⁶² through a strict restructuring programme aimed to achieve competitiveness in the sector by 2018. Within this framework, two main financing channels were devised originally to support hard coal producers either through general State budget (*Presupuestos generales del Estado*) for companies subscribing the so called *Contrato Programa* like HUNOSA⁶³, the state-owned mining company or through electricity tariff mechanisms for privately owned companies. It is since the early 90's and the implementation of consecutive National Plans for Strategic Coal Reserves (*Plan Nacional de Reserva Estratégica de Carbón*) in 1990-1994, 1995-1997, 1998-2005 and 2006-2012 that the sector is facing major restructuring programmes. Three main drivers have been guiding these plans until today: a) strict targets for reductions in production for uncompetitive units based on excessive production costs⁶⁴, b) staffing reduction programmes to improve productivity and c) economic restructuring policies for the coal-mining regions.

Since the publication of the 2006-2012 Plan establishing specific dates to phase out support to coal by 2018⁶⁵ the Ministry has committed itself 'to adopt the necessary measures to guarantee that coal plants purchase the agreed volume quotas' set by the Government in the

⁵⁹ National Inventory of National Coal Resources. 1992

⁶⁰ tce = ton coal equivalent assume higher calorific value of 7,000 kcal/kg

⁶¹ For Spanish standards proven reserves consist of very probable and probable. In general truly recoverable. Data shown in Figure 24.

⁶² It is since mid- 80s that excess supply conditions as a result of new market entrants like Australia, South Africa, Colombia and China reduces significantly coal prices and in turn Spanish coal imports increase.

⁶³ Created in 1967, Hulleras del Norte S. A. (HUNOSA) today fully own by the state, employing 74,000 staff in 2013.

⁶⁴ According to the Plan 2006-2012 coal production units with operating expenses over 120 Eur/tce in subterranean mines or over 90 Eur/tce in opencast should be closed.

⁶⁵ Under the National Plan for Strategic Coal Reserves 2006-2012, operating aid is to be reduced by 1.25% per year for underground mines and 3.25% per year for opencast mines. Production is due to fall from 12.1 million tonnes in 2005 to 9.2 Mt in 2012, and employment from 8,310 to 5,302.

referred plan. In line with EU's order 1407/2002 only hard coal production remains subject to the plan meaning brown lignite production, quite significant in the Galicia area had to be discontinued in 2007. According to the latest plan⁶⁶ extending to 2018, the action framework sets a significant cut to state-aid with a gradual decline in maximum subsidies over the period: 1 Eur/t in 2013 and 0.5 Eur/t in 2014 with no more aid from 2015 for the surface mining activity and 30 Eur/t in 2013 decreasing by 5 Eur/t every year thereafter to subterranean mining. Table 6 shows production programme according to the *Plan Marco 2013-2018* providing estimations for subsidized production and expected production until 2018. Unfortunately, only around 60% of intended production has been met in 2013 and 2014.

Tons	2013	2014	2015	2016	2017	2018
Maximum subsidized quantity	5,800,082	6,506,552	2,719,650	2,668,236	1,999,899	1,789,945
Underground	2,136,478	2,719,560	2,719,650	2,668,236	1,999,899	1,789,945
Open pit	3,663,604	3,786,992				
Expected production	6,554,447	6,819,914	6,708,679	6,570,798	5,959,861	5,837,407
Underground	2,761,919	2,903,809	2,723,617	2,668,236	1,999,899	1,769,945
Open-pit	3,792,528	3,916,105	3,985,062	3,902,562	3,959,962	4,067,462

Table 6_Expected total and subsidized coal production. Source: *Marco de actuación para la Minería y las Comarcas Mineras 2013 – 2018*

Table 7 below shows the progression of subsidies-cutting exercise until 2013 with a number of subsidies formally considered by the Ministry, not including additional support to HUNOSA from SEPI⁶⁷ (this not included in the table for the sake of clarity and simplicity).

⁶⁶ *Marco de Actuación para la minería del carbón y las Comarcas Mineras en el periodo 2013-2018.*

⁶⁷ Sociedad Estatal de Participaciones Industriales (SEPI).

Meur	2008	2009	2010	2011	2012	2013
Total operating cost	508.4	498.6	476.9	533.0	425.3	268.2
Private firm subsidies	249.0	244.1	240.4	229.1	111.0	38.4
Hunosa subsidies	78.6	78.6	79.2	72.5	57.2	77.9
Total	836.0	821.4	796.5	834.5	593.5	384.5
Aid per tonne (Eur)	32.89	27.39	33.26	46.55	27.55	31.07

Table 7_Operating aid to coal mining companies, 2008-2013. Source: Ministry 2014

As it can be seen operating cost support for hard coal production has declined substantially, reaching less than 400 MEur in 2013 from more than 800 MEur in 2008. This decrease has been significant not as much regarding unitary values per ton but in total value given the sharp production cutbacks until today.

In an effort to provide stability to the situation the European Commission has recently approved Spain's coal mine Closure Plan, on the basis that it complies with the requirements of the EU's 2010 framework on the closure of coal mines. The Closure Plan seeks to guarantee the orderly closure of 26 of Spain's coal mining units by the end of 2018. It includes €2.13 billion of government subsidies for aid to cover both, the production losses and the exceptional costs; the latter extended until 2021. As per the previous agreement on the Closure Plan, the receipt of this aid is tied to the requirement that mines benefitting from the help must close by the end of 2018. However, some concerns remain as to exactly when and how the Closure Plan will be implemented⁶⁸, which suggests that closing most of Spain's coal mines will slide beyond 2018.

Recently as of October 2016, the Council of Ministers approved to launch an additional €36.1 million, designed to alleviate the fall in prices of this mineral on the international markets. This new additional aid will amount to 10 euros per tonne for 2016 what results in a total amount of the aid for the coal mining sector in 2016 exceeding 60 million euros, this including ordinary mechanisms to support the sector of €25.3 million for 2016, and which operate as an exception to the close of the budget year. The aim is to fully cover the losses of the uncompetitive mines included in the Closure Plan, all of them underground.

⁶⁸ The fact that Spain has been without an elected government for almost a year and the difficulties expected to pass the General State Budget for 2017, may result on delays for the additional funds required to fund the closure aid programme in 2017.

It is not anticipated that state-aid support to the coal industry after 2018 will be allowed to sustain uncompetitive operations in the market place. As a matter of fact current plans to extend committed support with the mining industry until 2018 have not been fulfilled. In this sense, EU's necessary approval of any proposal from the Spanish Ministry will be a key issue in the following years. Although the European energy security strategy does not rule out explicitly the use of indigenous coal in Member countries as long as its use falls under general environmental policies⁶⁹, the need to create new and particular legislation that does not violate state-aid regulations will be a serious challenge for the Spanish coal sector.

3.6.4 Historical and current coal prices in Spain

Broadly speaking since the 80s, the working principle in the industry has been based on the commitment by the coal plants themselves to buy production volumes, very often on a long-term basis, and including some fringe benefits and in parallel coal mines receiving a subsidy on current production to balance their operating accounts. Benefits from this scheme for a structurally loss-making sector have always been considered regarding the final objective to improve the security of electricity supply overall. Within this plan, in 1998 domestic coal sales arrangements with electricity producers were formally liberalized and therefore coal plants started to negotiate supply alternatives, obviously limited by geography and by plant's design specifications. Coinciding with this liberalization process and the increasing competition, especially from CCGTs, pressure on prices and coal specifications resulted in growing pressure on mining operators. In some cases like the Galician plants, As Pontes and Meirama, plant owners were forced to convert the existing facilities to imported coal solely.

It is no surprise that the Ministry has done much to support both domestic coal and related electricity market operations. The best and most recent example of these efforts has been the latest piece of legislation providing support to domestic coal producers in 2011, i.e., RD 134/2010. This norm regulated, until the end of 2014, the dispatch and revenues of coal plants using domestic coal and has not been rolled out towards 2018. Interestingly and aside from purely regulated measures, the RD RGS can also be seen as an effort by the Ministry to be transparent in the coal sector and prepare the path for true competition past 2018.

Figure 25 shows a comparison of final cost of production equivalent to incomes from power producers plus premium from the Ministry⁷⁰ (solid dark red), imported coal prices at the gate (ex-ship)⁷¹ using an average transport cost for the sector (solid green) and the price agreed

⁶⁹ For example additional efforts in research, development and deployment of Coal Carbon Storage to fully benefit from this technology.

⁷⁰ Subsidy or premium in this case results from the difference calculated by the Ministry between production costs and incomes from power plants (not available for 2015).

⁷¹ From companies importing goods with the obligation to report the volumes and prices on a monthly basis.

between power plants and coal producers (dash) without premium. In addition, the international MCIS NWE benchmark is shown.

Figure 25_Evolution of imported coal in Spain and MCIS benchmark. Source: Ministry/Carbunion

Figure 25 shows that Spanish coal production has been heavily subsidized at a rather constant rate over international prices so that producers could compete with imported coal⁷². It is interesting to see that the cost of coal delivered at Spanish power stations (dash) more or less tracks the cost of coal imports, but with much less volatility this feature possibly coming as a result of a lagging effect embedded into the base price formula. As a consequence of this feature (similar in Germany and the UK) Spanish generators are typically protected from the price volatility due to having a significant proportion of their coal supplies with domestic producers. It has to be noted that prices quoted for domestic coal have been transformed at equivalent energy content of imported coal by year.

Figure 26 shows in more detail the breakdown of invoiced price plus the premium cost making the total cost of production (stacked bars) and against imported coal ex-ship. It also shows the yearly evolution of subsidies as the difference between production costs and imported coal ex-ship (dash on secondary vertical axis).

⁷² Year 2015 not included since data on the subsidies as a difference between incomes and expenses for indigenous coal production are not provided by the Ministry.

Figure 26_ Evolution of domestic coal producers' margins. Source: Authors based on Ministry

It can be noticed that the average premium over imported coal ex-ship benchmark stays at around 32 Eur/t over the whole period (dash red), increasing to 45 Eur/t in some cases, these variations, in general, are independent of changes in the world market.

3.6.5 Evolution of coal power generation

3.6.5.1. Government intervention

In line with old EU Directive 2003/54/CE and current Directive 2009/72/CE, Article 15.4, transposed into Law 24/2013, the Spanish Government 'for reasons of security of supply, direct that priority be given to the dispatch of generating installations using indigenous primary energy fuel sources, to an extent not exceeding, in any calendar year, 15 % of the overall primary energy necessary to produce the electricity consumed in the Member State concerned'. This provision has been the legal foundation for Ministry's decrees developed with the fundamental objective to guarantee that the coal-fired generation fleet will continue to operate as an essential element for the security of supply in Spain. It can be easily understood that these measures have been responsible for extended benefits achieved by coal plants associated with domestic coal but also for the survival of the mines supplying those plants.

The current Spanish Government has been negotiating (as the previous one) to smooth the transition to a subsidy-free sector in 2018. However, the stance taken by this Government seems to have been stronger, probably favoured by the economic crisis and that came less support for the sector overall.

As part of a protracted negotiation process with the coal sector and power operators, in 2015 the Government announced publicly that a new mechanism to support the generation from domestic coal up to 2018 was to be approved. As a matter of fact, a detailed proposal was sent to the CNMC in May 2015⁷³ to allow that necessary investment in emission reduction measures, although exclusively applicable for NO_x, could be considered a regulated expense to be remunerated by the electricity system. The mechanism would endeavour to ensure that at least 7.5% of the total generation comes from domestic coal in the future. In spite of these efforts by the Ministry, the CNMC rejected the proposal in September 2015 on the grounds of state-aid compatibility. At the moment is still unclear how the Ministry will manage this highly sensitive matter given the European directive. According to our understanding Red Eléctrica (REE), the System Operator continues to work on an operational proposal, which would imply a similar amendment of the day-ahead market implemented than the RD 134/2010. In any case, the initial intention to reach the already mentioned 7.5% of total electricity generation, seems far beyond a realistic target in the future given the clear commitment by regulators encouraging mine operators to downscale their operations.

3.6.5.2. Cost advantage of imported coal

Coal plants in Spain are located either around the major coalfields or near the coast enabling access to imported coal around the Spanish coast line (see Figure 27). Given that the internal coal market is an assortment of different types of coals, Spanish coal-fired stations are typically able to utilise a broad range of coal products in the blend. Although many issues have to be overcome to accommodate the optimum combination, sulphur, ash, volatile content and other properties can better be adjusted by blending.

As it was to be expected using coal available in each mining area is not the optimum way to operate a plant. The capacity to handle a broad variety of coal qualities is vital when adapting to changing conditions, for example, due to progressive depletion. In spite of specific quality issues, it is easy to understand that imported coal can displace domestic coal easily when either blending or market conditions suggest switching. Perhaps the most interesting example is Endesa's Teruel plant where due to the high sulphur content of the sub-bituminous coal in the area, it had to accommodate a blend of imported coals to operate at a much lower level of SO₂ emissions. Other good examples are As Pontes and Meirama power plants in Galicia (2 GW of generating capacity). In both cases and view of the cessation of domestic lignite production in 2008, both plants have been fully converted to burning imported bituminous coals from USA, Indonesia or Northern Europe already with a low sulphur content.

⁷³ *Propuesta de Orden por la que se regula el mecanismo de capacidad para la mejora ambiental en determinadas instalaciones de producción de electricidad. 27th May 2015.*

Figure 27_ Coal-fired power plants in Spain. Source: Authors

All of the 26 units currently in operation use imported coal, and just 11 units rely mainly on domestic coal. Plants at the coast in Andalucía, i.e., Los Barrios and Litoral have dedicated import jetties with conveyors linked directly to the coal storage piles for the power stations. In the North, the ports of Gijón (El Musel) and Aviles are linked by rail to the power stations of Aboño, Lada, Soto and Narcea. In the case of Endesa's Compostilla the alternative to use either Asturian or Galician ports is available. The port of Santander delivers to the Guardo plants either by rail or road transport. As Pontes and Meirama receive coal via the port of La Coruña and El Ferrol and Puentenuevo uses the Southern port of Huelva. It is apparent that in general all power plants are geared up towards burning imported coal, and even if the domestic industry declines, there appears to be little impediment to operations.

In regard to availability of the domestic coal base, in the long-term only Teruel mining area shows potential for scale of production what in turn will give impetus to imported coal to be increasingly used so plants can operate under satisfactory conditions in the years to come.

3.6.5.3. Environmental constraints

The operation of coal-fired power plants depends crucially on pollution control regimes. In Spain, these are largely determined by UNECE⁷⁴ protocols and EU directives, notably the National Emission Ceilings Directive (2001/81/EC), the Large Combustion Plants Directive (LCPD, 2001/80/EC) and the Directive 2010/75/EU on Industrial Emissions. In the case of Spain EU regulations have provided unifying guidance to set and establish clear objectives on the main environmental issues mainly related to three types of emissions: SO₂, NO_x, and dust. In parallel the Ministry has taken decided efforts to streamline those environmental objectives transposing the directives, in particular:

- Directive 2001/80/EC Large Combustion Plant Directive (LCPD) adopted through the National Plan for Reducing Emissions from Large Combustion Plants (PNRE-GIC)⁷⁵ includes all existing coal-fired power plants, i.e., commissioned before 1987 and sets obligations on emission limit values (ELVs) to be complied with by the end of 2015.
- Directive 2010/75/EU Industrial Emissions Directive (IED) repeals LCPD from 1st January 2016 and sets stricter ELVs and more thorough controls than the LCPD. From January 2016 existing LCPs shall ensure that their emissions into the air do not exceed the ELVs set out in Part 1 of Annex V of the IED.

In the 80s and 90s power plants, although complying with the required limits at the time of commissioning, had to adapt to successive new initiatives of environmental legislation. The increasing reduction in SO₂ soon after resulted in the installation of more efficient flue-gas desulphurization (FGD) equipment through retrofit programmes. In Spain, nearly all the plants built in that period have been fitted with FGD at basic levels. It has to be noted that to avoid excessive cost of running the FGD, power plants can also use blending so to reduce the load onto the FGD, although this will, in turn, affect plant's performance. Regarding reduction of NO_x emissions, power plants have been typically fitted with so called primary emission reduction methods like low-NO_x burners which still provide for a significant reduction of emissions globally.

Since the IED came into effect requiring further reductions in SO₂ and NO_x more investment in upgrading FGD and secondary emission reduction measures like selective catalytic reduction (SCR) has been made. As a consequence, the relative contribution of power plants to overall emissions declined substantially, especially for SO_x (decreasing from 70% to 40%).

⁷⁴ United Nations Economic Commission for Europe. UNECE

⁷⁵ *Plan Nacional de reducción de emisiones de las grandes instalaciones de combustión existentes. 2007.*

Figure 28 shows how SO_x decreased steadily between 2007 and 2010, by around 90%, whereas Figure 29 shows how NO_x has been reduced by about 20%.

Figure 28_ SO_x emissions by Spanish power plants. Source: LRTAP. Authors

Figure 29_ NO_x emissions by Spanish power plants. Source: LRTAP. Authors

Moreover, significant amount of particulates reduction was also achieved also due to flue-gas desulphurization (see Figure 30).

Figure 30_ PM10 emissions by Spanish power plants. Source: LRTAP. Authors

Also with the IED publication, the regulatory framework changed for all the existing installations. In short, the Directive offers two alternatives to allow some flexibility for compliance with the new standard:

- The Transitory National Plan⁷⁶ (PNT) prepared by the Ministry provides for the possibility for certain LCPs to operate for complying with the ELVs for SO_x, NO_x, and dust, as set out in part 1, Annex V of the IED, from 1st January 2016 until 30 June 2020. However, every PNT shall include detailed information on the necessary measures to guarantee that each plant complies with the ELV's set out in the IED as of 1 July 2020. In particular, the PNT ensures that all the LCPs included in the plan make the necessary upgrades to achieve the required reduction in emissions while continuing to operate. The IED sets minimum limits for emissions of SO_x, NO_x, and dust to the air from LCPs with a thermal rating equal to or greater than 50 megawatts. The PNT scheme also allows LCPs but only to those licensed before 27 November 2002, to trade their annual allowances for sulphur dioxide, nitrogen oxide and particulate matter (dust) with other LCPs within the PNT scheme without interrupting operations in a significant manner.
- To be specific, the PNT calculates, for each installation, total emissions by pollutant 'ex-ante' in tons derived from new emission limits and expected production. Consequently, the PNT controls that every facility complies with the maximum emission allowed every

⁷⁶ Plan Nacional Transitorio. November 2015.

year with no further obligations for the LCDs as long as total emissions between 2016 and 2020 do not reach maximum emissions for the plan. Figure 31 shows the decline in the level of emissions, in absolute terms, expected at the end of the period 2016-2020 and compared with 2011-2013 average emissions (dash) assuming all LCPs involved fulfill the necessary investment to reach those levels.

Figure 31_ SO₂ - NO_x and PM₁₀ limits in Spanish PNT vs. average in 2011-2013. Source: Ministry

- The Limited Lifetime Derogation (LLD). The IED allows certain LCPs to be exempted from meeting the ELVs and desulphurization rates set out in the IED, provided that they are not included in the PNT, i.e., they opt-out from committing to 2020 emission levels despite fulfilling certain conditions. One of them, the most important is the obligation to submit to the competent authority a written declaration confirming that the plant will not operate for more than 17,500 hours starting from 1 January 2016 and ending no later than 31 December 2023.

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CHAPTER 4. ANALYSIS OF THE TRUE NATURE AND PRICE LEVEL OF SPANISH COAL PRICE THROUGH EVIDENCE-BASED DECISION-MAKING

Given the complexity of the coal sector in Spain against the background of a number of political, entrepreneurial and socioeconomic factors, a more in depth evaluation of the true market price of Spanish coal looking forward is needed. In this manner, we can be certain that the coal price benchmark used for later analysis is in line with market expectations and therefore helps to obtain consistent results. As already discussed, in traded markets there is a close relationship between gas and coal where the relative level of prices drives gas for coal switching in the power sector what in turn moves power sector gas demand. Even if this market mechanism does not directly affect long-term gas prices, it may influence gas prices at the margin and therefore altering Spanish gas average price. This chapter analyses the complexity in the coal industry, with the main objective to evaluate the potential for Spanish coal price convergence. In order to do that, we have to assess the economic feasibility of alternatives in the Spanish coal mining sector in the long run.

4.1 Introduction

Multi-Attribute Utility Theory (MAUT)⁷⁷ is a structured methodology designed to handle the tradeoffs among multiple objectives that fit perfectly within our objective in this chapter and on which we will base our assessment on Spanish coal dynamics. In order to proceed, we split our work into three areas of competence, i.e., mining region, mining technology and type of coal, to analyse which is the optimum alternative within each class and for a variety of criteria. In this way, the study provides a view of the likely path forward associated with alternative scenarios producing a set of pricing outcomes. As a result, we also offer a view on indigenous production costs against competition with imported coal in the future as well as on potential charges for the future design of an Emergency Plan for security of supply reasons.

As regards the applicability of this chapter's research and aside from price determination, we believe it may contribute to both energy planning and sustainability of energy systems (Cartelle-Barros, 2016) as it provides a compilation of preferred options for a mining plan over time. In order to do that, the study considers the main drivers behind those options, i.e., attributes in the model, affecting that plan. Particularly relevant to our study is the recently approved Closure Plan by the EU based on the previous EU's framework setting the requirements necessary for closure of coal mines. As per previous legislation, mines included in this plan and benefitting

⁷⁷ The meaning of this term in the setting of Multicriteria decision-making relates mainly to optimizing the use of a scarce resource like coal in light of specific criteria or attributes.

from aid to this end must close by the end of 2018. In this sense, it might seem reasonable to assume that in line with EU energy supply security policies, the Spanish Government should devise a new mechanism mainly as an extension of the current Closure plan to implement a reserve access scheme. This action plan would allow mining companies participating to remain operational for security reasons.

It needs to be highlighted that the intention at this stage is not to solve a mathematical energy resource allocation problem leading to production volumes estimates but rather provide an objective picture of expected coal price levels and despite the likely influence of subjective appreciations such as environmental or social responsibility issues. Regarding additional benefits provided, we believe that globally it will help agents to better understand the repercussions of the major restructuring process in the Spanish coal sector and also to figure out what will be the role of domestic coal in the coming years. More widely, the study might contribute to understand better potential for further Government decisions and policies affecting coal mining in Spain.

4.2 Materials and definition

The data used in this study are those provided by the current Ministry of Energy, Tourism and Digital Agenda (Minetad)⁷⁸, related to coal mining production for years 2008 and 2013⁷⁹ by product, i.e. anthracite, bituminous coal ('hulla') and sub-bituminous coal ('lignito negro'), published by province, aggregated by region, i.e. Asturias, Castilla y León, Castilla La Mancha and Aragón and available with a breakdown by technology, i.e. surface (OC) and underground (SUB) mining. Operating costs include all operating expenditures such as labour, supplies and materials, equipment operation and miscellaneous costs incurred at the mine site, including supervision, administration, and on-site management. Costs, however, do not include exploration, permitting, or milling and are expressed in eur/ton.

4.2.1 Operating cost and productivity by product

Regarding productivity performance, the picture of Spanish coal mining facilities shows a wide variety of outcomes. Figure 32 shows productivity against operating expenses⁸⁰ by the three coals currently produced in Spain and its evolution from 2008 up to 2013 as a snapshot. Unit costs and output within the lower right quadrant represent the most desirable outcome

⁷⁸ Former Ministry of Industry Energy and Tourism (Minetur).

⁷⁹ It needs to be noted that although data for 2014 is available at the end of 2016, data from 2013 has been used. The fact that 2014 is a particularly controversial year due to both rapid regulatory changes and abnormal climate conditions, this leading to erratic operations of coal power plants using indigenous coal, justifies that.

⁸⁰ For the analysis of operating costs in this section an equivalent calorific value of 6,257 kcal/kg has been used to derive tonne coal equivalent (tce)

(lower unit costs and higher output per employee per year). The relative market share of each product is represented by the size of the bubble.

Figure 32_Coal mining productivity vs. operating costs by product in 2008 and 2013. Source: Ministry/Authors

An examination of each coal product can deliver useful insights into its path towards higher productivity. Sub-bituminous processing has made significant efforts to boost its productivity while maintaining the same level of operating costs over the period. However, for bituminous coal and especially for anthracite, which accounts for about 17% of total production, productivity has not improved while operating costs across the 2008–2013 period have increased by about 15% and 30% CAGR respectively. These results illustrate how reducing the scale of mining operations has had undesirable economic repercussions for productivity related factors (Kuby and Xie, 2001).

4.2.2 Operating cost by region and by mining operations

About operating costs by type of mining operations and by region, Figure 33 shows a comparison of anthracite indicating lower subterranean operations (SUB) costs versus sub-bituminous with the lowest cost including opencast operations (OC).

Figure 33_ Coal mining production by region. Imported coal equivalent 2013. Source: Ministry 2013.

As it can be seen Asturias clearly shows the highest cost, curiously at opencast not at subterranean, far from being sustainable in the long-term. Bituminous coal with equivalent costs⁸¹ (not shown) of between 83 Eur/tce for subterranean and 91 Eur/tce for opencast, show some potential for further operations in the North of Spain and Puertollano but far from price advantage of sub-bituminous coal in Teruel area.

4.2.3 The model

Multi-Criteria Decision Making (MCDM) is a well-known branch of a general class of operations research models which deal with decision problems under the presence of some decision criteria. Several methods have been developed in different categories, i.e., priority based, out-ranking, distance based, etc. Pohekar and Ramachandran (2004), sharing common characteristics related to the conflicting evaluation of alternatives due to incomparable units or difficulties in the selection of alternative options. In particular, we will consider multi-attribute decision analysis (MADA) methodology where a small number of alternatives are to be evaluated against a set of attributes some of which might often be hard to quantify⁸². In this

⁸¹ Cost data facilitated for bituminous coal by the Ministry of Industry do not differentiate by region.

⁸² Another well-known branch of decision making is multiple-objective decision making where the alternatives are not predetermined but instead a set of objective functions is optimized subject to a set of constraints.

sense, the best alternative among other comparable is selected concerning each attribute. The MADA process consists of four stages according to Clemen and Reilly (2001): the framing of the decision and identification of the goals, identification of all decision alternatives and any related attributes, the specification of preferences and finally ranking of the decision alternatives.

A wide variety of methods within a MADA framework exists, which differ mainly on the different screening process used about the various alternatives to arrive at a dominant one. Among those, we have selected a multi-attribute utility theory (MAUT) method (see Wallenius et al., 2008) to both formalize a common unit's assessment but also specify the decision maker's preferences for each attribute based on the potential utility of outcomes. This method allows for an objective evaluation of performance with a quantifiable outcome given that the nature of the information provided can also be quantified, in our case, mainly operation costs and productivity values furnished by the Ministry as well as relevant information on installed capacity by region using domestic coal or average distance from ports. It needs to be noted that MAUT methods have been widely used for decades and a significant amount of literature is available. Therefore we believe that the model selected includes all the necessary elements to make a sound judgment (Keeney and Raiffa, 1976). Examples of other methods available based on different postulations such as outranking procedure (ELECTRE and PROMETHEE), establishing preferences (AHP and ANP), and those grounded on the concept of analyzing distances to the best solution, such as TOPSIS (Munier, 2011) could also be considered in the context of future work.

It is important to note that preferences for decision-making using MAUT take the form of a particular utility function which is defined over each attribute. The utility functions mathematically transform initial values, e.g., operations costs into utility values which are set on a normalized scale, 0 to 5 in our case. Once the preferences for individual attributes have been specified, then the decision-maker can establish preferences between the attributes by specifying the weights in a multi-attribute utility function. The multiplicative form of the equation for the utility value is defined as follows:

$$1 + ku(x_1, x_2, \dots, x_n) = \prod_{j=1}^n (1 + k_j u_j(x_j))$$

Here j is the index of the attribute, k is overall scaling constant, weight or importance of criterion (or attribute) with k_j being the scaling constant for attribute j . $u(\)$ is the overall utility function operator whereas $u_j(\)$ is the utility function operator of alternative x for each attribute j (Vincke, 1992).

Finally, based on the findings, we create two different scenarios forward: high-demand (short-term) and low-demand (medium and long-term), mostly depending on demand conditions to summarize and describe the evolution of indigenous coal production in the future.

4.2.4 Empirical results

In this section, we examine the long-term performance of existing coal deposits in Spain using structured MAUT methodology. As discussed three groups determining a range of different alternatives are analysed, i.e., Geographical location, mining technology, and coal type. By each of classes some comparable options arise as follows:

1. Geographical location: Asturias, Castilla y León (CyL), Castilla La Mancha (CM) and Aragón.
2. Mining Technology: Opencast mining (OC) and subterranean mining (SUB).
3. Coal type: Anthracite, Bituminous and Sub-bituminous.

In order to assess the performance of each alternative, we define a set of criteria (attributes) which will deliver an assessment for each option within each. Table 8 shows the characteristics of the different criteria considered each of them introducing concepts and parameters with economic interpretation.

Criteria	Definition
Operating cost	How expensive in eur/ton equiv is the operation of mining considering a weighted average of actual production by region, technology or by product
Productivity by coal type	Average measure of efficiency of production expressed as the ratio of output to man/year, i.e. output per unit of input. (Ton/manyear)
Operating cost by OC mining	How expensive in eur/ton equiv is the operation of surface mining (OC) considering a weighted average of production by region or by product
Operating cost by SUB mining	How expensive in eur/ton equiv is the operation of subterranean mining (SUB) considering a weighted average of production by region or by product
Operating cost in Asturias	How expensive in eur/ton equiv is the operation of mining in Asturias considering a weighted average of production by technology or by product
Operating cost in CyL	How expensive in eur/ton equiv is the operation of mining in Castilla y León considering a weighted average of production by technology or by product
Operating cost in CM	How expensive in eur/ton equiv is the operation of mining in Castilla La Mancha considering a weighted average of production by product
Operating cost in Aragon	How expensive in eur/ton equiv is the operation of mining in Aragón considering a weighted average of production by technology or by product
Coal Plant dependence	How much dependence from coal plants nearby is expected in MW. A high degree of dependence is good for mines nearby survival
Difficult access to imported coal	Logistics costs in average distance from port. A high value is good for mines nearby survival

Table 8_Description of Criteria. Source: All operating costs provided by the Ministry and authors' calculations. Coal Plant dependence data based on installed capacity data provided by the Ministry. Difficult access to imported coal data provided by Ministry.

In order to begin the optimization process, an initial evaluation of the different alternatives that could succeed in resolving the problem by class and versus each criterion is

performed. It needs to be noted that results show values relative to their production units in Eur/ton, in MW equivalent to assess coal plant dependence and in Km from port per MW equivalent to assess average proximity to importing facilities.

Table 9 shows data corresponding to different alternatives within each class.

Alternatives	Mining in Asturias	Mining in Castilla y León	Mining in Castilla la Mancha	Mining in Aragón	Opencast mining	Subterranean mining	Anthracite mining	Bituminous mining	Sub-bituminous mining
Criteria	1	2	3	4	5	6	7	8	9
Operating cost	88,7	90,1	87,5	72,6	82,0	81,1	92,3	87,5	72,6
Productivity by coal type	-	-	-	-	-	-	749	1.032	10.555
Operating cost by OC mining	141,4	95,9	87,5	72,9	-	-	112,3	91,1	72,9
Operating cost by SUB mining	83,1	83,7	-	71,2	-	-	82,5	83,8	71,2
Operating cost in Asturias	88,7	-	-	-	141,4	83,1	80,4	87,5	-
Operating cost in CyL	-	90,1	-	-	95,9	83,7	96,5	87,5	-
Operating cost in CM	-	-	87,5	-	87,5	-	-	87,5	-
Operating cost in Aragon	-	-	-	72,6	72,9	71,2	-	-	72,6
Coal Plant dependence	714	1.761	312	1.050	-	-	929	929	1.050
Difficult access to imported coal	0,2	0,6	0,7	0,8	-	-	0,5	0,5	0,8

Table 9_MAUT Original units. Source: Authors

Table 10 shows normalized values obtained on a 0-5 scale using an appropriate scaling factor through linear interpolation. It also shows relative weightings for each criterion to give them their relative priority in the decision. A simple approach we use is to give the most important criterion a weight of 25% and then assign weights to the rest based on that standard. Table 10 lists the criteria and weights developed in this manner using authors' experience and coal market experts' opinions. Access to imported coal is the most important criterion in the decision, with operating costs by a region having low weights.

Alternatives		Mining in Asturias	Mining in Castilla y León	Mining in Castilla la Mancha	Mining in Aragón	Opencast (OC) mining	Subterranean (SUB) mining	Anthracite mining	Bituminous mining	Sub-bituminous mining
Criteria	Weight	Geographical location				Technology		Product type		
Operating cost by coal type	10%	2	1	2	4	2	2	1	2	4
Productivity by coal type	13%	-	-	-	-	-	-	0	0	4
Operating cost by OC mining	8%	0	1	2	4	-	-	0	1	4
Operating cost by SUB mining	8%	2	2	-	4	-	-	2	2	4
Operating cost in Asturias	4%	2	-	-	-	0	2	2	2	-
Operating cost in CyL	4%	-	1	-	-	1	2	1	2	-
Operating cost in CM	4%	-	-	2	-	2	-	-	2	-
Operating cost in Aragón	4%	-	-	-	4	4	4	-	-	4
Coal Plant dependence	20%	2	5	1	3	-	-	3	3	3
Accessibility to imported coal	25%	1	4	4	5	-	-	2	2	3
Weighted Scores		1,1	2,3	1,7	3,1	0,5	0,5	1,6	1,9	3,1

Table 10_MAUT Normalized units. Source: Authors

As it can be seen, our research shows that sub-bituminous mining operations in Aragón offer the best performance and optimum operating conditions way ahead of any other region (dark green). Regarding which of the other three regions could be addressed as a long-term alternative for the energy security of supply, possibly Castilla y León would be the preferred option (light green). Interestingly, when the analysis is made regarding technology both surface and underground mining show a similar degree of attractiveness what indicates that technology factors have limited capacity to discriminate between alternatives and therefore it is expected that variations in this criterion, for example performing a sensitivity analysis, would not influence the decision. In terms of product type, sub-bituminous coal production seems to be without any doubt the clear winner.

As discussed, we can use the results of our research as a platform to advance future developments of the coal mining sector. In this sense we can anticipate at least two different scenarios mostly depending on demand conditions that could summarize expected evolution, as follows:

4.2.4.1. High-demand scenario. Short term.

In the high scenario, actual availability of coal can maintain ongoing mining operations in the North of Spain, and eventually, domestic coal supply reaches a reasonable share of total electricity generation. In this situation, domestic coal can be considered an appropriate complement to imported coal providing back-up when necessary. Under this scenario, mining activities in Asturias and Castilla y León can maintain a minimum scale of operations either opencast or subterranean. In the case of production in the area of Teruel production can be considered to be stable.

4.2.4.2. Low-demand scenario. Medium and long-term.

In the low scenario, coal plants have been adapting to using mostly imported coal as a result of uneconomical domestic coal supplies, except for the ongoing production of sub-bituminous coal in Aragón. In this scenario operations in the Northern part become increasingly downsized, and mines in that area remain fundamentally as backup support to operations with Castilla y León the best placed to stay as the preferred mining area serving for energy security reasons.

4.3 Conclusion

Using MCDM (Multi-Criteria Decision Making) and multi-attribute utility theory (MAUT) methodology to advance future developments in the Spanish coal sector, enables us to provide evidence to support the importance of imported coal's role in the dynamics of Spanish energy sectors and especially in the natural gas sector. The scope of the investigation is extended to draw out insights in respect of coal's overall contribution to energy security in the future.

Our results indicate that despite the reasonable availability of coal resources in the North of Spain, both in Asturias and Castilla y León, the only alternative that can be regarded commercially viable on an ongoing basis, seems to be opencast sub-bituminous coal production in Aragón. Production costs of coal in all regions except Aragón in the area of 90 Eur/tce⁸³, appear to be far away from a reasonable benchmark to compete against imported coal in the future. Also, we anticipate that only mines in Castilla y León, apart from those in Aragón, are in a position to be considered for energy supply security in the future. The proximity of Asturias' mines to the coast put them in a difficult situation to continue operating in the future given the competitive conditions of imported coal globally.

⁸³ 6,257 Kcal/Kg High Calorific Value, this is equivalent to around 80 Eur/tce of imported coal quality in 2014.

Based on these results it can be advanced that although in the short term mining areas in the North of Spain will continue to produce, in the medium and long-term, only sub-bituminous opencast mining activities in Aragón would remain competitive against international coal price benchmarks. Even more importantly, given the scale of the business, imported coal price will determine the reference cost base of Spanish power plants and therefore will also render the benchmark price (import parity price) comparable with the price of gas to produce electricity. In this sense, we conclude that the use of the price of coal on the international market proves to be justified as coal price benchmark for further analysis focusing on long-term dynamics.

CHAPTER 5. ANALYSIS OF DETERMINANTS OF SPANISH WHOLESALE GAS PRICES

Although in traded markets natural gas prices are mainly a function of market supply and demand, long-term gas contracts retain their essential characteristics over time, especially oil indexation, which makes price variations mainly dependant on structural determinants of the base price. Probing this, price escalation mechanisms and the influence of the components in the traditional netback formulae are relevant factors to be taken into account when setting long-term gas prices as much as gas market trends. In this chapter, we unveil which are the different elements that drive Spanish long-term gas prices, and we also quantify the association between variables using correlation and regression tools. The analysis in this chapter can be considered as a stage preliminary to subsequent core research on both analysis of fundamental value and commodity market dynamics.

5.1 Introduction

Energy commodity prices including electricity prices are expected not to be independent of each other as they are naturally influenced by economic forces and market agents with different intensity. This means that energy commodities might be tied up showing a different level of relationship in both the short and the long run.

In this sense, price correlation, a relatively straightforward metric but extremely informative about the co-movements of prices or returns, can be used to analyse short term links previously to describe any dynamic causal relationship in the long-term. As it is well known, estimated correlations may be unstable or spurious when time-series are typically described as nonstationary processes, and their economic interpretation will not be meaningful⁸⁴. Despite this and the likely possibility for the energy variables analysed to be non-stationary, the correlation coefficient will show useful time changing structures over the selected period.

At this point, to determine in the clearest manner the main factors determining Spanish gas prices, a pre-selection of best predictors is performed. In the light of experience gained on the ground⁸⁵ and previous research, see Cansado-Bravo and Rodriguez-Monroy, 2013; 2016, there is a previous choice of a range of variables that may be affecting SGP based on their direct links through the gas price formula including gas to gas competition price markers. Consequently, we analyse in which manner that linkage manifest, e.g., when lagging effects are more visible and therefore which predictor would be the best to be included in a regression

⁸⁴ A spurious regression occurs when a pair of independent series, but with strong temporal properties, are found apparently to be related according to standard inference in an OLS regression

⁸⁵ Numerous public industry researches as well as strictly confidential pricing terms (more than 40 different contract prices in total) have been gathered for this purpose.

model⁸⁶. After this, consideration is given to defining the best regression model that does not degrade the quality of the OLS regression estimates and therefore does not lead to the confusing identification of effects. It has to be noted that along this chapter we are mainly interested in how one variable's value could predict the value of another, and therefore we use absolute values. A simplified example of a similar case only connecting Spanish gas prices and Brent would be a simple linear regression such as $P_{SGP} = a + b (P_{brent})$. It has to be noted that if we transformed this into a regression between returns, we would be trying to determine how the variations are correlated which would also imply a base effect much less useful for our purpose here.

5.2 Materials and definition

Before diving into more sophisticated selection techniques, an individual assessment of most typical components in the long-term gas base price formulae is needed. It has to be noted that the quality of the data is the highest as it is provided by reputed international sources aiming to improve their calculation methodology constantly.

5.2.1 Brent Crude Oil price (US dollars per barrel).

Brent crude oil price can be considered the main exogenous factor explaining gas prices mainly because it is very frequent links through the gas base price formula calculation. Out of experience on gas contracts but also based on the characteristics of oil indexed swing options in Europe, we know that some formulas are more popular than others. Examples of common formulas in Spain are 3-3-1, 3-1-1, 6-0-1 and 6-1-3⁸⁷. It has to be noted that although long-term gas price formulas are regularly reviewed through contractual negotiations, price reviews do not substantially affect the base price formula calculations. It is also worth mentioning that although Brent price swings are daily,⁸⁸ we will strictly consider the application of monthly gas prices based on a rolling average of past oil and refined products prices.

In Figure 34 we compare the different lags to start calibrating the regression model. Gas prices are normalized values in respect of Brent oil prices and not in \$/MMBtu to better notice how the different rolling Brent lines fit with the red SGP line.

⁸⁶ Predictors in dynamic regression models may include lagged values of exogenous explanatory variables (distributed lag, or DL terms), lagged values of endogenous response variables (autoregressive, or AR, terms), or both.

⁸⁷ Oil price indexed formulas typically consist of three parameters: the number of averaging months resulting in a gas price that is the average of past oil prices within a certain number of months, the time lag that determines the time lag between the months the average is taken of and the months the price is valid for and finally the number of validity months setting the number of months for which the price is valid.

⁸⁸ Daily Brent price movements especially affect gas operations since the closer to the fixing day the more prices for averaging are known and therefore players can better advance opportunities to buy gas and store it.

Figure 34_Selection of oil price lags. Selection of price lags

Not surprisingly it can be seen from the chart that B613 is the Brent series that would correlate best with Spanish gas prices. Table 11 shows the strength of the different price lags correlation to SGP showing similar values for B601 and B613 of 0.98, higher than the rest.

Table 11_ Pearson's linear correlation analysis of selected variables

However, the analysis of the four different lags considered in isolation gives an R^2 value of 0.969 for B613 slightly higher than that of B601 (0.958). Based on the experience gathered, these results confirm that the more common indexation in long-term gas contracts in Spain is the reference to a six month rolling average of Brent price with one month lag valid for the following three months. Other contracts signed on a three and nine months rolling average basis seem to be less frequent.

It has to be noted that at this point other tests including the t-test to evaluate the significance of predictors, and the F-test, which is used to assess the joint significance of the entire lag structure are not considered necessary.

5.2.2 Gasoil and Low Sulphur Fuel Oil (US dollars per ton)

As explained and arising as a result of the main pricing principle dominating Europe, a substantial part of Spanish long-term contracts are also indexed to refined products in addition to Brent oil price. Although some old contracts included HSFO as an index after being banned by the EU this index has been replaced. As with Brent oil indexed contracts, oil products indexation

intents to find a reference price through changes in the prices of fuels assumed to be closest competitors of gas.

After the analysis to determine Brent oil price best fit and for consistency, we will consider GO601 and LSFO601 as initial parameters for our regression exercise expecting that both will improve SGP predictions and model fit. Using, in this case, a moving average instead of a step function will simplify calculations with no effects on the results of the analysis. Figure 35 shows the exceptional fit of GO601 and to a lesser extent of LSFO601 with SGP.

Figure 35_ GO601 and LSFO601 vs. SGP

5.2.3 Coal (US dollars per ton)

As discussed, the most visible link between traded gas and coal prices is found when analyzing operations at the electricity market by gas and coal-fired power generation plants in spite of direct links found in some long-term gas contracts. In this respect, the decision to generate electricity or not, will depend on the relative position of the spark spread for CCGTs relative to the dark spread for coal plants, i.e., it is the relative level of gas against coal prices rather than the absolute gas price levels which determines gas advantage versus coal in the power sector. Particularly relevant in this case is the fact that there is a market-related relationship between gas and coal prices as they are substitutes for electricity generation. In this sense and given the rigid structure of long-term gas pricing, coal price links with Spanish gas

prices seem further away than for oil prices. Moreover, the potential relationship between coal and gas may break down in the case one of the energy sources is affected by a structural shock⁸⁹. In the case of Spain, since gas contracts are strongly tied to oil prices, oil and coal price movements compare directly regarding open scope for cheaper coal for electricity production at the margin. In this sense, only a remaining balance to be satisfied by marginal gas may compete with coal in the short-term. Figure 36 illustrates the normalized prices of coal and SGP since 2002 showing periods of relative competitive advantage between the two.

Figure 36 _Coal vs. SGP

As it can be seen, and despite the lagging effects embedded in SGP, both commodities run very much in parallel despite different paths in the short-term. The fact that oil and coal markets are interconnected globally under economic fundamentals⁹⁰ explains those similarities between coal and SGP. Interestingly, there are similar reactions to significant events like the

⁸⁹ In the case of traded gas markets this could be applicable to structural shocks in demand or production as in the event of shale gas boom in the US.

⁹⁰ At fundamental market level, firstly, a rise in oil prices leads to a rise in fuel costs for coal producers. Secondly, a rise in crude oil prices also reflects positive sentiments for the overall energy sector. Energy stocks, including coal stocks, generally follow crude oil prices. .

2008 financial crisis or the serious downturn in crude oil prices at the end of 2014 pulling all energy-related stocks, including coal stocks, down.

5.2.4 National Balancing Point (NBP) (US dollars per MMBtu)

The spot market for LNG in Spain may still be small relative to the contract market, but it is important when traders set prices at the margin. We consider that the NBP market, the most liquid in Europe, is the one that would better represent the potential for hub pricing influences into Spain in the long-run. This is due not only to the fact that NBP prices provide a clear benchmark for LNG short-term trade in Europe but also because it is the most liquid gas hub keeping US HH aside. Moreover, other liquid hubs that could have been considered in the analysis, e.g., TTF or Zeebrugge are highly correlated with NBP and therefore would not add substantial inside into the study. It is important to highlight that during the analysis, the NBP benchmark in addition to being a reference for marginal market pricing globally, reflects supply-demand dynamics of the gas market in the UK⁹¹.

Figure 37 shows the different dynamics of NBP and SGP despite the potential for a similar long-term mean reversion pattern.

⁹¹ By 2010, spot gas price indexation accounted for approx. 90% of all gas sales in the UK, whereas only for 25% in Continental Europe (Koenig 2012).

Figure 37_ NBP vs. SGP

5.2.5 Spanish Electricity Marginal price (SMP) (US dollars per MMBtu)

As discussed, although gas markets and electricity markets are interconnected, the resulting electricity wholesale price (SMP) is influenced itself by another large number of interacting forces. In Spain and under real competitive bidding conditions, the resulting SMP is predominantly determined by the cost of gas, given the role of CCGTs in setting marginal prices. So it is essential to focus on spark spreads, or gas plant generation margins when assessing electricity prices. Furthermore and although a basic feature of efficient market hypothesis is the absence of correlations between price increments over any time scale, what should be leading to a random walk-type behavior of prices, recent studies like Alvarez-Ramirez and Escarela-Perez (2008; 2009; 2010) have suggested that this is not the case, and correlations are present in the behavior of diverse electricity markets. They show that over a wide range of time scales, electricity prices are multi fractal, an indication that electricity price formation is a complex process involving not only power supply and demand factors but also market design or the market power of incumbents as price drivers.

Other authors also confirm that a quite sophisticated approach like cointegration analysis under multi-market conditions connecting the different single-market spot-price models, is needed to investigate the medium and long run relationship between electricity

prices and SGP, (Gjølberg, 2001; Panagiotidis and Rutledge, 2007; De Jong, 2009). In particular from the results found by D'Ecclesia (2012)⁹² evidence of the existence of two cointegrating relationships were found, i.e. one common (stochastic) trend among the three commodity price series using the Johansen method but also a common trend that may be interpreted as a source of randomness (the oil market) affecting the dynamics of the two other commodities (electricity and gas).

Interestingly in respect of the Spanish gas and electricity markets, see Figure 38 below, SGP prevailing tendency for growth since 2008 has not been transferred into Spanish electricity market prices this mainly as a result of the impressive new renewable capacity expansion in Spain and diminished thermic gap available to operate CCGTs. In this sense, possibly one of the most relevant investigations on this matter, i.e., Furió and Chuliá, 2012 reveals that Spanish electricity forward prices show causation effects, both in price and volatility, from Brent crude oil and natural gas forward markets in Europe. As a consequence of these results, it is easy to conclude that Spanish gas prices, those setting electricity prices at the margin but also embedding a direct link with Brent prices, are truly connected with electricity prices in Spain. These results are of practical importance for both the wholesale and retail gas and electricity markets' participants as well as the regulator.

⁹² D'Ecclesia study analyses the interaction of Brent oil price, NBP price and EEX electricity indexes.

Figure 38_ SMP vs. SGP

5.2.6 Consumer Price Index Consumer

Index prices are also typically embedded into long-term formulas as a reference to update base gas prices regularly. For our exercise, the Spanish IPC⁹³ has been used. Moreover, we will take the view that economic growth although at the local Spanish level, provides valuable input to the equation regarding the income elasticity of energy demand changes in Spain.

5.2.7 Euro-dollar exchange rate

Due to the nature of oil and oil prices quotation in dollars, exchange rates are also included in the purchase formula of long-term gas contracts. As one may think, understanding exchange rates is complex since currencies and commodities are deeply interconnected. For example, oil-dollar interaction works both ways and not only because the weakness of the dollar is translated to a higher oil price, but also because oil prices in relation other currencies can exercise pressure on the dollar as well. To make things even more severe depreciation of the

⁹³ Índice de Precios al Consumo IPC is Spanish official CPI index.

dollar, for example, will also affect the cost of other imported goods to the extent that domestic goods and services might be substituted for imports in response to the decrease in the relative cost of purchases from abroad, i.e., purchase parity arbitrage.

Due to all this, of all the effects analysed in this Chapter, probably the euro-dollar exchange rate is the less obvious candidate for our final list of predictors and a clear relationship with SGP is not anticipated. However and in line with our intention to provide at least initially a list of best potential regressors for SGP, a typical average euro-dollar 3-0-3 index used in long-term gas indexation formulas has been selected. Figure 39 shows that despite strengthening of the dollar, SGP as well as oil prices, have been following a growing trend until the second part of 2014. Since then, stronger dollar conversion runs in parallel with weaker oil prices as it would be expected.

Figure 39_IPC and Ex rate €/€ vs. SGP

The table below shows a summary of variables and acronyms considered in this chapter.

Type	Factor	Description	Units
Response variable	SGP	Monthly Spanish Wholesale gas price	\$/MMBtu
Explanatory variables	Oil and oil products		
	B613	Average price of previous 6 months valid for next three months	\$/ton
	G601	Average NWE Gasoil FOB 0.2% S price of previous 6 months for current month	\$/ton
	LSFO601	Average NWE LSFO FOB 0.1% S price of previous 6 months for current month	\$/ton
	Gas market		
	NBP	Monthly average spot NBP	\$/MMBtu
	Other markets		
	Coal	Monthly average McCloskey ARA Coal price	\$/ton
	ED301	Average euro_dollar exchange rate of previous 3 months for current month	€/€
	Spanish market		
	IPC	Monthly Consumer Price Index published by INE	-
	SMP	Monthly average Spanish electricity pool price	€/MWh

Table 12_ List of variables considered in the analysis

5.3 Analysis of correlations

Before using more automated selection techniques for the best predictors, we will qualify linear relationships between each of the pairs of variables initially selected. Calculating linear correlations before using diagnostic tests is a useful way to identify which variables have a more straightforward relationship. Moreover, examining scatter plots of the cross-correlations give a very useful information about covariation⁹⁴ of the selected variables to anticipate future regression quality. We understand that the period considered for the analysis, i.e., 15 years of monthly observations for each of the variables, determines a sufficiently wide range of observations avoiding underestimation of the correlations involved.

Some other factors behind the interest in correlations are:

⁹⁴ Covariance quantifies the strength of a linear relationship between two variables in units relative to their variances. Correlations are standardized covariances, giving a dimensionless quantity that measures the degree of a linear relationship, separate from the scale of either variable.

- Since the ultimate objective of the correlation analysis is mainly to increase forecasting accuracy to a later extent, in general, low correlated variables will be less useful than high correlated assuming representative sample sizes.
- We will assume, according to Cohen (1988) that correlation coefficients less than 0.10 are considered to be low, $r=0.30$ a moderate relationship and $r=0.50$ strong relationship. Although we understand that in general low correlations could arise as a result of contamination by other hidden variables, in our case and assuming commodity prices, reflect fair market conditions, a correlation lower than 0.30, normally considered the observable relationship by chance, would be unlikely.
- Cohen (1988) also shows that for a power test of 90% (90% of probability to reject or not accept the null hypothesis of no relationship in the case that is false) the minimum size of the sample would be 113 that is much lower than our sample of 180 historical SGP values. It is important to mention that for extrapolation in the future; we will be able to extrapolate the relationship effect (different from zero) but not its dimension.

Results from cross-correlations (Pearson's linear correlation coefficient) of selected variables in addition to those already shown in Table 11 are presented in Table 13 below:

Table 13_ Pearson's linear correlation analysis of selected variables

As it can be seen, correlation of SGP is substantial with NBP and IPC prices. All p-values⁹⁵ between pairs of variables are small, i.e., less than 0.05 and therefore all correlations are significantly different from zero what is a promising initial result. It is most remarkable the extremely high correlation of SGP with the IPC, i.e., 0.78 this possibly as a consequence of the influence of crude oil prices on the Spanish inflation calculation rather than by the direct effect of an inflation factor into the gas price formula. It is also interesting to see how correlation to NBP is slightly higher than to coal confirming that the effect of NBP prices into SGP is more intense than that of coal. As expected, euro-dollar correlation with SGP is hard to explain and in fact is negative possibly as a result of the strong negative correlation between the dollar and crude oil price.

Table 14 shows semipartial correlation coefficients⁹⁶ by keeping those effects different from oil, oil products, and coal, aside whereas in Table 15 we can see the semipartial correlation of other predictors keeping oil, oil products, and coal effects aside.

	Gas Price	B613	G601	LSFO601	Coal
Gas Price	1,000000	0,827544	0,811333	-0,021012	0,174285
B613	0,827544	1,000000	0,850500	-0,079915	0,183967
G601	0,811333	0,850500	1,000000	0,182283	0,388431
LSFO601	-0,021012	-0,079915	0,182283	1,000000	0,533923
Coal	0,174285	0,183967	0,388431	0,533923	1,000000

Table 14_ First semipartial correlation analysis

⁹⁵ P-values for Pearson's correlation using a Student's t distribution for a transformation of the correlation.

⁹⁶ Semipartial correlation indicates incremental variability explained eliminating (holding) other variables aside.

	Gas Price	NBP	SMP	IPC	ED301
Gas Price	1,000000	0,133534	-0,110355	0,324303	-0,154121
NBP	0,133534	1,000000	0,364162	-0,124182	0,126249
SMP	-0,110355	0,364162	1,000000	-0,316086	0,289624
IPC	0,324303	-0,124182	-0,316086	1,000000	-0,650993
ED301	-0,154121	0,126249	0,289624	-0,650993	1,000000

Table 15_ Second semipartial correlation analysis

As it was to be expected, most traded fossil fuel predictors, i.e. Brent and gasoil maintain a high degree of correlation when maintaining constant the rest of non-fossil fuel variables but surprisingly fuel oil and coal lose significant prediction power advancing that these two variables will have a much lower effect on the SGP estimation than the first two. When looking at Table 15, non-fossil fuels variables partial correlation eliminating fossil fuels influence diminishes to a great extent. Interestingly, in this case, partial correlation of SMP with NBP is higher than with SGP suggesting the importance of marginal gas prices into electricity prices.

5.4 Regression analysis

In line with common practice for predictor selection, we use both t-statistics on individual coefficients parameters and F-statistics on an aggregated basis to measure statistical significance of the model⁹⁷. Results initially obtained (model M0) are shown in Table 16.

⁹⁷ It has to be noted that when using these statistics, omitting predictors with insignificant individual contributions can hide a significant joint contribution. Also, t and F statistics can be unreliable in the presence of colinearity or trending variables. As such, those issues will be addressed in parallel with predictor selection.

	Predictor	Standard error	t-statistic	p-value
Intercept	1,242086	0,539421	2,302627	0,022505
B613	0,029768	0,003504	8,495719	0,000000
G601	0,004208	0,000670	6,276592	0,000000
LSFO601	0,001319	0,000588	2,242538	0,026212
NBP	0,048211	0,016218	2,972611	0,003379
Coal	-0,002476	0,001431	-1,730623	0,085323
SMP	-0,006312	0,002579	-2,447767	0,015385
IPC	0,013085	0,004642	2,819044	0,005385
ED301	-0,590433	0,411030	-1,436472	0,152695

Table 16_ M0 model parameters properties

The t-statistics⁹⁸ which scale the coefficient estimates by their standard errors (computed under the assumption of normal innovations) show that six of the eight predictors analysed are significant using a confidence interval of alpha 0.05, i.e., B613, G601, LSFO601, NBP, SMP, and IPC. Brent and gasoil appear especially significant here highlighting that significance of a predictor is relative to the other predictors in the model. From these results some warnings can be flagged:

- All the signs of the resulting coefficient estimates are consistent with theoretical expectations, except for SMP that reduces SGP value and is possibly included as adjusting parameter.
- In principle factors that appear to be non-significant can be discarded at this point. Interestingly, standard error (SE) for NBP is high, but the value of the predictor is also high what results in a relatively consistent t-statistic.

Confidence intervals⁹⁹ for the selected predictors are calculated as follows.

$$CI = (Estimate \pm ME) = (Estimate \pm t \times SE(estimate))$$

⁹⁸ t-statistic for each coefficient to test the null hypothesis that the corresponding coefficient is zero against the alternative that it is different from zero, given the other predictors in the model. Note that $tStat = Estimate/SE$.

⁹⁹ The standard deviation describes the spread of a sample distribution. The SE describes certainty with which we know the mean of the underlying population based upon our sample of it. More specifically, the SE is the theoretical standard deviation of the sample-mean's estimate of a population mean. To make the SE more informative we can convert it to a confidence interval.

Table 17 below shows some of the main parameters assessing Goodness of Fit overall for the regression model above.

<i>M0</i>			
Number of observations	180	R	0,991
Root Mean Squared Error	0,324	R-squared	0,983
F-statistic vs. Constant model	1240	Adjusted R-sq	0,982

Table 17_ Estimates of linear regression model M0¹⁰⁰

As can be seen and despite the fact that a few non-significant predictors are included, the value of R^2 is considerably high, i.e., 0.983, suggesting that the model explains about 98% of the variation in SGP, what is an excellent result on the initial combination of eight variables. A high value of R also indicates a proper stance for predictions.

In order to maximize the proportion of variability accounted for, we reduce the initial set of predictors to B601, GO601, LSFO, NBP, SMP, and IPC, according to the results obtained in the previous analysis and calculate the corresponding regression (model M1). Table 18 shows that although the proportion of variability, i.e., multiple squared correlation and R^2 , does not improve, we assure that the coefficients used in the regression are significant, i.e., we select only those predictors that contribute significantly to the regression equation.

<i>M1</i>			
Number of observations	180	R	0,991
Root Mean Squared Error	0,325	R-squared	0,983
F-statistic vs. Constant model	1640	Adjusted R-sq	0,982

Table 18_ Estimates of linear regression model M1

¹⁰⁰ R-squared and Adjusted R-squared: Coefficient of determination and adjusted coefficient of determination, respectively.

F-statistic vs. constant model: Test statistic for the F-test on the regression model. It tests for a significant linear regression relationship between the response variable and the predictor variables.

Root mean squared error (RMSE): Square root of the mean squared error, which estimates the standard deviation of the error distribution.

Table 19 shows that all the variables selected in M1 except LSFO601 are now significant.

	Predictor	Standard error	t-statistic	p-value	
	Intercept	0,617584	0,370559	1,666628	0,097398
	B613	0,031309	0,003116	10,048203	0,000000
	G601	0,004168	0,000567	7,354437	0,000000
	LSFO601	0,001131	0,000574	1,970281	0,050402
	NBP	0,045684	0,016228	2,815073	0,005442
	SMP	-0,007674	0,002461	-3,117968	0,002133
	IPC	0,013345	0,004645	2,873143	0,004573

Table 19_M1 model parameters properties

In order to find the most efficient equation, we complete our investigation by using automated procedures for selecting predictor variables. These procedures differ from each other regarding the definitions they use for what it means for an equation to be efficient. These definitions translate into algorithms for selecting some variables for inclusion and leaving out others. Of the three most important procedures typically used, i.e., forward, backward and stepwise¹⁰¹, we will use the latter. The stepwise method is similar to the forward method¹⁰² except for the fact that within the former method, the unique contribution of every variable in the equation is tested at every step. This is a way of getting rid of predictor variables that, at some point, are overlapped by the contributions of enough other predictors that it no longer makes a significant contribution to the equation. It also takes into account the extreme sensitivity of a coefficient to insertion or deletion of other predictors.

Table 20 shows main output statistics. As it can be seen, when comparing with previous model statistics, this model while explaining a similar amount of variability, i.e., around 98%, does not achieve the lowest RMSE value. However F-statistic model results reveal that the M2 model is more significant than any of the two previous models.

¹⁰¹ Stepwise regression is a systematic procedure for adding and removing multiple linear regression predictors based on F statistics.

¹⁰² The forward method determines which variable has the highest correlation with the gas price and finds of the remaining predictors makes the largest unique contribution to the equation and it tests this unique contribution to see if it's significant.

M2			
Number of observations	180	R	0,991
Root Mean Squared Error	0,328	R-squared	0,982
F-statistic vs. Constant model	1930	Adjusted R-sq	0,982

Table 20_ Estimates of final linear regression model M2

Interestingly, as it can be seen in Table 21, after the stepwise process, all the regressors are maintained.

	Predictor	Standard error	Status	p-value
B613	0,031967	0,003124	In	0,000000
G601	0,004946	0,000410	In	0,000000
NBP	0,040290	0,016128	In	0,013410
SMP	-0,008717	0,002423	In	0,000419
IPC	0,012480	0,004662	In	0,008141

Table 21_ Estimates of parameters in model M2

Table 21 indicates that signs of the coefficient estimates are consistent with theoretical expectations except again for SMP that reduces value. In this case and spite of contradictory economic logic, we leave SMP in the final regression model as an adjusting parameter. The t-statistics show that all predictors finally selected are significantly different from 0 at the 5% level with B613, GO601 been especially significant. Therefore and despite the high degree of correlation between B613 and GO601, we leave the model as it is, despite the most likely presence of multicollinearity between the two. In this sense, multicollinearity does not affect the efficacy of extrapolating the fitted model to new data provided that the predictor variables follow the same pattern of multicollinearity in the new information as in the data on which the regression model is based. Therefore and as long as the degree of collinearity between Brent and Gasoil is that strong our analysis will be of value. Moreover given the fact that our objective is not to estimate the group of coefficients fairly accurate, the analysis is valid even in the presence of collinearity, (Gujarati 2010).

In spite of the good results achieved, we still need to clarify which level of approximation we achieve with the M2 model. Table 22 decomposes the ANOVA table into the model terms to

test whether any of the regressors are significantly associated with SGP. The corresponding F-statistics¹⁰³ in the F column are for assessing the statistical significance of each term.

	Sumsqr	DF	MeanSq	F	p-value
B613	11,275678	1,000000	11,275678	104,739821	0,000000
G601	15,656703	1,000000	15,656703	145,435180	0,000000
NBP	0,671870	1,000000	0,671870	6,241000	0,013410
SMP	1,392866	1,000000	1,392866	12,938341	0,000419
IPC	0,771447	1,000000	0,771447	7,165970	0,008141

Table 22_ M2 ANOVA Table¹⁰⁴

The observed results for the ANOVA test indicate that the slope is significantly different from zero especially for Brent and gasoil this reflecting eventually the price of gas would mostly be related to the price of those regressors. It has to be noted that the ANOVA p-values give us the same results as the ones from t-statistic parameters previously¹⁰⁵. We conclude also based on the economic logic that only Brent, gasoil and NBP seem to explain most of the variation of SGP with full economic logic.

Our final model M2 is therefore as follows:

$$SGP_t = 0.68 + 0.031967 * B613_t + 0.004946 * G601_t + 0.040290 * NBP_t - 0.008717 * SMP_t + 0.012480 * IPC_t \quad (2)$$

5.5 Principal Component Analysis

5.5.1 Data Exploration

Principal Component Analysis (PCA) is a multivariate statistical technique that transforms an original set of correlated variables into a new smaller set of uncorrelated vectors

¹⁰³ The F-test in this case tests whether the coefficient of the indicator variable is different from zero or not. That is, whether this variable has a significant effect on SGP or not.

¹⁰⁴ DF: Degrees of freedom for each term/ MeanSq: Mean squared error for each term. Note that MeanSq: SumSq/DF

¹⁰⁵ Due to the relation between t-statistic and F- statistic calculations p-value for the t-test is the same as the p-value for the F-test. Hence in simple linear regression, the two significance tests for the slope give the same results in both the F-test (using ANOVA table) and the t-test.

and constructs independent new variables which are linear combinations of the original ones. In this sense projecting a multivariate sample, i.e., our set of SGP predictors into a low-dimensional space (typically 2 or 3 dimensions) while reorganizing variability of the parameters will account for the most important directions of the variability of the data set.

Figure 40 shows, first of all, the variability of predictors in a multiple Box plot indicating that dispersion around the mean¹⁰⁶ of oil and oil products is significantly higher than the rest of predictors, excluding perhaps IPC. This would re-confirm that high variability of SGP even larger than NBP seems to be largely influenced by oil and oil products¹⁰⁷.

Figure 40_Box plot variability of predictors

5.5.2 Component coefficients

Reorganizing our initial set of predictors (a total of eight) into two main variables will simplify understanding variability. In Figure 41 we can see the results from the PCA computation. The first graph shows the centered and scaled ratings projected onto the first two principal component and a line following time evolution of events. Interestingly extreme values (noted in

¹⁰⁶ Interquartile range (IQR): the distance between the upper and low quartiles.

¹⁰⁷ Note that all variables are in their unit as it is appropriate to compute principal components for raw data.

the red circle) correspond to high and low extreme values during 2008 and 2014 showing some extraordinary variability over those periods.

Figure 41_Components distribution and percent explained

The second graph on Figure 41 shows the first five (instead of a total of eight) components that explain about 97% of the total variance. There is a clear difference of variance accounted for by each component with the first element, i.e., explaining 69% of the variance and the rest. This is an indication that choosing two elements for the analysis might be reasonable.

Table 23 shows the resulting variance explained by each component.

	<i>PCA1</i>	<i>PCA2</i>	<i>PCA3</i>	<i>PCA4</i>	<i>PCA5</i>	<i>PCA6</i>	<i>PCA7</i>	<i>PCA8</i>
<i>Standard deviation</i>	8.30	3.38	3.04	2.06	1.69	1.64	0.75	0.42
<i>Variance (%)</i>	68.83	11.43	9.22	4.25	2.87	2.67	0.56	0.17
<i>Cummulative variance</i>	68.83	80.25	89.47	93.72	96.59	99.26	99.83	100.00

Table 23_ Principal Component Analysis

All eight predictors are represented in Figure 42 also called a bi-plot by vector¹⁰⁸. The direction and the length of the vector indicate how each variable contributes to the two principal components in the graph. This 2-D bi-plot also includes a point for each of the 180 observations, with coordinates indicating the score of each observation for the two principal components in the plot. For example, points near the left edge of this plot have the lowest scores for the first principal component. The points are scaled concerning the maximum score value and maximum coefficient length, so only their relative locations can be determined from the plot¹⁰⁹.

¹⁰⁸ A note to this is that typically a bi-plot is less useful for visualizing the relations among the predictors that lead to nearly collinear relations. However bi-plots of the smallest dimensions show these relations directly, and can show other features of the data as well, such as outliers and leverage points.

¹⁰⁹ Some general characteristics of bi-plots are:

- The variable vectors have their origin at the mean on each variable, and point in the direction of positive deviations from the mean on each variable.
- The angles between variable vectors portray the correlations between them, in the sense that the cosine of the angle between any two variable vectors approximates the correlation between those variables.
- Similarly, the angles between each variable vector and the biplot axes approximate the correlation between them.
- Because the predictors are scaled to unit length, the relative length of each variable vector indicates the proportion of variance for that variable represented in the low-rank approximation.
- The orthogonal projections of the observation points on the variable vectors show approximately the value of each observation on each variable.

By construction, the observations, shown as principal component scores are uncorrelated.

Figure 42_Main PCA contribution dimensions 1 and 2

As it can be seen all the variables except ED301 are positive in respect of the first principal component, on the horizontal axis, and therefore all those seven variables are directed to the right of the plot this indicating that as we knew Euro/Dollar exchange rate is an odd parameter for the regression.

In respect of the second principal component, on the vertical axis, has positive coefficients for ED301, SMP, NBP and Coal and slightly negative for B613, GO601, LSFO601, and IPC. This means that the second principal component is somehow more restrictive than the first and distinguishes among gas prices that have high values for SMP but also for NBP and low for the rest and gas prices that have the opposite. Our understanding is that this second principal component might be indicating a more market oriented gas price formation whereas the first principal component would be more oriented towards the intrinsic oil and oil products formulation of the SGP long-term formula contract.

As well, high leverage observations, so called outliers in the predictor space, can be seen as observations far from the centroid in the space of the smallest principal components

(dimensions 5 and 6 in our case). On Table 24 we highlight the information that should attract our attention in respect of the five predictors finally selected¹¹⁰.

Number	sValue	C_Index	B613	GO601	LSFO	NBP	Coal	IPC
1	2.402	1.000	0.000	0.000	0.000	0.001	0.002	0.002
2	0.326	7.377	0.013	0.002	0.020	0.003	0.099	0.280
3	0.260	9.241	0.007	0.000	0.000	0.041	0.340	0.542
4	0.213	11.286	0.002	0.000	0.011	0.750	0.219	0.007
5	0.092	26.114	0.457	0.003	0.633	0.011	0.106	0.164
6	0.050	47.746	0.521	0.994	0.335	0.193	0.234	0.005

Table 24_ Revised condition indices and variance proportion (* 100)

As can be seen, the largest condition index corresponds to a near linear dependency involving B613 and GO601 given the clear relationship between both through downstream operations and the second largest involving B613 and LSFO601. Figure 43 below shows the rather different behaviour of fuel oil concerning crude oil price considering component 5 but also the clear distinction between oil and refinery products group and the rest when filtering by component 4

¹¹⁰ Note decimals for variance proportion indices have been removed and values higher than 50 are highlighted.

Figure 43_ PCA contribution dimensions 5 and 6

5.6 Conclusion

Our main objective in this chapter has been to examine Spanish gas prices in relation to a set of factors and at the same time be flexible as to test multiple scenarios where the effects of each of the variables, with or without the consequences of the other variables, can be taken into account. Subsequently, an unbiased OLS estimator is calculated including a thorough review and justification of the key assumptions needed during the OLS process, i.e., assumptions on samples being random, independent and normal. An interesting part of the study has been devoted to correlation issues given the presence of highly correlated variables, like Brent and gasoil prices and the potential for each of them not contributing in predictive power beyond the other. If this were the case, the semipartial correlations of these two variables would be small. We found, however, the opposite, i.e., high semipartial correlations between the two apparently indicating both being unique regarding predictive power.

From the initial set of selected variables, i.e. Brent, gasoil, fuel oil, NBP, SMP, IPC and exchange rate Euro/US dollar and through a comprehensive selection process we found that Brent oil price, gasoil price (these two lagged 6 months) and NBP are the predictors that contribute most to the best prediction of SGP. The F-ratio from the ANOVA table indicates that the slope of the regression on each of them is significantly different from zero. Doubts about the economic logic behind SMP resulting negatively correlated reduces its role to a mere

adjusting parameter. The analysis of Principal Components (PCA) following previous regression investigations shows clearly that SGP is influenced in a very different manner from crude oil and refined products on one side and from traded market prices such as NBP or Coal.

Given the robust results obtained after the regression model selection process, some additional concluding elements resulting from this process are described below:

- M2 model fit, as measured by the root-mean-squared error (RMSE) does not improve relative to M1, however, and considering is that the coefficient of determination R^2 explains similarly about of 98% we believe that the stepwise process produces a more robust result also considering similar conditions related to the parsimony of both models.
- By accepting M2 model results we also entirely in agreement with previous research considering that fuel oil is not closely linked to crude oil price (Asche, 2010) and in this sense introducing fuel oil as a regressor would not be supported by theoretical reasons and in spite of some connections between SGP and fuel oil through old contract formulas.
- The significance of the M2 model, as measured by the F-Statistic improves. This is a typical result from a stepwise process confirming that the idea to abandon fuel oil as a predictor would be beneficial for the analysis.
- From the last model M2, theoretical considerations regarding SGP influences are in agreement with the expected outcome except for SMP, possibly included as a mere mathematical adjusting parameter.
- The presence of collinearity between B613 and GO6013 seems to be acceptable as it does not affect the efficacy of extrapolating the fitted model to new data provided that these two predictor variables follow the same pattern of multicollinearity in the new set of data, i.e., and as long as the degree of collinearity between Brent and Gasoil is that strong our analysis will of value. Moreover, given the fact that our objective is not to estimate the group of coefficients fairly accurate, the analysis is valid even in the presence of collinearity, (Gujarati 2010).

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CHAPTER 6. EVALUATION OF THE UNIT ROOT HYPOTHESIS

As discussed, one of the main objectives of this thesis is to investigate whether there is scientific base for a time trend decomposition of Spanish gas and other energy commodities. To do this, we build upon existing literature by employing an updated data series that incorporates the two largest oil price crashes for about 30 years. In particular, the purpose of this chapter is twofold: on the one side to provide evidence that Spanish gas prices inherit the stochastic properties of crude oil looking to other energy markets in parallel. This analysis is motivated by the fact that the likely presence of breakpoints in processes that are stationary are often similar to stochastic processes with nonstationary properties. Secondly, to examine in more detail timing and characteristics of the effects from the events happening over the period regarding Spanish gas prices trends. It can be said that this chapter is at the heart of the research work developed in this thesis, as it covers one of the key issues providing support to understand patterns of Spanish gas prices in the long-run better.

6.1 Introduction

The type of trend dynamics, stochastic or deterministic, exhibited by the price of a resource commodity should play a critical role in the development and empirical verification of theories which may explain long-term behaviour. However, the nature of trends can only be assessed by empirical testing. To this end, we present a set of unit root testing procedures to characterize trends observed in Spanish gas prices but also for intercomparison with other five related variables, crude oil included. It becomes especially important in the context of this chapter, the concept of persistence and the notion of memory properties of time series, i.e. to what extent the effect of an infinitesimally small shock in the price series will be influencing the future predictions for a long time, issues that will be addressed further in Chapter 8. Although persistence on the mean has been investigated in depth for oil prices series (Pyndyck, 1999; Taback, 2003; Taback and Cajuero, 2007; Bacon and Kojima, 2008; Ghoshray, 2011), the existing literature is far from a consensus on its unit root properties in spite of the fact that generic tests are mostly unable to reject non-stationarity recognizing that oil prices are consistent with there being a unit root.

Of all the factors involved in determining the term structure of crude oil prices, the effects of structural breaks are the most challenging. According to Ozdemir et al. (2013) and Kang et al. (2011), the inclusion of information regarding structural changes reduces volatility persistence and improves the understanding of volatility transmission in crude oil markets. Related to this, the presence in the sample period of two major events is particularly relevant. Firstly, the credit crunch in 2008 associated with strong movements in key macroeconomic time series and on oil and natural gas in particular. Oil prices fell from a high of 133.2 \$/bbl in July 2008 to a low of 46.7 \$/bbl in March 2009, but even more importantly, the increase in prices resulted in over-stimulated supply conditions and an explosion in the number of new oil supply alternatives. Secondly, the collapse of oil prices since late 2014 with WTI crude prices dropping

from over 100 \$/bbl to less than 60 \$/bbl with Brent oil prices following suit. Oil prices continued to slide into 2015, favoured by OPEC's decision of seeking to protect market share, dipping below 40 \$/bbl after making a modest recovery. Figure 44 shows the recent development in the prices of oil and oil products from 2002 until the end of 2016.

Figure 44_ Historic crude oil (\$/bbl) and gasoil and LSFO (\$/ton) prices. Source World Bank.

There are many similarities and differences among the two oil price crashes although possibly differences are more revealing of how traded oil markets behave. In the first place, the 2008-2009 crash was precipitated by global events mainly the financial crisis with oil prices during that crash highly correlated with equity and exchange rate movements (Singleton, 2008). Due to this interaction and the uncertainty regarding the health of the global economy, volatility spiked in 2008. However, the impact of shocks to equity markets on volatility during the recent crash was muted (Baffes and Kshirsagar, 2016). Figure 45 below shows crude oil price level (blue) and 30-day window volatility (orange) over the 2008-2009 period (left figure) and the 2014-2015 period (right figure).

Figure 45_Oil prices (levels and volatility) during the two price collapses. Source: World Bank

As it can be seen, volatility was much less elevated during the oil price crash in 2014-2015 with a dispersion of price changes that was considerably smaller than comparable oil price declines. As a matter of fact, that macroeconomic shocks are closely related to crude oil price variations does not come as a surprise. Actually, the amount of research on the relationship between oil price volatility and other aspects has been intense in fields like macroeconomy and exchange rates (Huang et al., 2005; Van Robays, 2016; Mensi et al., 2015; Su et al., 2016) or stock markets (Sadorsky, 1999; 2003; 2012; Hayette, 2016; Huang et al., 2017). Interestingly, both oil supply shocks and real economic shocks lead the correlation between economic uncertainty and oil returns to fluctuate over time (Yin, 2015).

In the second place, the decline in the second half of 2014 was considerably sharper for oil than for other commodities whereas almost all commodity prices, including coal, metals, food commodities, and agricultural raw materials, declined by similar magnitudes in 2008¹¹¹ (Baffes and Dennis, 2013). This is even more evident given the fact that linkages between oil and other commodities differ individually, e.g., oil prices do not have for example much impact on beverage or cereal prices, but they have a substantial impact on metal prices (Rafiq and Bloch, 2016). See Figure 46 below.

¹¹¹ For example, while oil prices declined by 45 percent from July to December 2014, the largest price declines among other commodities were half as much, e.g. iron ore fell by 29 percent and palm oil by 18 percent.

Figure 46_Commodity price indices. Source: World Bank

Third and perhaps the most important factor from a market point of view: although after the financial crisis virtually all commodity prices rebounded, helped by production cuts and strong emerging market demand, global oil supply started building up. Interestingly enough, this development was led by additional sources of oil supply, mainly from shale, but also from other unconventional sources including biofuels, Canadian oil sands, and from non-OPEC members such as Brazil, China, and Russia. See Figure 47 below.

Figure 47_Crude oil supply growth since 2011. Source: IEA

As a result of all this, by 2014, global oil supplies had begun to exceed demand by nearly 1 mb/d, led by U.S. oil production growth. At the same time, OPEC members decided to protect market share by allowing prices to drop and prices fell to less than 30 \$/bbl in January 2016. Possibly, the key to today's oil market is whether the forces that caused the price collapse were temporary, like those in 2008, or long lasting. Moreover, shale oil production remains the marginal source of new oil and the price will very much depend on the evolution of this technology.

Within this background, further research into the stationarity properties of Spanish gas prices, directly linked to oil prices and with a focus on extreme market events seems especially desirable¹¹². In this regard, research by Perron (1989), critically reviewing Dickey and Fuller (1979), is particularly influential as it shows that generic unit root tests may have little power when the true data generating process includes a broken trend and is stationary. Since then, a wide variety of models has been suggested for endogenously¹¹³ determining the break date with, broadly speaking, three alternative routes being proposed. Firstly, some authors focus on the consequences of using an estimated break date in relation to the unit root testing objective. Examples of this type of practice include Banerjee et al. (1992), Zivot and Andrews (ZA) (1992)

¹¹² As discussed, volatility characteristics of Spanish gas prices, other key aspect relevant to this thesis, will be covered in Chapter 8.

¹¹³ We refer generally to a random event, i.e. assumed to be unknown to the investigator, which can be modelled as an outcome of an internal estimation procedure during the unit root testing process versus pre-detection and testing in a separate step.

and Perron and Vogelsang (VP) (1992). Secondly, the approach followed by Saikkonen and Lütkepohl (2012) and Lanne et al. (LLS) (2001) that extends the approach of Elliot, Rothenberg and Stock (1996) which propose estimating all nuisance parameters of the process in a first step in such a way that the limiting distributions of the subsequent unit root tests do not depend on the estimator of the break date. Thirdly, the minimum Lagrange Multiplier (LM) unit root test in the presence of a structural break is proposed by Lee and Strazicich (LS) (2004) as an improvement to the previous tests. This test is unaffected by structural breaks under the null and therefore avoids spurious rejections commonly found in ADF-type endogenous tests. It has to be noted that in addition, as referred in Section 2.2, a wide variety of techniques to detect the presence of structural changes without any prior knowledge as to whether the noise component is stationary or not has been developed and intensively used. In this regard, theoretical work developed by Kim and Perron (2009) will also be considered in empirical work along this chapter to complete the assessment.

In spite of the enormous amount of work analyzing unit root properties of crude oil treating the structural break as an endogenous occurrence, work comparing results using different testing methodologies is scarcer. Research on this chapter attempts to fill this gap by investigating the stochastic properties of SGP and the three most traded oil-related products, i.e., crude oil, gasoil and fuel oil but also of other two influential factors possibly explaining Spanish gas prices path, i.e., NBP and coal prices, using a comprehensive approach. To the best of our knowledge, this study is the first that addresses a systematic review of endogenous testing procedures in such a degree of detail regarding energy variables. In particular, the selected procedures are those proposed by Perron and Vogelsang (VP) (1992), by Lanne et al. (LLS) (2001), by Lee and Strazicich (LS) (2004) and also by Kim and Perron (2009) (KP), the latter offering the particular view according to the two-step analysis approach. Within this setting, our aim is to optimize validity and comparability of results but also to expand the level of understanding of those methods. Of separate interest are the results of the break dates estimates themselves and the insight gained on this using each test.

6.2 Materials and definition

In order to define which variables will be examined, we extend the scope outlined in Chapter 5 but we decide to leave LSFO and coal included in the analysis as they may provide valuable information to reach better conclusions. It has to be noted that in this chapter we are only interested in energy-related variables in relation to SGP. Data used are the logarithmic prices¹¹⁴ of the six variables, i.e., Brent crude oil (Brent), gasoil (GO), low sulphur fuel oil (LSFO),

¹¹⁴ By taking logarithms of variables which are multiplicatively related and/or growing perhaps even exponentially over time, the growth pattern is linearized

NBP and coal monthly average prices to benefit from the inherent properties of the logarithmic function in unit root testing. It also needs to be noted that the decision not to factor in time lag effects into crude oil and oil products prices, will enable to identify effects more clearly especially regarding the timing of break events. The data set includes monthly price indices spanning from 2002 to the end of 2016, i.e., 180 different data per time series which we believe sufficient to assure a fair analysis of stochastic properties of the variables considered. It has to be highlighted that regarding the power of the tests, the span of the data rather than the number of observations per se, is key. Moreover, the selected time frame coincides with a particularly revealing period of the recent evolution of the EU energy market and the strong efforts to gain competitiveness in the gas sector.

Figure 48 shows the normalized prices of all the variables analysed versus SGP and the remarkable fit between Brent, GO and LSFO and SGP.

Figure 48_All factors vs. SGP

Table 25 below shows a summary of variables and acronyms considered in this chapter.

Sector	Factor	Description	Units
Oil and oil products	Brent	Average price of current month FOB	\$/ton
	GO	Average NWE Gasoil price of current month FOB	\$/ton
	LSFO	Average NWE Low Sulphur Fuel oil 0.1% S price of current month FOB	\$/ton
Gas market	SGP	CNMC monthly Spanish wholesale gas price	\$/MMBtu
	NBP	Monthly average spot NBP	
Other markets	Coal	Monthly average MCIS Coal price	\$/ton

Table 25_List of variables considered in the analysis

Descriptive statistics for all the variables in levels are summarized in Table 26.

Variable	Mean price level	Standard deviation	Coefficient of Variation (%)	Skewness	Kurtosis
SGP	7,0	2,4	34,9	0,02	1,7
Brent	69,9	31,0	44,3	0,20	1,8
Gasoil	624,6	266,8	42,7	0,17	2,0
Fuel oil	380,9	187,0	49,1	0,34	1,7
NBP	6,8	2,9	41,9	0,29	2,6
Coal	77,3	31,7	41,0	1,33	6,0
lnSGP	0,04	0,03	89,10	2,05	9,71
lnBrent	0,07	0,06	84,43	1,58	6,06
lnGasoil	0,06	0,06	89,64	1,63	6,18
lnFuel oil	0,08	0,06	85,54	1,58	5,94
lnNBP	0,12	0,10	86,53	1,31	4,59
lnCoal	0,06	0,06	98,41	1,98	7,63

Table 26_Descriptive statistics for variables in levels and logs

From Table 26, the coefficient of variation suggests that there is a similar month-to-month variation in all of the prices, with SGP showing a relatively lower rate, this is not surprising

given the low-variance nature of long-term gas prices. Regarding the statistical distribution of price levels, most of the series exhibit mild positive skewness implying that the right tail is particularly extreme than in the normal case. The estimated kurtosis values for prices in levels are, except for coal, smaller than 3 (the kurtosis for a standard normal random variable). Hence there is some evidence of platykurtosis for most of the series. Overall, the selected time series display medium variability, positive skewness and negative excess kurtosis giving each series a long right tail but thinner tails overall. Figure 49 shows time variations of monthly log prices and first differences over the study period for all the variables considered.

Figure 49_Evolution of prices in levels and log value of time series analysed

As it can be seen, Brent crude oil and SGP data sets share large swings in common taking into account the lagging effect of oil indexation and the smoothing effect of rolling average used in gas price formulas. Not surprisingly both price series show a similar upward trend in spite of the effect of shocks during 2008's recession pulling down the trend line with no clear indication of mean reversion. Common peaks anticipating potential structural breaks are observed at the beginning of 2003 and the Iraq war, in mid-2008 as a result of the financial crisis and at the

beginning of 2012. Conversely, shocks affecting NBP prices over the sample period are not necessarily similar, like those at the beginning of 2006 with soaring NBP prices. It is interesting to realize that in spite of a well-connected LNG market worldwide, Spanish gas prices show a very limited response to other than crude oil-related fundamentals.

6.3 Empirical results and discussion

In this section, we examine the unit root properties of the six selected variables and identify the months in which structural break occurs. Accordingly, we employ up to eight different unit root tests, falling within three broad categories, assessing each price series. The autocorrelation function (ACF) of the level of each price series and corresponding ACF of the first difference are indicative of a difference stationary generating process in levels for all the variables (results not shown)¹¹⁵. Our first set of tests, those popular in the literature, are the generic ADF and KPSS tests including a linear time trend. Our second and third tests categories include one-break and two-break unit root tests respectively. The combination of testing procedures allows us to elucidate better the quality of results based on the evidence that each test provides. Moreover, given the very delicate task and the size distortions arising when testing near-stationary and almost-integrated series, power properties of the various tests as per supporting research will be at the heart of our inquiry. More specifically the question to be answered for each of the individual variables will be: ‘do the data favor a view that the trend is always changing, or it is rather changing at most occasionally and also coinciding with an expected date?’, in other words ‘if allowance is made for the possibility of some few large permanent changes in the trend function, is a unit root present in the structure of the stochastic component?’.

When testing for unit roots, it is essential to specify the null and the alternative hypotheses appropriately to determine the most convenient form of the test regression in line with the underlying DGP. Furthermore, the structure of deterministic terms in the maintained regression will influence the asymptotic distributions of the unit root test statistics. As it can be seen in Figure 49, all the variables under investigation, similarly to typical financial series, can be better characterized as a random walk like behavior with drift whereas the differenced series behave very much like a white noise process. In this sense, throughout the testing process, the alternative including a constant and a linear trend in the maintained regression seems the most

¹¹⁵ The sample autocorrelation function ACF of a series in levels will generally damp out to zero rather quickly with increasing lag if the series is stationary. Regarding examination of the ACF of first differences, if, for example, the underlying generating process is a random walk, the first difference of the series should be pure white noise.

plausible description of the data under both the null and alternative hypotheses (Hamilton, 1989). The standard conventional level for inference throughout the study is 5 percent.

6.3.1 ADF Test Results

Before implementing more complex unit root testing procedures, it seems appropriate to report traditional ADF and KPSS test results to log prices to test whether all the variables can be considered, at least initially, nonstationary in first differences and first order integrated in levels. With a view to specify the number of lagged difference terms in the test regression, we use the Bayesian Information Criterion (BIC) to be consistent with the analysis in this chapter more concentrated on inherent properties than focused on prediction overall. The theoretical properties of the test statistics require that we choose the number of lag terms in the Dickey-Fuller equations to be large enough to eliminate the effect of the correlation structure of the errors on the asymptotic distribution of the statistic. In most cases, we prefer the model that has the fewest parameter to estimate, provided that each one of the candidate models is correctly specified. This is called the most parsimonious model of the set. In this regard, the Akaike Information Criteria (AIC) does not always suggest the most parsimonious model, because the AIC function is largely based on the log likelihood function. Davidson and McKinnon (2004) indicate that whenever two or more models are nested, the AIC may fail to choose the most parsimonious one, if that these models are correctly specified. Hence, asymptotically, BIC would pick the more parsimonious model than AIC might suggest. Usual Ljung-Box Q-test to assess serial autocorrelation at the selected lags probe that in all cases a number of lags are sufficient to remove serial correlation in the residuals.

Table 27 summarizes the results of various tests performed to account for the alternative that the series is stationary, rejecting the unit root null in favour of the alternative (ADF test) or accounting for a stationary null versus the unit root alternative (KPSS test). Although all indicates that all series are trending, we include non-trending model results that would show more power to reject the null hypothesis than models including a trend, which is not contained in the data.

	<i>Log price in levels</i>				<i>Log price 1st differences</i>			
	<i>Without trend</i>		<i>With trend</i>		<i>Without trend</i>		<i>With trend</i>	
	<i>ADF</i>	<i>KPSS</i>	<i>ADF</i>	<i>KPSS</i>	<i>ADF</i>	<i>KPSS</i>	<i>ADF</i>	<i>KPSS</i>
Brent	0.534	7.667	-1.590	2.853	-4.770	0.236	-3.437	0.213
GO	0.742	7.803	-1.822	2.819	-6.325	0.228	-11.353	0.184
LSFO	0.489	7.455	-1.391	2.837	-4.978	0.298	-8.504	0.290
SGP	0.344	9.855	-0.052	2.850	-6.343	0.463	-11.255	0.222
NBP	0.518	5.189	-2.302	1.613	-5.564	1.074	-9.582	0.147
Coal	0.584	4.567	-1.858	2.733	-5.952	0.526	-9.543	0.453
cValue	-1.942	0.463	-3.443	0.146	-1.944	0.463	-3.443	0.146

Table 27_Generic unit Root tests

Tests results indicate that none of the six variables is stationary at the standard conventional level with and without a trend. The ADF test does not reject the null hypothesis of a unit root for the levels of the six prices. The KPSS test, in which the null hypothesis is stationarity, indicates that the null hypothesis is rejected for the level forms of all series. When the tests are applied to the first-differences of the variables, these results strongly imply that all variables are stationary, being integrated of order one.

Results from the standard unit root tests can be misleading when structural breaks remain unaccounted for tending to lose power dramatically against stationary alternatives with a low-order, moving average process (Perron, 1989). Due to this, it remains unclear the exact cause of failure to reject the null. We use six more efficient procedures to test the null hypothesis that each series contains a unit root including one or two structural breaks.

6.3.2 Unit root with one structural break

Before further testing, two main choices related to the nature of the DGP need to be answered. Firstly the question about how the effect of the breaks is incorporated into the process and secondly how to characterize the form of the break under the trend-break stationary alternative, i.e., mainly deciding about the most relevant model for inference¹¹⁶. In regards to the first question, we will use econometric models preferably allowing for smooth transitions from one level to some other level over an extended period, i.e., innovational models. We believe that in our case, smooth transitions, sometimes expanding for a few

¹¹⁶ Basically we refer to standard model classification that we will use, i.e. Model A ('crash'), B ('changing growth') or C ('mixed') in Perron (1987). See Appendix 2.

months, is a more realistic option than assuming an abrupt shift to a new level. The second question is less easy to answer and although data are clearly trended in all cases, this theoretically leading to a simplified alternative, i.e., whether there has been a break in the level or also in the trend, since the break date is treated as unknown, inevitably the form of break will be unknown as well. Furthermore, misspecification on the shape of the break can be critical, and the performance of the different tests used may vary significantly depending on the break model selection.

Following the initial decision to consider inference jointly on the unit root and the break but also to treat the form of the break as unknown when testing, Sen's (2001) proposed strategy seems best suited for our analysis as it also strengthens the idea of using the general-to-specific principle what has been done widely in practical studies of model selection. Therefore, we initially start with a general level specification that incorporates both a changing slope as well as a changing intercept and then evaluate the significance of the coefficients of the dummy variables. To avoid loss of power when the break occurs according to the Crash model, this also necessary for a consistent estimate of the break date, an assessment of robustness is also performed (Hatanaka and Yamada, 1999).

Table 28 shows the results of selected unit root test allowing for one structural break. In the first place, the empirical results of the ZA unit root using the minimum t-statistic ($t_{\alpha ZA}$) for break date selection (Crash and Mixed models). Secondly, results of two unit root tests using VP innovational outlier procedure either minimizing the t-statistic for the intercept break coefficient (t_θ) or maximizing the absolute value of the slope break coefficient (t_γ), despite the slight reduction of power in this case. In all cases, the method for deciding the number of additional lags in the autoregressive equation is given by BIC. Inference on nonstationarity in the case of discrepancy between models indicates rejection or acceptance of the unit root null according to which modelling alternative shows the most robust specification. It has to be noted that the presence of the end points causes the asymptotic distribution of the statistics to diverge towards infinity. Therefore, trimming is performed to remove endpoint values from consideration as the break date in all cases.

Table 28 also shows results from three more tests statistics allowing for one structural break, i.e., following LLS methodology where the level shift point (τ) is viewed as an unknown valued parameter, KP's pre-detection technique ($t_{\alpha\lambda}$) and finally the minimum LM LS (2004) unit root test statistic ($t_{\alpha LS}$). It has to be noted that in the case of LLS tests performed under the strategy to choose the break date which leads to the minimal objective function in the estimation of the nuisance parameters, selecting the AR order has been proved to be critical in order not to jeopardize the power of the test. It can be noticed during the testing process that overstating the AR order reduces power progressively whereas severely understating the order makes power to drop comparatively faster. In our case and following LLS indications, a reasonably large AR order, i.e., six has been used to select the break date. In this step, a shift

dummy is always used as shift function what could jeopardize a true break point being chosen. However, once the break date is selected, a different shift function can be chosen. In our case and based on LLS's Monte Carlo results, showing that additional flexibility in the shift function has a negative impact on the properties of the tests, we also use a dummy shift function to be conservative in compiling the reported results. BIC criteria are consistently used to select the AR order in the maintained regression. In the case of the KP test procedure, as discussed previously, their modelling approach concentrates on estimating the break date by minimizing the sum of squared residuals of the relevant regression. AR order is also chosen using BIC selection criteria, and only the results from the innovational model option are shown, this for consistency with the original strategy.

Model		Crash		Mixed		
Variable	t-statistic	Value	Break date	Value	Break date	Inference
Brent	$t_{\alpha ZA}$	-4,100	2014-06	-3,714	2010-11	N-S
	$t_{\Theta/ \delta }$	-3,210	2014-07	-3,699	2010-11	N-S
	τ	-1,687	2015-01	-	-	N-S
	$t_{\alpha \lambda}$	-	-	-3,577	2013-02	N-S
	$t_{\alpha LS}$	-1,789	2008-12	-2,873	2014-8	N-S
Gasoil	$t_{\alpha ZA}$	-3,634	2014-08	-3,347	2010-12	N-S
	$t_{\Theta/ \delta }$	-2,666	2014-08	-3,337	2010-11	N-S
	τ	-1,698	2003-04	-	-	N-S
	$t_{\alpha \lambda}$	-	-	-3,254	2011-11	N-S
	$t_{\alpha LS}$	-1,795	2010-04	-2,926	2010-4	N-S
Fuel oil	$t_{\alpha ZA}$	-4,888	2014-09	-4,340	2011-01	S
	$t_{\Theta/ \delta }$	-3,488	2014-08	-4,324	2011-1	N-S
	τ	-1,100	2008-08	-	-	N-S
	$t_{\alpha \lambda}$	-	-	-3,823	2011-10	N-S
	$t_{\alpha LS}$	-1,849	2009-07	-3,765	2014-5	N-S
SGP	$t_{\alpha ZA}$	-2,473	2014-09	-2,462	2012-11	N-S
	$t_{\Theta/ \delta }$	-1,830	2014-07	-1,981	2010-11	N-S
	τ	-1,602	2009-02	-	-	N-S
	$t_{\alpha \lambda}$	-	-	-2,547	2013-08	N-S
	$t_{\alpha LS}$	-1,631	2008-11	-2,884	2011-11	N-S
NBP	$t_{\alpha ZA}$	-4,058	2004-09	-4,394	2004-09	N-S
	$t_{\Theta/ \delta }$	-3,687	2013-12	-4,024	2006-2	N-S
	τ	-3,567	2005-12	-	-	S
	$t_{\alpha \lambda}$	-	-	-4,384	2005-11	S
	$t_{\alpha LS}$	-3,766	2005-11	-4,059	2005-1	S
Coal	$t_{\alpha ZA}$	-2,824	2011-11	1,122	2007-07	N-S
	$t_{\Theta/ \delta }$	-0,732	2008-08	-3,199	2008-11	N-S
	τ	-2,055	2008-11	-	-	N-S
	$t_{\alpha \lambda}$	-	-	-3,617	2008-06	N-S
	$t_{\alpha LS}$	-2,542	2009-06	-4,328	2008-4	N-S

Table 28_Unit root tests with one structural break. Brown shadow shows similar break point detection than Brent.

As it can be seen, results from all tests suggest that we cannot reject the unit null in favour of the one break alternative for any of the variables¹¹⁷ except for fuel oil using the ZA model test and NBP when applying three different tests, i.e., LLS, KP, and LS (green in the table).

These results confirm that in general testing for unit root endogenously maintains the difficulty in rejecting the unit root hypothesis in finite samples (Perron 1989) but also stronger support for convergence using LM unit root tests, this in line with relevant literature analyzing economic series (Berk and Roberts, 1995, Lee and Strazicich, 2004). Moreover, the fact that the one-break minimum LM unit root test exhibits no size distortions in the presence of a break under the null would imply unambiguously a stationary trend process, this applicable to NBP in our case. Results from the KP test supporting this view, introduce a new proposition as this test allows a break under both the null and alternative hypotheses while pre-testing for trend breaks in a way that is robust to whether the time series are characterized as $I(1)$ ¹¹⁸ or $I(0)$ processes. Interestingly and under the null, in all tests performed the estimates of the level shift parameters have the highest significance levels resulting from level break tests using the Crash model whereas slope shift parameters are especially significant when using the Mixed model tests. This could be indicative of the importance of both level shift, and slope changes in the series analysed when considering one structural break.

Some more detailed considerations can be outlined though. Figure 50 shows tests statistical results for Brent and SGP (top charts) and NBP and Coal (bottom diagrams) prices using the VP break date selection process over the minimum t-statistic (t_θ) and over the Dickey-Fuller (DF) t-statistic (this not shown in Table 28).

¹¹⁷ Results for Brent are well in line with Maslyuk and Smyth (2008) and Ghoshray (2011) examining Brent crude oil spot and employing in both cases Lagrange Multiplier (LM) unit root tests with one and two endogenous structural breaks proposed by Lee and Strazicich (2003, 2004).

¹¹⁸ When the nonstationary series can be transformed to the stationary series by differencing once, the series is said to be integrated of order 1 and is denoted by $I(1)$, or in common, a unit root process. If the series needs to be differenced d times to be stationary, then the series is said to be $I(d)$.

Figure 50_VP test breakpoint estimation over t_{θ} and Dickey-Fuller (DF) t-statistic.

From this figure but also (see dates shadowed in brown) it can be seen that the pattern of structural breaks on the level detected for Brent and SGP are exactly similar giving more weight to events happening after 2014. Regarding the dynamics of coal prices, it can be seen the overwhelming importance of the 2008 financial crisis in their evolution.

Figure 51 shows VP tests results over the minimum t_{γ} statistic using a Mixed specification. It can be highlighted that in this case breaking points for both Brent and SGP are again exactly similar being advanced to November 2010 whereas for coal, break point patterns are similar to those using the Crash model located in 2008. In a different fashion, NBP prices seem to be more affected by internal market dynamics showing a break date on trend in early 2006.

Figure 51_VP test breakpoint estimation over t_y and Dickey-Fuller (DF) t-statistic.

From the results of tests performed in this section, it may be concluded that in hindsight, Brent and SGP, maintain the highest degree of similarity regarding the response to structural changes when compared to other refined oil products. It can be observed that gasoil is second closer and fuel oil third. Independently, NBP prices divert from this pattern and respond according to own hub influences and changing circumstances in the UK gas market. Separately, coal is especially affected by overarching events as a result of the financial crisis in 2008, both on level and slope. It is important to note that similarities between Brent oil and SGP are the highest also through the range of unit root tests performed. Regarding methodology employed, although according to the literature ZA tests may suggest dates slightly delayed compared with VP tests, selected break dates in our research are very similar in both cases indicating that both $t_{\alpha ZA}$ and $t_{\theta/y}$ statistics do a similar job picking the true break date. Moreover, effects on size distortions due to the magnitude of the suspected shifts, these well within those commonly seen in macroeconomic data, seems not to pose a problem for these tests.

Overall, it can be concluded that using endogenous testing models produce statistical inference that is substantially similar for Brent prices and Spanish gas prices, independently of the optimization sequence and the parameterization of the structural break under the null and the alternative. Moreover, when inference is carried out without taking an a priori stand on the

persistence of the noise component, strong evidence regarding the continued persistence of Brent and SGP prices remains.

6.3.3 Unit root with two structural breaks

The results of the Lumsdaine and Papell (1997) (LP) and Lee and Strazicich (2003) (LS) unit root tests with two structural breaks are presented in Table 29.¹¹⁹

Model		Crash		Mixed		
Variable	t-statistic	Value	Break date	Value	Break date	Inference
Brent	LP	-4,274	2005-5	-6,002	2008-7	N-S
			2014-9		2013-4	
	LS	-2,010	2008-12	-4,781	2005-4	N-S
			2012-5		2014-8	
GO	LP	-4,014	2008-9	-5,874	2008-7	N-S
			2014-8		2013-4	
	LS	-1,931	2007-10	-4,677	2004-5	N-S
			2010-4		2014-8	
LSFO	LP	-4,775	2005-5	-5,701	2008-9	N-S
			2014-9		2013-4	
	LS	-2,142	2007-10	-5,059	2012-5	N-S
			2009-7		2015-5	
SGP	LP	-3,435	2005-6	-7,010	2009-1	S
			2014-9		2013-10	
	LS	-1,727	2008-11	-4,657	2008-11	N-S
			2010-10		2012-1	
NBP	LP	-4,586	2009-1	-6,020	2005-10	N-S
			2014-9		2011-12	
	LS	-4,010	2005-11	-5,195	2004-12	S
			2014-12		2011-12	
Coal	LP	-4,510	2007-3	-5,646	2007-8	N-S
			2013-11		2010-9	
	LS	-2,704	2006-1	-5,188	2007-4	N-S
			2009-6		2008-8	

¹¹⁹ Inference on nonstationarity in case of discrepancy between models indicate rejection or acceptance of the unit root null following Sen's recommended process followed by a robust assessment.

Critical values are -6.16 and -6.75 at the 5 percent of significance for each of both models respectively. It has to be noted that although LP reports critical values, these are specific to the sample size employed in their study. Critical values for the LM test vary according to the location of break (LS, 2003). Break date denotes the corresponding month of the most significant value statistic

Table 29_Lumsdaine and Papell/Lee and Strazicich UR tests with two-structural breaks. Brown shadow shows similar break point detection than Brent.

Stationarity inference provided by LP and LS tests is in general similar than that from one-break unit root tests except for SGP prices as the null is rejected in the LP Mixed model (in green on the table) as a result of a significant change of slope in October 2013 altering the decision about nonstationarity previously reached. On the contrary, previous stationarity assessment of fuel oil is weakened on the understanding of the ability of the two-break test to expand insight within a long-run context. These results reveal that one of the key elements in unit root testing is the consideration about the number of structural breaks. In this sense, and for SGP prices the analysis finds arguments to consider events at the end of 2013 large enough to induce stationarity on the series in the long run.

Regarding the location of break dates and using LP tests, Brent and SGP reaction to outside events is the most similar using both Crash and Mixed specifications. Selected break points show values in 2005 and 2014 (Crash) and in 2008 and 2013 (Mixed), these results clearly different from resulting break dates for NBP and coal. As with the one break tests, coal series break points overwhelmingly reflect financial crisis events but not oil-related events after 2014. Besides, trend shifts characteristics also reveal how close SGP dynamics are to those of Brent prices and not to those of NBP or coal prices. Trend coefficients calculations (not shown) of crude oil-related products¹²⁰ captured by LP unit root tests indicate the importance of changing-slope events compared to level variations after 2014 but also indicate exactly the opposite in 2008, i.e., a changing shift in level predominant over slope change.

Results on stationarity from the LS tests are easy to reconcile with one-break LS unit root tests, and the resulting inference confirms the previous non-stationarity found endogenously for SGP and Brent using the endogenous one-break LM test. In regards of Brent, gasoil, fuel oil, and SGP prices break dates results conflict and illustrate the weaknesses inherent in break date detection in LS unit root testing.

To conclude on the stationarity results of the two-break tests and supported by detailed research on the performance of both LP and LS testing methods, see Berck and Roberts, 1995;

¹²⁰ Here we mean Brent crude oil, SGP, gasoil and fuel oil.

Lee and Strazicich, 2004; Postali and Picchetti, 2006; Narayan and Narayan, 2007, it seems reasonable to assume that LS procedure would offer an improvement over ZA and LP methods. As discussed, these tests are oversized, i.e., tend to over-reject the null whereas LM tests performance, especially for the two-break crash model, is stable for small breaks. Similarly to one-break tests, both LS tests provide a similar characterization in favour of the stationary/trend-break hypothesis for NBP prices. This consideration reinforces stationarity properties of NBP but neglects stationarity of SGP series revealed by LP tests. In regards to break date detection capabilities, however, the outlook is reversed, and as exposed in the literature, we corroborate that LS tests have difficulties in this area.

Supported by LP results, SGP patterns fully coincide with Brent reaction to events both after 2008 and during late 2013. Going one step ahead, if we analyse each slope dummy over the different regimes, three in total when considering two-structural breaks, the underlying trend in each regime can be identified. For example, given that over the period we consider two structural breaks, the sample period chosen can be divided into three regimes. Table 30 shows trend coefficients, all negative as a result of events in 2008 and 2014.

		<i>Brent</i>	<i>SGP</i>	<i>GO</i>	<i>LSFO</i>
2008	coefficient	-0,29%	-0,18%	-0,30%	-0,16%
	t-stat	-2,926	-3,344	-2,919	-1,756
2014	coefficient	-1,29%	-1,12%	-1,06%	-1,54%
	t-stat	-5,474	-7,0156 (*)	-5,321	-5,369

Table 30_Coefficient of each slope dummy over the different regimes for the crude-oil related products.

As it can be seen, SGP has a trend coefficient always less negative than Brent oil, and therefore the impact of events is slightly lower as a result of indexation feature in the gas base price formula. Interestingly, in 2008 impact for SGP was greater than for LSFO and in 2014 higher than for GO. This is an indication of SGP well placed within crude-oil related products dynamics. Results show that the impact on SGP prices of 2008 events was lower than the reaction to events starting in 2012 relative to Brent price moves. Taking into account changes to Brent trends in the slope it can be seen that whereas in 2008 only 62% of the Brent shift is found in SGP, in 2014 as much as 86% of Brent shift is reflected by SGP with a significant t-statistic indicating extraordinary effects of events in 2014. This is a fascinating result since this different behaviour does not derive from the pure evolution of base price indexation standards over a four year period. All seems to indicate rather; ample LNG market oversupply conditions are very much underlying this effect.

In general, results reveal the additional advantage of the two-break test regarding detection of a second breaking point stressing the similarities and differences relevant for understanding the time series behaviour. In general, LP tests confirm the influence of crude oil markets effects in the four oil-related variables, i.e., Brent, GO, LSFO and SGP, evolving in different environments than the other two commodities, NBP, and coal.

6.3.4 Price series history and structural breaks

This section provides a detailed discussion of the major events that are likely to have impacted on the series analysed in view of break date detection capabilities of the unit root testing procedures employed. Over the period of interest, i.e., 2002 to 2016, there are four key points to note. First the period until mid-2008 with prices steadily increasing due to strong demand growth for crude oil driven by non-OECD countries, particularly China and India. Second, the period after the second half of 2008 and the sharp decline in commodity prices quickly followed by a surge in the price of oil as the global economy rebounded. Thirdly, a period of relatively stable but historically high prices from 2011 until 2013 with oil volatility dropping to historic lows amid concerns about the world's economy and oil demand. Finally, the fourth period running from 2014 and continuing into 2016 characterized by the collapse in prices driven by market slowdown and increased supply.

In line with this chronology of events, our investigation reveals key aspects of the response to those shocks by the price series analysed. Table 31 and Figure 52 show for each of the six variables analysed corresponding structural breaks according to the final decision on inference and following implementation of the different tests performed within the devised strategy. It is noted that allowing for two breaks produces a richer set of results, not necessarily a more precise definition of the location of break dates.

	SGP	Brent	GO	LSFO	NBP	Coal
ZA	2014-9	2014-6	2014-8	2014-9	2004-9	2011-11
VP	2014-7	2014-7	2014-8	2014-8	2013-12	2008-8
LLS	2009-2	2015-1	2003-4	2008-8	2005-12	2008-11
LS1	2008-11	2008-12	2010-4	2009-7	2005-11	2009-6
LP2A	2005-6	2005-5	2008-9	2005-5	2009-1	2007-3
LP2B	2014-9	2014-9	2014-8	2014-9	2014-9	2013-11
LS2A	2008-11	2008-12	2007-10	2007-10	2005-11	2006-1
LS2B	2010-10	2012-5	2010-4	2009-7	2014-12	2009-6

Table 31_Summary of most relevant break dates Crash model. Break dates significant at 5 percent (dark brown shaded) and similar break dates (light brown shaded).

Figure 52_Summary of suggested break dates Crash Model

Interestingly, Crash model results show an overwhelming influence of crude oil market fundamentals in 2014 according to ZA/VP/LP tests that are fully incorporated on SGP, GO or LSFO prices. In the case of NBP, UK gas market fundamentals rather than oil driven elements appear to be key. Specifically, it can be highlighted the situation in the UK around 2006 with declining supplies of natural gas from the North Sea pushing wholesale gas prices higher in addition to reduced supply from Continental Europe. In this situation, the UK has had to import more supplies, either through LNG shipments or via pipelines from the Norwegian gas fields leading to an unprecedented gas balancing alert, published by National Grid and causing gas prices to skyrocket. In the case of coal markets, there is a perception that events affecting price shocks are more widely spread possibly as a result of independent coal market effects. Table 32 and Figure 53 show selected break dates in the Mixed model.

	SGP	Brent	GO	LSFO	NBP	Coal
ZA	2012-11	2010-11	2010-12	2011-1	2004-9	2007-7
VP	2010-11	2010-11	2010-11	2011-1	2006-2	2008-11
LS1	2011-11	2014-8	2010-4	2014-5	2005-1	2008-4
KP	2013-8	2013-2	2011-11	2011-10	2005-11	2008-6
LP2A	2009-1	2008-7	2008-7	2008-9	2005-10	2007-8
LP2B	2013-10	2013-4	2013-4	2013-4	2011-12	2010-9
LS2A	2008-11	2005-4	2004-5	2012-5	2004-12	2007-4
LS2B	2012-1	2014-8	2014-8	2015-5	2011-12	2008-8

Table 32_Summary of most relevant break dates Mixed model. Break dates significant at 5 percent (dark brown shaded) and similar break dates (light brown shaded).

Figure 53_Summary of suggested break dates Mixed Model

In the case of the Mixed models' evaluation, results show, again, how important are events after 2010 leading to the dramatic price drop in crude oil prices at the end of 2014. As it

can be seen both 2008 financial crisis and crude oil price drop in 2014 effects on Brent prices are perfectly replicated by SGP allowing for a time lag of six months (LP test). In a similar fashion other tests, i.e., VP or KP detect a changing slope trend in 2010 and 2013 respectively coinciding for both series. Similarly to Crash models results, both NBP and coal prices do not seem to follow Brent oil response patterns to market shifts. As a matter of fact, NBP and coal discriminate by the relative influence of their respective market factors more than as a result of Brent oil reactions. Thus, for example, it can be seen that the strong effects of the active hurricane season during the third quarter of 2005, marked as a relevant event for NBP prices, seem to be more important than the situation around July and August of 2007 previous to the earthquake in Japan around mid-July 2007. In parallel, coal displays a high number of outliers in 2007 and 2008 driven, in large part, by the global markets where U.S. coal was in demand but also by the escalating delivery costs due to the growing fuel surcharges added by transportation companies. Once more, it can be seen that even global traded markets like coal can be responsive to other commodities fundamental drivers, including crude oil prices, very rapidly.

Figure 54 shows a snapshot of break dates selected by test-type and the remarkable similarities between dates chosen for both SGP and Brent price series. It is also interesting the narrower span for Brent and SGP break dates according to endogenous unit root tests not allowing for a break under the null and the broader range of alternatives using LS tests.

Figure 54_Summary of intervals for the suggested break dates by test-type (only Mixed model)

6.4 Conclusion and recommendations

It is widely admitted that failing to check for the structural break effects into time series properties leads to confusing results concerning stationarity properties. In particular, generic unit root tests may have little power when the true data generating process includes a broken trend and is stationary. In this chapter, we have investigated the stochastic properties and changing trends of six non-renewable resource prices throughout a structured strategy with a view to optimizing testing quality, validity and relevance of results. For this, we have considered an integrated strategy for unit root testing in the presence of structural breaks which combine traditional endogenous testing techniques as well as pre-detection approaches. For all the time series under investigation, the analysis provides individual characterizations on the effects of extreme events since 2002 such as the slowdown resulting from the financial crisis in 2008 or the significant price drop in 2014 arising from crude oil and natural gas oversupply situation after nearly five years of stability. In this sense, our main objective has been to identify differences and similarities between crude oil price and Spanish gas prices through the assessment of stochastic properties and break date characterization. In parallel, the analysis of other global commodities such as gasoil, fuel oil, NBP or coal, incorporate additional views to improve the outcome.

The key findings drawn from our research in this chapter are:

6.4.1 Unit root test results

- Generic unit root tests are not able to reject the null hypothesis of a unit root for the levels (ADF) or are able to reject level-stationarity (KPSS) in monthly prices for all the variables analyses including SGP. However when we include one structural break results suggest that we cannot reject the unit null in favour of the one break alternative for any of the variables except for fuel oil and NBP. The fact that the one-break minimum LM unit root test exhibits no size distortions in the presence of a break under the null would imply a stationary trend process for NBP unambiguously. Moreover, KP robust results whether the time series are characterized as $I(1)$ or $I(0)$ processes this.
- Stationarity inference provided by the two-break test is in general similar than that from one-break unit root tests except for SGP prices as the null is rejected by the LP Mixed model as a result of a significant change of slope in October 2013 altering the decision about nonstationarity previously reached. In this sense, and for SGP prices the analysis finds arguments to consider events at the end of 2013 significant enough to induce stationarity on the series in the long run. Previous stationarity assessment of fuel oil is weakened and NBP stationary reinforced on the understanding of the ability of the two-break test to expand insight within a long-run context. These results reveal that one of the key elements in unit root testing is the consideration about the number of structural breaks.

- Of particular interest to our research and especially supported by LP results, we find that when analysing slope dummy coefficients for SGP and Brent over the different regimes, three in total when considering two-structural breaks, the underlying trend in each regime is especially revealing. In this sense, SGP has a trend coefficient always less negative than Brent oil what is a reasonable result assuming that the impact of events is slightly softer on SGP as a result of indexation feature. Even more, when compared with refined products' reaction we find that the impact of events on SGP is well placed within those products' dynamics. However, regarding the specific relationship SGP-Brent oil, results show that the relative impact of 2008 and 2014 was different for each of these two variables. Taking into account changes in the slope, it can be seen that whereas in 2008 only 62% of the Brent shift is found in SGP, in 2014 as much as 86% of Brent shift is reflected by SGP and even more importantly with a significant change of slope on SGP prices indicating extraordinary effects of events in 2014. Moreover, unit root testing hypothesis results on stationarity of SGP since 2002 until 2016 as a consequence of this. This is a fascinating result and does not derive from the pure evolution of base price indexation standards over a four year period. Rather, ample LNG market oversupply conditions in addition to proportional oil market effects were at the heart of the extreme reaction in this case. These results show that in the case of SGP, combined effects of the strong decline of oil prices together with the significant LNG oversupply situation in 2014 may lead to stationary conditions overall.

6.4.2 Break points selection and market assessment

- In regards to break date detection capabilities, the outlook also confirmed in the literature, favours the use of ZA, VP and LP 'no-break in the null' testing procedures. Moreover, from our testing analysis, it can be seen that LS tests demonstrate poor break detection capabilities. Following on this reasoning only outcomes from those three tests referred before will draw comments in this section.
- Allowing for changing intercept results in a similar breakpoint for the Brent related variables, i.e., SGP, Brent, GO and LSFO in 2014 whereas allowing for a changing intercept and slope break dates move backwards as early as 2010, this advancing the intensity of changes in both price level and slope as a consequence of the 2014-15 price crash.
- Within the two-break time span considered, improving the one-break outlook, we find that using the Crash model a regime ending in 2005 and another in 2014 set up the evolution of SGP in line with Brent dynamics. When analysing SGP prices using the Mixed model, 2009 and 2013 are plausible dates for slope changing regimes also exactly coinciding with Brent prices shifts. This feature supports the importance of the immediate stabilization of oil prices occurring around March 2012, common to oil and Spanish gas prices and before the severe downturn post-2014. Consequently and given the nature of events in late 2014, it can

also be inferred that crude oil supply-demand fundamentals were the main driver of SGP dynamics since 2002.

- Results for NBP and coal prices show a different behaviour to SGP, as those commodities are mainly determined by conditions specific to their own market dynamics. Interestingly, the effects of the financial crisis on NBP prices is not as relevant as market events resulting from LNG oversupply conditions and sporadic gas market events, reinforcing the idea that UK gas market fundamentals more than external events are more influential regarding the NBP market. As an example, we found that the strong effects from the active hurricane season during the third quarter of 2005 or the situation around July and August of 2007 with high levels of gas storage in the US previous to the earthquake in Japan around mid-July 2007 seem to be more relevant than the 2008 financial crisis. In the case of coal markets, there is a perception that events affecting price shocks are more widely spread too.

6.4.3 Unit root testing methodology

Firstly, it is important to mention that the application of a well-structured unit root testing strategy allowing for breaks in the trend has been essential to providing improved results over traditional generic root testing methodology (Perron, 1989) but also to develop an organized framework for testing producing a large number of relevant outcomes. Although, as discussed, other approaches have been proposed in the literature, especially those based on the assessment of the presence of a structural change without any prior knowledge as to whether the noise component is stationary or contains an autoregressive unit root, these alternatives are those possibly presenting greater uncertainty in trend break detection from the pre-tests used. Simulation results suggest that this problem becomes increasingly pronounced the greater the number of breaks in the series other things being equal. Unsurprisingly drawbacks using that framework may lead to serious power and size distortions. In this regard, our decision to develop a strategy mainly based on endogenous unit root testing procedures facilitates the integrated approach to stationarity assessment but also improves break-dating analysis. Main conclusions related to the methodology employed are:

- Results confirm that in general testing for unit root endogenously maintains the difficulty in rejecting the unit root hypothesis in finite samples (Perron 1989) but also stronger support for convergence using LM unit root tests, this in line with relevant literature analysing economic series (Berk and Roberts, 1995, Lee and Strazicich, 2004). Moreover, we couldn't find under the scope of our investigation significant difference using pre-testing methods, leading to think that perhaps the consideration of the nature and dating of the break itself would not be a so relevant issue supporting the controversy over the persistence of crude oil related products.

- According to the literature, it seems reasonable to assume that LS procedure would offer an improvement over ZA and LP methods. As discussed, these tests are oversized, i.e., tend to over-reject the null whereas LM tests performance, especially for the two-break crash model, is stable for small breaks. Similarly to one-break tests, both LS tests provide a similar characterization in favour of the stationary/trend-break hypothesis for NBP prices. This consideration reinforces stationarity properties of NBP but neglects stationarity of SGP series revealed by LP tests. In regards to break date detection capabilities, however, the outlook is reversed, and as exposed in the literature, we corroborate that LS tests have difficulties in this area.
- In general, results reveal the additional advantage of the two-break test regarding detection of a second breaking point stressing the similarities and differences relevant for understanding the time series behaviour. Both LP and LS procedures, give more importance systematically to changing-slope events (Mixed model) than to level variations (Crash model) except in the case of NBP prices. This could be an indication that NBP prices are less affected by cycles and more by regular gas hub market events influencing price levels. In this sense, it can be concluded that SGP prices dynamics clearly follow Brent prices cycles away from traded gas hub patterns and in this sense being less affected by shift changes in level.
- In terms of test type results related to SGP and Brent prices, endogenous models using innovational outlier specifications are seen to reflect long-term dynamics better as affected by market fundamentals either as a shift on level or regarding a change of slope, i.e., anticipating events as early as 2010. Interestingly, when considering the impact of the break almost instantaneously, i.e., within a month time, as per Lanne et al. (2001), results are rather different, and equity market shocks associated with greater volatility in 2008-2009 seem to be more influential than events in 2014, curiously except for Brent. This finding reveals in our view that when considering the effect over a shorter period, SGP prices seem to be slightly more sensitive in sentiment to fast and sudden unexpected events rather than to crude oil market-related forces.

As discussed above, it can be concluded that Brent oil is the clear driver of Spanish gas prices, especially in changing slope patterns whereas other traded commodities evolve in rather different patterns, being especially reactive to each market conditions in levels.

6.4.4 Recommendations

These results have significant consequences for economic analysis, forecasting, and policy-making decisions. In particular, the prediction of oil and oil products prices is shown to depend critically on whether series are modeled as differenced or trend stationary. Interpreting rejections of the unit root null as a reflection of long-term trends that are smooth with

occasional large shocks instead of changes in the drift of the $I(1)$ process introduces a significant enhancement for inference also in the shorter term. In the case of traded NBP volumes, it reinforces the idea of mean-reversion over business cycle horizon, this consistent with this commodity being sold according to supply-demand conditions where prices typically revert to a long-run marginal cost reference, which changes only slowly. Within this context, the fact that events like the financial crisis in 2008 or the oil crash in 2014 seem not to result in permanent deviations from the steady growth path means that highs and lows of these commodities would have an ongoing impact in the long-run.

In the case of Spain, it would be expected that given the prevalence of transitory, short-terms effects of NBP traded gas, increasing penetration into oil-driven local markets should result in stronger mean reverting properties in MIBGAS market. From a market point of view, these results are promising and could provide a ground for further assessment of near-term gas trade in a traditionally long-term gas market as Spain. At the other end of the spectrum, coal reveals itself as strongly difference-stationary implying a more difficult proposition regarding price modelling and policy stabilization measures as price shocks are mostly permanent, reinforcing the idea of an efficient market.

CHAPTER 7. COINTEGRATION ANALYSIS

As a necessary complement to Chapters 5 and 6, in this chapter, we complete our investigation of long-term relationships between Brent crude oil price and SGP using a wider scope of research into cointegration analysis. In essence, cointegration analysis attempts to reveal why, in the face of the many developments that can cause permanent changes in the dependent variable, SGP in this case, there might be some long-run equilibrium relation, represented by some linear combination of them. Moreover, as a result of the modelling approach used to analyse the potential cointegrated relationship, this long-run link can be quantified. Ignoring the cointegration aspect in time series may lead to a spurious regression problem, which occurs if arbitrarily trending and non-stationary series are regressed on each other.

7.1 Introduction

As shown by Granger and Newbold (1986) using linear regression on non-stationary time series data could produce spurious correlation since standard detrending techniques can result in data that are still non-stationary. For integrated $I(1)$ processes, Granger and Newbold (1986) showed that de-trending does not work to eliminate the problem of spurious correlation and that the superior alternative is to check for cointegration. Two series with $I(1)$ trends can be cointegrated only if there is a stationary relationship between the two. Since then, testing for cointegration has become a crucial tool to test the hypothesis concerning the relationship between two or more variables having unit roots. The usual procedure for testing hypothesis concerning this relationship might be biased if the non-stationary variables are cointegrated. Therefore, investigating into cointegrating relationships adds significant value to the debate concerning commodities price paths. It does not come as a surprise in this case that deep investigation into cointegration characteristics of energy commodities such as crude oil, natural gas, electricity, and even agricultural commodities or metals has been gaining momentum in the last years.

7.2 Materials and definition

7.2.1 Johansen Maximum Likelihood (ML) procedure

We use, similarly to Chapter 5 prices in levels of Brent crude oil, SGP, gasoil, low sulphur fuel oil, NBP, and coal in levels over the period 2002 - 2016, a time-frame consistent with the analysis in previous chapters that will also help to assess Spanish gas market evolution and competition standards. It needs to be noted that although taking log prices would have been a reasonable step to for ensuring linearization, for our purposes in this chapter this procedure has, however, the disadvantage of losing valuable information. By contrast, the aim of the

cointegration analysis is to detect any stochastic trend in the real value of price data and use these common trends for a dynamic analysis of correlation in returns at a later point (Alexander, 2001).

Throughout the chapter, we will be using the Johansen test, a test for cointegration that allows for more than one cointegrating relationship¹²¹, and therefore enables harmonized information to be produced among the variables involved. In this way, we are able to extract organized information about Spanish gas price links with crude oil but also with other previously selected variables. The fact that there might be a long-run relationship between crude oil prices and the price of the different energy variables, SGP included, might be an indication that there is a long-run relationship between the prices of those variables themselves. If this is the case, a more profound market integration would exist indicating that a change in crude oil prices would imply a response in the relative price of the other energy markets by adjusting production mix. It has to be noted though that since the relation between Brent and SGP is linear, leaving market factors aside, we take the view that linear cointegration methods are suitable for our purpose and only the linear test for cointegration is performed. However, theoretical studies might suggest that the adjustment between crude oil and other variables such as gasoil or coal may call for nonlinear threshold cointegration rather than a linear cointegration model.

Based on previous research in Chapter 5, the order of integration of the variables in levels is first assessed. In contrast to Engle and Granger (1987), the framework established by Sören Johansen allows for the feature of self-cointegration. In other words, in the quite popular likelihood-based VAR cointegration technique due to Johansen, one only needs to take care that all variables are either $I(1)$ or $I(0)$. The procedure produces a set of results which can be used to determine the number of cointegrating vectors present. There will be possible $x-1$ vectors, where x are the number of variables included in the model. Based on this result, the long-run coefficients can then be determined, and the resultant error correction model produced resulting in two sets of coefficients: one set representing the long-run path and another set which are the speeds of adjustment and roughly equal to the error correction term. The technique produces two statistics, the likelihood ratio test based on maximal eigenvalue of the stochastic matrix and the test based on trace of the same stochastic matrix which inferences might be a little bit different. The standard approach to the Johansen ML procedure is first to calculate the Maximum Eigenvalue and Trace statistics and then compare these to the appropriate critical values. More in depth, the test is based on an examination of a matrix π that can be defined as the product of two matrices:

¹²¹ Unlike the Engle-Granger method although it follows the same principles.

$$\pi = \alpha\beta'$$

The matrix β gives the cointegrating vectors, while α gives the amount of each cointegrating vector entering each equation of the VECM, also known as the ‘adjustment parameter’. With regards to the two main statistics usually employed, the main difference between the two lays in the consideration of the null hypothesis. In the case of the Trace test this is a joint test where the null hypothesis is that the number of cointegrating vectors is less than or equal to r , against a general alternative that there are more than r . Alternatively, the maximum Eigenvalue test conducts separate tests on the individual eigenvalues, where the null hypothesis is that the number of cointegrating vectors is r , against an alternative of $(r+1)$. The two statistics are:

$$\lambda_{Trace}(r) = -T \sum_{i=r+1}^g \ln(1 - \hat{\lambda}_i)$$

$$\lambda_{Max}(r, r+1) = -T \ln(1 - \hat{\lambda}_{r+1})$$

Where $\hat{\lambda}_i$ is the estimated value for the i th ordered eigenvalue from the π matrix. The standard approach to the Johansen ML procedure is first to calculate the Trace and Maximum Eigenvalue statistics, then compare these to the appropriate critical values.

7.3 Empirical results

7.3.1 Granger causality test

Although, as discussed before, the connection between Brent oil prices and SGP is established through the direct link in the long-term gas contract formula, to evaluate the strength¹²² of the link a previous statistical evaluation is needed. To do this, we use the Granger (1969) approach to the question of whether, and to what extent, Brent causes SGP and how much of the current SGP can be explained by past values of Brent. In our case, SGP is said to be Granger-caused by Brent if this helps in the prediction of the former, or equivalently if the coefficients on the lagged are statistically significant. It is important to note that Granger causality measures precedence and information content but does not by itself indicate causality in the more common use of the term.

¹²² Previous to quantify the level of exposure and the numerical relationship between the variables.

Effectively, we use the well-known Granger Causality Test. In this test the null hypothesis is that, given two variables A and B the B does not Granger Cause A. In our case, we specify the two series, e.g., SGP and Brent, along with the significance level and the maximum number of lags, i.e., 5% and 12 respectively in our case. The test produces a F-statistic for the Granger Causality Test along with the corresponding critical value. We reject the null hypothesis that Brent does not Granger Cause A if the F-statistic is greater than the critical value. The results from the test on levels are shown in Table 33 below.

<i>Null hypothesis</i>	<i>F-Statistic</i>	<i>p</i>
SGP does not Granger cause Brent	0,9223	0,5266
Brent does not Granger cause SGP	10,8236	$0,4 \cdot 10^{-15}$
GO does not Granger cause Brent	2,2595	0,0119
Brent does not Granger cause GO	2,1625	0,0165
LSFO does not Granger cause Brent	0,8201	0,6295
Brent does not Granger cause LSFO	1,7717	0,0582
NBP does not Granger cause Brent	1,2284	0,2692
Brent does not Granger cause NBP	2,2676	0,0116
Coal does not Granger cause Brent	1,1747	0,3067
Brent does not Granger cause Coal	3,7648	0,0001

Table 33_Granger causality tests results

As it can be seen, considering Brent as the independent variable, the F-statistic is higher than the 5% critical value for all the variables considered, except for LSFO. Thereby the null hypothesis that oil price shocks do not cause a change in those variables, except for LSFO can be rejected. Concerning the causation of SGP, results show overwhelmingly that Brent Granger-causes SGP as it was to be expected. Interestingly and in line with other results in previous chapters demonstrating that fuel oil is not a relevant predictor of SGP, Granger cause of fuel oil with respect to Brent oil prices appears not to be significant.

7.3.2 Cointegration background

As discussed in Section 2.3, a significant number of empirical studies have investigated the relationship between crude oil and other commodities using the cointegration approach. However, little investigation has been done into links with long-term gas prices in this respect. In this section, we test the presence of linear cointegration between SGP and Brent crude oil but also with the rest of selected energy prices following the necessary methodology developed by Johansen (1995) using the ML estimator. The advantage of using this estimator is that it gives asymptotically efficient estimates of the cointegrating vectors and the adjustment parameters, but it also permits hypothesis testing for the parameters in the possible cointegration vector

(Johansen and Juselius, 1990). The basic relationship that will be considered for testing SGP cointegration resulting in a linear combination that is stationary through testing the linear regression residuals ε_t for stationarity, is as follows:

$$SGP = \delta + \beta_1 \text{Brent} + \beta_2 \text{GO} + \beta_3 \text{LSFO} + \beta_4 \text{NBP} + \beta_5 \text{Coal} + \varepsilon_t \quad (3)$$

Where δ is a constant that captures differences in the levels of the prices and β ¹²³ establishes the long-term trend between both prices through a separate contribution of each explanatory variable in determining the SGP¹²⁴. This equation describes a situation where prices although generally unstable in their levels, exhibit mean-reverting spreads (generalized by the cointegrating relation) that force the variables to move around common stochastic trends what would not be realistic in the short-term. To avoid this, we approach our investigation through dynamic cointegration analysis and the development of a vector autoregressive error correction model (VECM)¹²⁵ that will allow us to determine cointegration quality testing as well as potentially exogeneity testing for the variables. Similarly to VAR modelling a VECM model overcomes the problem of endogenous variables as all the explanatory variables are lagged, which are assumed to be pre-determined or exogenous and all the equations are exactly identified, whereas the non-lagged variables are not used as explanatory variables¹²⁶. Finally potential to produce impulse response functions add flexibility to determine the effects of a shocks of any of the variables to the VECM. The Johansen test is based on a vector autoregressive error correction model (VECM) that can be written as:

$$\Delta y_t = -\Pi y_{t-1} + \sum_{i=1}^{n-1} \Phi_i \Delta y_{t-i} + \varepsilon_t \quad (4)$$

Where π is a matrix containing the long-term parameters¹²⁸, i.e., α and β whereas φ_i are the coefficients that measure the cumulative long-term effects instead of pure transitory

¹²³ β coefficients represent the long-run vector. An alternative interpretation is that the β coefficients represent each cointegrating vector entering each of the VECM equations.

¹²⁴ This is also known as the Law of One Price (LOP)

¹²⁵ A VECM is more appropriate to model macro and several financial data. It distinguishes between stationary variables with transitory (temporary) effects and nonstationary variables with permanent (persistent) effects.

¹²⁶ In short, using the Johansen test we are sure that the cointegration test is invariant to the ordering of variables

¹²⁷ If the variables in y_t are all $I(1)$, the terms involving differences are stationary, leaving only the error-correction term to introduce long-term stochastic trends. The rank of the impact matrix π determines the long-term dynamics. If π has full rank, the system is stationary in levels.

¹²⁸ In general, there may be multiple cointegrating relations among the variables in y_t , in which case the vectors α and β become matrices A and B, with each column of B representing a specific relation.

effects. As an example, when two variables are cointegrated, the VECM formulation is of the type:

$$\begin{aligned}\Delta y_t &= \beta_{y0} + \beta_{y1}\Delta y_{t-1} + \dots + \beta_{yp}\Delta y_{t-p} + \gamma_{y1}\Delta x_{t-1} + \dots + \gamma_{yp}\Delta x_{t-p} \\ &\quad - \lambda_y (y_{t-1} - \alpha_0 - \alpha_1 x_{t-1}) + v_t^y \\ \Delta x_t &= \beta_{x0} + \beta_{x1}\Delta y_{t-1} + \dots + \beta_{xp}\Delta y_{t-p} + \gamma_{x1}\Delta x_{t-1} + \dots + \gamma_{xp}\Delta x_{t-p} \\ &\quad - \lambda_x (x_{t-1} - \alpha_0 - \alpha_1 y_{t-1}) + v_t^x,\end{aligned}\tag{5}$$

This equation incorporates both short-run and long-run effects, captured by coefficients (delta) and (lambda) respectively. Actually (lambda) is the so called long-run adjustment coefficient which measures how fast SGP converges towards the long-run equilibrium.

To start, we confirm that all the variables considered are non-stationary and first order integrated. Although included in Chapter 5, Table 27 shows the results of the test performed including a trend that accounts for the alternative that the series is trend-stationary (ADF test) or accounting for a linear trend where the null is $I(0)$ (KPSS test). AIC determines the number of lags through the testing exercise¹²⁹. From that, it can be seen that both tests provide strong indications that both levels and log- prices are nonstationary. It has to be highlighted though that in the case of the NBP series, considering other unit root testing approaches as in Chapter 6 but also shorter time frames, NBP prices reveal a weak case for nonstationarity that leads to conclude that they might be trend stationary¹³⁰ (this also in line with results in Asche et al. , 2012). In any case and for consistency of results throughout the thesis, we initially assume that NBP prices can be considered embedding enough persistence to proceed with cointegration testing to investigate the dynamics of relationships between each of them. Out of precautionary considerations and although we mainly focus on the characteristics of the long-run price relationships embedded in the SGP series, inconsistencies related to other variables such as NBP, are highlighted during the cointegration analysis.

7.3.3 Identifying multiple cointegrating relations

¹²⁹Akaike Information Criterion: the most suitable model has the lowest value of the Akaike information criterion.

¹³⁰ Previous ADF results by Authors considering the period 2002 to 2013 reject the null of a unit root for NBP prices (results not shown in the analysis).

We start the analysis by determining the number of single cointegrated realities within the selected variables. It needs to be said that the modern approach to cointegration testing originated with Engle and Granger (1987) by simply regressing the first component of y_t on the remaining elements of the time series and test the residual for unit root thereafter¹³¹. Unfortunately, the Engle-Granger test is less appropriate for a multivariate analysis, compared to the Johansen ML procedure, because it fails to account for the simultaneous equation bias, whereas the Johansen approach is able to overcome the problem. The Engle-Granger test also has low power and might accept the null of no cointegration when in fact it is present. The selection criteria for the optimum lag length¹³² in the original VAR model is made based on BIC criterion¹³³. In this case, a VAR model with two lags is preferred over the rest. The lag length chosen to whiten the error term for autocorrelation suggested four lags. Lagrange multiplier for the presence of autocorrelation up to 10th lag analysis and Jarque Bera tests are not reported.

Following on this, we proceed with the two standard cointegration tests to determine the rank of the coefficient matrix π , i.e. ,the trace and eigenvalue test, are reported in Table 34 below. Both test statistics have non-standard distributions, which are a function of the multivariate Wiener process. Critical values have been tabulated by Johansen (1988). The two tests examine sequentially the possibility of no cointegrating relation against the alternative that there are cointegrating relations, and then the null of one cointegrating relation against the possibility of two cointegrating relations.

¹³¹ The null hypothesis is that the series y_t are not cointegrated, so if the residual test fails to find evidence against the null of a unit root, the Engle-Granger test fails to find evidence that the estimated regression relation is cointegrating.

¹³² The number of lags to use in the model at the beginning is unknown. The selection methodology starts with an initial maximum of p lags which are assumed to be more than necessary. Residual diagnostic tests like normality, serial correlation, and heteroskedasticity are conducted, and the VAR system is tested for stability. The goal is to obtain results that appear close to the assumption of white noise residuals.

¹³³ We follow general econometric standards as follows:

- a) for forecasting, AIC will asymptotically select the model with the smallest squared forecast error (AIC is said to be efficient),
- b) to find the true model, BIC will asymptotically find it (BIC is said to be consistent) and
- c) to test some hypothesis, it would be generally better to build a model within which this is feasible (e.g. with the likelihood ratio test).

$H_0 : \text{rank}=P$	h	Trace Test	Critical Value (5%)	p-value	h	Max test	Critical Value (5%)	p-value
$P=0$	1	222.05	95.75	0.001	1	112.75	40.08	0.001
$P \leq 1$	1	109.30	69.82	0.001	1	57.84	33.88	0.001
$P \leq 2$	1	51.46	47.86	0.022	1	29.75	27.59	0.026
$P \leq 3$	0	21.71	29.80	0.348	0	11.39	21.13	0.630
$P \leq 4$	0	10.32	15.49	0.286	0	7.15	14.26	0.522
$P \leq 5$	0	3.17	3.84	0.075	0	3.17	3.84	0.075

Table 34_Multivariate Johansen test for SGP and rest of products

As it can be seen, the null hypothesis is rejected for ranks up to 2, while the null hypothesis is not rejected for the ranks from 3 to 5. These results show evidence of cointegration among the six series, which move together with a mean-reverting spread according to three cointegrating vectors. Both the maximum eigenvalue test and the trace test suggest that there are three cointegration vectors in this system, and accordingly, three stochastic trends. Both statistics are higher than 95% critical value regarding results for a cointegration rank less than or equal to $r=3$ what translates into cointegration rank being equal to three (number of variables in the system minus the number of cointegrating vectors: $6-3=3$). As it can be seen, in this case, cointegrating vectors are the same as cointegration order being equal to three. Three linear combinations in line with three cointegrating vectors result therefore in stationarity. In short, the null hypothesis which denies first-degree cointegration between the series is rejected up to three cointegration rank because hypothesis test results are higher than the corresponding 95% critical values.

There are two possible explanations for these results: either two of the price series in the system have an independent stochastic trend and therefore do not belong in the system, or for some price series there are cross-links between at least two sets of variables independently of each other. To be specific about which the same stochastic trend links prices, independent bivariate cointegration tests are conducted. The results reported are on Table 34 with shaded figures when cointegration at some levels has been found.

Variables	$H_0 : \text{rank}=P$		Max Test		Trace test
SGP-Brent	$P=0$	1	21.9966	1	25.7514
	$P \leq 1^*$	0	3.7548	0	3.7548
SGP-GO	$P=0$	1	16.8259	1	20.3131
	$P \leq 1^*$	0	3.7990	0	3.4873
SGP-LSFO	$P=0$	0	11.0794	0	14.8784
	$P \leq 1^*$	0	3.7990	0	3.7990
SGP-NBP	$P=0$	1	21.5453	1	25.1432
	$P \leq 1^*$	0	3.5980	0	3.5980
SGP-Coal	$P=0$	1	24.4037	1	29.5449
	$P \leq 1^*$	1	5.1413	1	5.1413
Brent-GO	$P=0$	1	21.7531	1	27.9863
	$P \leq 1^*$	1	6.2333	1	6.2333
Brent-LSFO	$P=0$	0	8.2151	0	13.0601
	$P \leq 1^*$	1	4.8451	1	4.8451
Brent-NBP	$P=0$	1	19.8155	1	23.3971
	$P \leq 1^*$	0	3.5815	0	3.5815
Brent-Coal	$P=0$	0	7.0030	0	11.9074
	$P \leq 1^*$	1	4.9044	1	4.9044
GO-LSFO	$P=0$	0	8.3267	0	13.4952
	$P \leq 1^*$	1	5.1685	1	5.1685
GO-NBP	$P=0$	1	14.2884	1	17.6215
	$P \leq 1^*$	0	3.3331	0	3.3331
GO-Coal	$P=0$	0	8.3726	0	12.1714
	$P \leq 1^*$	0	3.7987	0	3.7987
LSFO-NBP	$P=0$	1	17.2431	1	20.3070
	$P \leq 1^*$	0	3.0639	0	3.0639
LSFO-Coal	$P=0$	0	9.8730	0	9.8730
	$P \leq 1^*$	0	2.6189	0	2.6189
NBP-Coal	$P=0$	1	26.0497	1	24.0497
	$P \leq 1^*$	1	7.0008	1	7.0008

Critical values at a 5% level for the Max test are 14.264 and 3.841 and for the Trace test 15.495 and 3.841

Table 35_ Bivariate Johansen test for SGP and rest of products

Results indicate that coal is not cointegrated with any of the other variables, suggesting that the price of this product is independent of the crude oil price. Interestingly, there seems not to be a clear cointegration relationship between Brent and Gasoil or fuel oil prices, this possibly as a result of fractional integration properties of refined products. Since all the prices appear to be cointegrated, other than coal, there is a strong indication that for at least one of the price series the relationship is weaker than the bivariate relationship suggested in Table 35. In this case and based on previous research we tend to think that fuel oil is not cointegrated in

reality with any of the other prices¹³⁴. Furthermore the weak link detected between fuel oil and NBP prices seems not plausible.

Expanding the analysis further, Figure 55 shows (top chart) the three cointegration vectors found and therefore the three potential cointegration relationships. When we analyse cointegration patterns of all the variables except fuel oil and coal, we find that also three cointegration relationships are found, similar in appearance to the former three cointegration relationships found for all the variables (bottom chart). This leads us to think that a close long-term relationship between SGP, crude oil, gasoil, and NBP exist, implying that the Spanish gas market is integrated with those markets. As a matter of fact, this link might be caused not only by the direct connection between SGP and crude oil but also through the relationship between NBP and Brent prices in the long-run.

Figure 55_Cointegration relations

¹³⁴ See Ashe et al (2003) and Gjølberg and Johnsen (1999) that provide evidence against the relationship between the prices of heavy fuel oil and crude oil.

In addition, the test for cointegration relationships produces maximum likelihood estimates of the coefficients of the VECM model with lag 1. In the case of the cointegration relationship between SGP and Brent and considering one lag in the VECM model indicates the slope of around 8% as a long-term stochastic trend for Spanish gas prices, this in line with experience in the market. Figure 56 shows this relationship including suggested intercept (data in \$/MMBtu).

Figure 56_VECM model long run relationship

Although a test for weak exogeneity would be necessary to reinforce the idea that Brent price is the price leader for the rest of variables (except fuel oil and coal), we rely on the extensive work already performed in this respect (Asche, 2003; 2012), clearly indicating that weak exogeneity cannot be rejected for crude oil while it can be rejected for refined products including gasoil and fuel oil. Those results would demonstrate that crude oil is the driving factor in the price generating process globally and that it is crude oil which connects the price series, all except fuel oil and coal, in the long-run.

7.4 Conclusion and recommendations

As described in the previous chapters and in spite of the fact that oil prices dominate the pricing formula for the long-term gas contracts in Spain, the fact that the gas market gradually will become fully deregulated may lead to changes in the way gas in Spain, assuming infrastructure limitations are considered, is priced. In order to respond to one of the

fundamental question raised, i.e. which is, and to what extent compared to other variables, SGP is affected by crude oil prices in the long-run and even more, is there a single long-term market clearly driven by Brent prices, we provide some insight in this chapter on these questions by testing for market integration.

Using multivariate Johansen tests allows us to investigate into cointegration properties of the selected variables and especially regarding the nature of the long-term relationship between crude oil price and Spanish gas prices. Our results indicate that there is a long-run relationship between the prices of crude oil and gasoil, NBP, and SGP. However, no such clear relationship between the prices of any of those variables and fuel oil or coal is found. In this sense, we ratify that it seems that the production and market fundamentals of fuel oil and coal markets are not affected by or affect demand for crude oil-related products.

The fact that there exists a long-term relationship between the SGP and the prices of Brent oil, gasoil, and NBP, but not between SGP and fuel oil or coal, may indicate that the linear relation with Brent of Spanish gas prices leads to complex connections with other global markets. In this sense, the influence of crude oil long-term trends on Spanish gas prices sets a links with NBP gas developments. Moreover, the missing connection between SGP or NBP with fuel oil or coal implies that there is no supply driven integration of these two global markets with gas markets.

Although not included in the analysis the fact that crude oil is weakly exogenous implies that in the long-run, changes in crude oil prices feed through some refined products but also through SGP and NBP prices. Hence the production variability and dynamics of crude oil will affect demand for the other products. A possible interesting area for further research involves the analysis of the short-run movements of the variables analysed but also the assessment of the proportional prices hypothesis and constant relative spreads between variables.

CHAPTER 8. ANALISIS OF OIL PRICE VOLATILITY AND SPANISH WHOLESALE PRICE RELATIONSHIP

Although persistence on the mean has been thoroughly investigated in Chapter 6 with a particular focus on the influence of structural breaks and changes in the trend across different regimes, this Chapter discusses the underlying relationship between oil and natural gas in Spain from a different angle. Our main concern here is the prospect for measuring and quantifying volatility in both SGP and crude oil prices to extract common predictability patterns and understand the volatility features that might be expected in SGP as a result of the analysis.

In this sense, the goal of this Chapter is twofold: on the one side to characterize a good volatility model by its ability to forecast and capture the commonly held stylised facts about conditional volatility. The stylised facts include such features as the persistence in volatility, its mean-reverting behaviour and the asymmetric impact of negative versus positive return innovations and the possibility that exogenous Brent crude oil prices may have a significant influence on SGP volatility. On the other side, as persistence often manifests as volatility clustering, a distinctive feature suggesting that the conditional variance of the return series may not be constant, we introduce an index to measure volatility clustering. In this manner, we are able to characterize the degree and nature of volatility clustering in Spanish gas prices in view of Brent influence. This index is calculated using a moving window reference to obtain valid rolling indicators related to volatility clustering effects in different periods.

8.1 Introduction

Knowledge about the persistence of volatility can enable researchers to obtain more efficient parameter estimates, as persistence suggests that current volatility can be predicted. Moreover, testing volatility effects of crude oil into Spanish gas prices may reflect in turn the level of influence of the most actively traded commodity on the development of Spanish gas events. As already discussed, crude oil prices display a high level of persistence, and therefore price shocks are likely to be long-lasting rather than short-term. In our case, examining the temporal properties of SGP and crude oil prices provides the level of granularity required to understand better what is driving the changes locally and how the underlying process can be measured. Furthermore, implications of this analysis for regulatory purpose and policy making are provided (Hubbard and Weiner, 1986)¹³⁵.

8.2 Material and definition

¹³⁵ One of the issues at debate is to what extent domestic policies or internationally coordinated efforts to restrain oil price increases can be beneficial. One such policy initiative is the release of oil held stockpiles. In this sense, uncertainty over the path of oil prices plays an important role explaining inventory behaviour.

8.2.1 Background

In line with our thesis work, the selected time scope accounts for a broad period of fifteen years, i.e., from 2002 to 2016, also coinciding with a fascinating period in the Spanish gas market that continues to undertake additional efforts to attract open gas market competition but at the same time consolidate a reliable and modern gas supply base, this effects leading to changing dynamics in Spanish gas prices. Also in line with the methodology for the data collection, we base our investigation on the main information publicly available in Spain for wholesale gas prices and in particular that provided by the regulatory body the CNMC.

Figure 57 displays time variations of monthly crude oil spot, SGP and NBP prices over the study period consistent with the special focus on these three variables in this Chapter. A consistent set of units has been selected for Brent crude oil prices, and for SGP and NBP prices. As can be seen, Brent crude oil and gas data sets share large swings in common taking into account the lagging effect of oil indexation and the smoothing effect of rolling average used in the gas price formulas. Not surprisingly both price series show a similar upward trend and reflect similarly two major events happening in the period: the credit crunch in 2008 pulling down the trend line with no clear indication of mean reversion and also the collapse of oil prices since late 2014 as a result of a serious oversupply situation. Common peaks are observed at the beginning of 2003, at the start of 2007, in mid-2008 and at the beginning of 2012. Conversely, shocks affecting NBP prices over the sample period are not necessarily similar as it can be seen at the beginning of 2006 with soaring NBP prices. It is interesting to realize that in spite of a well-connected LNG market worldwide, Spanish gas prices show a very limited response to other than crude oil- related fundamentals.

Figure 57_Evolution of Brent, Spanish Gas, and NBP prices

Regarding seasonality features of Spanish gas prices, a preliminary analysis reflects the potential for minor seasonal effects on a monthly basis supported by some beliefs that crude oil tends to have strong and weak months of the year (Ye et al., 2005). A deeper investigation into crude oil and SGP seasonality would not seem necessary to improve the quality of results whereas it will drastically increase the complexity involved.

Descriptive statistics for oil, gas and NBP prices returns series are summarized in Table 36. The SGP price had a small positive average return of about 3% per month with Brent returns marginally higher. Brent prices are the most volatile, measured by the coefficient of variation (44.30) slightly greater than that of NBP prices. All three markets show positive average returns indicating somehow tight supply conditions over the sample period as larger jumps outweigh smaller jumps. Interestingly, although not shown in the table, in the US and as a result of the discovery of hydraulic fracturing, Henry Hub prices, reflecting current supply and demand fundamentals in the country, show negative average gas returns.

	Brent		Spanish Gas Price		NBP Price	
	Prices	Returns	Prices	Returns	Prices	Returns
Number of observations	180	180	180	180	180	180
Mean	69,90	0,07	6,99	0,04	6,84	0,12
Standard deviation	30,97	0,06	2,43	0,03	2,87	0,10
Coefficient of Variation	44,30	85,71	34,80	75,00	41,86	83,33
Skewness	0,20	1,58	0,02	2,05	0,29	1,31
Kurtosis	1,78	6,06	1,74	9,71	2,57	4,59
Minimum	44,70	-0,04	4,78	-0,02	4,38	-0,09
1st Quantile	19,42	-0,31	2,93	-0,22	1,77	-0,48
Median	64,26	0,02	6,76	0,01	6,73	0,00
3rd Quantile	102,59	0,07	9,57	0,03	9,27	0,08
Maximum	132,72	0,20	11,57	0,13	16,68	0,49
JB test	1	1	1	1	0	1
JB Critical Value	5,65	5,65	5,65	5,65	5,65	5,65
JB Statistic	12,45	40,35	11,91	76,71	3,87	5,73
JB p-value	0,01	0,00	0,01	0,00	0,11	0,05

Table 36_Descriptive statistics for Brent oil (\$/bbl), SGP and NBP (\$/MMBtu)

As discussed in Chapter 6, regarding the statistical distribution of price levels, oil and gas series reveal similar evidence of positive skewness and negative excess kurtosis giving each series a long right tail but thinner tails overall. SGP returns display the highest kurtosis value (9.71) implying a strong leptokurtic distribution in line with many studies carried out on financial and crude oil series. In these studies, heavy tails in return distributions have always been observed despite the fact that no consensus has been reached on the exact form of the tails

(Tseng and Li, 2012; Auer and Schumacher, 2014). Moreover, these infrequent but extreme deviations anticipate that SGP prices are not truly independent and identically distributed (iid) (Charles and Darne, 2014). Crude oil and SGP returns departure from normality is confirmed by the Jarque - Bera (1987) test (see Table 36) that strongly rejects the null hypothesis of normality showing some extreme behaviour of returns versus open traded markets like the NBP market for which the Jarque-Bera test statistics accepts normality on prices.

To test the stationarity or non-stationarity of the price series we have considered ADF and KPSS test on log prices in levels and first differences (see Table 27). It has to be noted that throughout the testing process we have included a constant and a linear trend, i.e., the more general specification since we believe that it is a plausible description of the data under both the null and alternative hypotheses (Hamilton, 1994). In order to specify the number of lagged difference terms, i.e., lag length to be added to the test regression we use the Bayesian Information Criterion (BIC) to be consistent. Usual Ljung-Box Q-test to assess serial autocorrelation at the selected lags probe that in all cases a number of lags are sufficient to remove serial correlation in the residuals. Tests results indicate that none of the three variables is stationary at any conventional level. The ADF test does not reject the null hypothesis of a unit root for the levels of the three prices. The KPSS test, in which the null hypothesis is stationarity, indicates that the null is rejected for the level forms of all series. When the tests are applied to the first-differences of the variables, the results strongly imply that all variables are stationary, being integrated of order one, i.e., $I(1)$.

As a consequence of the preliminary investigation, it can be concluded that similarly to Brent oil price, accurate estimation of SGP prices given their inherent nature, would be highly unpredictable as their volatility could grow without binding in the long run. Moreover, the absence of stationarity also shows that there is no obvious arbitrage opportunity for the investors in the Spanish gas market, at least based on regular imported wholesale volumes.

8.2.2 Theory and calculation

8.2.2.1. Volatility clustering and nonlinear autocorrelation

As discussed before, and based on the impressive amount of information obtained over the last decade from financial markets and global commodities, researchers tend to agree on a few but an extremely representative set of stylized features, also applicable to crude oil markets. Interest on such characteristics like heavy tails in asset return distributions, persistence, volatility clustering or autocorrelation of squared oil returns are not purely academic but also associated with processes leading to improve forecasting uncertainty. It is worth noting that two of these features are found to be more relevant than others in regards to the characterization of volatility conditions. Firstly, shocks to the variance of returns and changes in conditional volatility that persist rather than dying down suggesting inherited persistence effects. Secondly and in addition to persistence, the fact that significant fluctuations seem to cluster together,

reveals itself as one of the underlying elements which help to begin to understand how volatility is affected by past realizations.

Commodity price volatility clusters and oil price, in particular, have been studied for some time now (Narayan and Narayan, 2007; Kuper, 2002; Vo, 2009) resulting in clear indications that large changes tend to be followed by large changes, and small changes tend to be followed by small changes. In this manner, large shocks of either sign are allowed to persist which can influence the volatility forecasts for several periods. Therefore, the accurate estimation of volatility is key to asset allocation, risk management, and derivative pricing, for instance. This clustering of large and small errors transmitted into SGP prices is apparent in Figure 57. A quantitative manifestation of this universal attribute of market data is that while returns themselves do not show the evidence of temporal correlations, the absolute returns or their squares do display a positive, pronounced slowly decaying autocorrelation which indeed exhibits power-law decay behaviour (Mandelbrot, 1963).

Figure 58 (top charts) show a comparison of autocorrelation for SGP returns with a sequence of absolute returns as an exponential function $|r(t)|^m$ for different power rates, i.e. 0.5, 1.25, 1.00 (SGP returns), 1.50 and 2 where the thin blue line stands for the critical value of 95% confidence interval. As it can be seen and although dependence of absolute returns declines as time lag increases in all cases, there exists evident volatility clustering features in the absolute returns as shown by the raising autocorrelation at higher power rate m .

Also, and in line with research in the area of finance (Tseng and Li, 2012; Cont, 2005; Wang et al., 2009) we also investigate on whether heavy tails and volatility clustering can be interconnected. To do this we compare SGP returns distributions with a Gaussian distribution, assuming this one to have the same mean and standard deviation of the monthly SGP returns series and no temporal correlations. As it can be seen in Figure 58 (bottom charts), when both gas and Gaussian series are reshuffled from the largest to the smallest value, the pattern of slow decaying behaviour is very similar. Moreover reshuffled SGP returns turn into a mere noise result analogous to the Gaussian series (this not shown). From here, it can be concluded that the slow decay behaviour in autocorrelation functions of absolute SGP returns is not related to its heavy-tailed characteristics but is directly related to the degree of clustering of the large fluctuations in the absolute returns.

Figure 58_ACF for absolute returns at exponential rate m (top) and Gaussian returns comparison (bottom)

8.2.2.2. The model

Empirical findings discussed in the previous sections together with experience in long-term gas contracting overwhelmingly support the fact that oil-driven stylized facts are also present in gas time series. Some of them appear to have more direct implications, i.e., skewness, kurtosis and heavy-tailed distributions but others are more complex and difficult to trace like those affecting volatility of returns. In this section, we aim to characterize a good volatility model for gas returns able to capture the above-stylized facts before analyzing differences and similarities with other GARCH-type analysis of oil prices dynamics.

There is a wide variety of studies addressing the performance of crude oil volatility but limited investigation into long-term gas contracts prices characteristics. In the literature of crude oil modelling, Generalized Autoregressive Conditional Heteroscedastic (GARCH) and Stochastic Volatility (SV) models have been widely applied to improve understanding of the stochastic process beneath crude oil prices (Kang and Yoon, 2009; Cheung, 2009; Sevi, 2014; Agnolucci, 2009; Narayan and Narayan, 2007; Mohammadi and Su, 2010; Wei et al., 2010; Kang et al., 2011; Charles and Darne, 2014; Hou and Suardi 2012) and to a lesser extent for gas prices (Reganrd, 2011). Moreover, autoregressive VAR, TVAR, VEC, VEC-GARCH, and DCC-GARCH framework has been widely applied to investigate spillover effects (Chang et al., 2010; Ji et al., 2014; Lin and Li,

2015; Souza et al., 2015). In addition, other specific modelling approaches like Markov regime switching (MRS) model, support vector machine (SVM), wavelet technique and a variety of hybrid methods combining the methods mentioned before, have also been used (Vo et al., 2009; Fong et al., 2002; Zhang et al., 2015b; Wang et al. 2016b). Possibly and in a category of its own the use of computational intelligence techniques to study the nonlinear, non-stationary and complex nature of crude oil prices has increased steadily in recent years (Chiroma et al., 2015; Li et al., 2016; Yu et al., 2016; Wang et al., 2016a). These computational intelligence algorithms include such as artificial neural network, genetic algorithms, expert system or hybrid intelligent system. Finally, limited research related to specific applications is also available, i.e., dynamic detection of fluctuation patterns (Gao et al., 2017) or hybrid models incorporating financial variables (Kristjanpoller and Minutolo, 2016). In summary, while crude oil markets form a complex system including non-linearities, multi-factor dimensions and are subject to the impact of structural breaks, forecasting methods are constantly emerging, and performance has been continuously improving.

The common strand in GARCH-type representations allowing a finite, time varying second-moment distribution of returns, addresses volatility clustering directly in the data and mitigates the problem of fat tails. Within this field, it is, however, difficult to identify a model that consistently dominates the other since model superiority is typically assessed about both the flexibility in capturing the stylized facts in which we concentrate, but also as regards to its ability to forecast¹³⁶ (Hansen, 2005; Cheung, 2009). Ample studies are addressing the accuracy of crude oil volatility modelling. Sadorsky (2006) for instance finds that the GJR model fits well for heating oil and natural gas volatilities, whereas the standard GARCH model fits are better for crude oil and unleaded gasoline volatilities. Narayan and Narayan (2007) favour the use of the EGARCH model, whereas Kang et al. (2008), conclude that the CGARCH and FIGARCH models are better to capture persistence in the volatility of crude oil prices. In contrast with this, Mohammadi and Su (2010) compared the forecasting accuracy of four GARCH models to suggest that conditional volatility of oil returns dissipate at an exponential rate as in the GARCH models rather than at a slow hyperbolic rate implied by the FIGARCH model. Wei et al. (2010) also conclude that none of the GARCH-class models, including the FIGARCH one, outperforms the others in all situations although nonlinear models like EGARCH or GJR-GARCH exhibit greater forecasting accuracy. More recently, Wang and Wu (2016) reveal that the multivariate GARCH model has better performance than the univariate GARCH model overall.

Modelling SGP returns, and their volatility is performed in three steps. The first step involves the specification of the ARMA (p, q) model for mean returns and diagnostic tests of

¹³⁶ It is important highlight that evaluating performance on out-of-sample forecasts may show an alternative proposal to model selection to capture stylized facts.

their residuals. The second phase is the specification of the GARCH (p, q) model for conditional volatility and its diagnostic tests. Thirdly we analyse asymmetric effects through extended GARCH models.

We begin by identifying and estimating an ARMA process for the mean. The autocorrelation and partial autocorrelation functions of SGP returns (not shown) suggest that data can be represented by an ARMA (3, 3) process, this different from standard random walk specifications on the mean for Brent and NBP returns or infrequent MA(1) specification Wei et al. (2010). Furthermore, Ljung-Box Q-tests suggest clear dependence only at lags 3 for SGP price despite multiple autocorrelation signals for Brent oil and NBP series (results not shown).

The following equation, therefore, gives the estimated ARMA (3, 3) model for SGP returns:

$$r_t = 0.0001 - 0.450 r_{t-1} + 0.447 r_{t-2} - 0.964 r_{t-3} + \varepsilon_t + 0.464 \varepsilon_{t-1} - 0.495 \varepsilon_{t-2} - 0.968 \varepsilon_{t-3} \quad (6)$$

Box-Pierce statistics computed from the residuals indicate that the ARMA (3, 3) process adequately accounts for the serial correlation in the data. However we still find evidence in the higher moments of the residuals that nonlinearity is present, i.e. we reject the hypothesis of 'no ARCH' effects. Engle¹³⁷'s tests for residuals indicate significant evidence in support of heteroscedasticity whereas autocorrelation of the squares of the ARMA residuals suggests dependence through order 2 in the ARCH process and 3 for the conditional variance GARCH process.

As discussed, the evidence gathered in the empirical literature on oil price volatility modelling, tends to support the view that GARCH models seem to work well in most applied situations in spite that there is potential for improvement through alternative methods (Hou and Suardi, 2012). However, to model volatility, and from experience in oil markets¹³⁸, is necessary to test the leverage effect of SGP returns. In line with this, three volatility models¹³⁹ - GARCH, EGARCH, and GJR-GARCH - are considered along with the report.

Following standard practice in the literature, model estimation is based on the maximum-likelihood principle once a distribution for the innovations, ε_t has been specified. Although we proceed from the assumption that the innovations are Gaussian, we also verify that

¹³⁷ Engle and Bollerslev, 1986.

¹³⁸ Evidence has been found for oil returns that 'bad news' have a higher capacity to generate high volatility than 'good news'.

¹³⁹ GARCH (generalized, autoregressive), EGARCH (exponential, generalized, autoregressive) and GJR (Glosten-Jagannathan-Runkle GARCH) models. Note that volatility of the EGARCH model is an explicit multiplicative function of lagged innovations. On the contrary, volatility of the standard GARCH model is an additive function of the lagged error which causes a complicated functional dependency on the innovations.

a t-distribution does not characterize the distribution of the returns better than the Gaussian distribution regarding volatility behaviour. In model selection, three indicators, i.e., the log-likelihood, the Akaike information (AIC) and the Bayesian information criteria (BIC) are used to evaluate the most appropriate models over alternative GARCH-type (p, q) models by varying p and q parameters from 0 to 3. As can be seen in Table 37, EGARCH shows superior results (largest log-likelihood and smallest AIC) to the rest. However, the GARCH (1, 1) was superior in BIC as this criterion imposes additional penalties for additional estimated parameters. This outcome is acceptable since EGARCH provides the richest range of parameterization to capture the stylized facts such as volatility clustering, leverage effect and long-memory in the volatility. We select within each class EGARCH (2, 1) as it has lower AIC, GARCH (1, 1) and GJR-GARCH (1, 1) for detailed diagnostics.

Model	Number of parameters	$\mathcal{L}$	AIC	BIC
G11	4	301.647	-595.294	-583.415
EG11	5	300.629	-591.258	-576.409
GJR11	5	301.652	-593.305	-578.456
G21	5	301.647	-593.294	-578.445
EG21	6	304.176	-596.353	-578.534
GJR21	6	301.652	-591.305	-573.486
G33	8	303.121	-590.242	-566.483
EG33	11	304.790	-587.581	-554.913
GJR33	11	303.291	-584.583	-551.915
G23	7	303.036	-592.072	-571.284
EG23	10	304.669	-589.337	-559.639
GJR23	10	303.420	-586.840	-557.142
G31	6	301.647	-591.294	-573.475
EG31	7	304.177	-594.354	-573.565
GJR31	7	301.652	-589.305	-568.516
G32	7	303.073	-592.146	-571.357
EG32	9	304.604	-591.209	-564.480
GJR32	9	303.282	-588.564	-561.836

Table 37_Model selection criteria

Table 37 presents the in-sample estimation results for the different volatility models discussed. The lower part of Table 37 shows some of the results of the diagnostic test on standardized residuals, i.e., a Q test on squared standardized residuals, an ARCH test, and a Jarque–Bera test.

The results reported for Ljung - Box Q and the Engle's Arch tests confirm that the three models appropriately reproduce ARCH effects revealing the absence of significant autocorrelation of ε_t^2 at the 95% confidence level.

SG returns									
	GARCH (1,1)			EGARCH (2,1)			GJR-GARCH (1,1)		
	Coefficients	Error	Statistic	Coefficients	Error	Statistic	Coefficients	Error	Statistic
C	0.007	0.003	1.954	0.006	0.003	2.110	0.007	0.003	1.958
K	0.001	0.000	1.630	-1.229	0.372	-3.305	0.001	0.000	1.526
GARCH(1)	0.531	0.186	2.853	1.507	0.138	10.952	0.536	0.196	2.737
GARCH(2)				-0.705	0.160	-4.395			
ARCH (1)	0.248	0.092	2.688	0.253	0.089	2.848	0.259	0.125	2.080
Leverage 1				0.020	0.049	0.398	-0.019	0.159	-0.118
Log(L)	301.647			304.176			301.652		
Ljung-Box Q-test	p-value	Qstat	Critical	p-value	Qstat	Critical	p-value	Qstat	Critical
p-value[2]/Q[2]/Critical	0.315	2.312	5.992	0.738	0.609	5.992	0.311	2.336	5.992
p-value[5]/Q[5]/Critical	0.357	5.513	11.071	0.664	3.234	11.071	0.336	5.706	11.071
p-value[10]/Q[10]/Critical	0.116	15.453	18.307	0.309	11.652	18.307	0.105	15.827	18.307
p-value[15]/Q[15]/Critical	0.197	19.377	24.996	0.405	15.665	24.996	0.183	19.713	24.996
p-value[20]/Q[20]/Critical	0.341	22.000	31.410	0.597	17.860	31.410	0.320	22.393	31.410
h Engle's Arch test	0			0			0		
p-value/stat/critical Engle's Arch	0.528	0.398	3.842	0.659	0.195	3.842	0.511	0.570	3.842
Jarque-Bera Test/p-value/stat	0	0.221	2.553	0	0.500	0.532	0	0.208	2.652

Table 38_Estimation results for different volatility models for gas returns

Concluding results from the detailed comparison of the three selected models lead us to favour the EGARCH (2, 1) model that not only shows a large log-likelihood and the lowest AIC despite being penalized on an additional number of parameters but also incorporates some attractive features. First, it does not impose restrictions on any model parameters. Second, it includes a provision for oscillatory behaviour in the conditional variance and at the same time indicating whether shocks to the variance are persistent or not. Third, the EGARCH model allows evaluation of asymmetric volatility effects. Assuming $\varepsilon_t = \sigma_t z_t$ and $z_t \text{ iid } N(0,1)$ the selected EGARCH (2, 1) model reads as follows:

$$\begin{aligned} \log \sigma_t^2 = & -1.229 + 1.507 \log \sigma_{t-1}^2 - 0.705 \log \sigma_{t-2}^2 + 0.253 \left[\frac{\varepsilon_{t-1}}{\sigma_{t-1}} - E \left\{ \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right\} \right] \\ & + 0.020 \left(\frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right) \end{aligned} \quad (7)$$

It is interesting to note that the resulting EGARCH model could slightly improve the widely used GARCH specification when modelling oil returns as evidenced by studies favouring nonlinear GARCH-class models Narayan and Narayan (2007), Wei et al. (2010). More importantly and as seen in Table 37 estimates for ARCH and GARCH parameters are statistically significant especially for the EGARCH (2, 1) model what leads us to conclude that this specification is the more robust. Analysing further resulting parameters, we have the following results regarding two main features of price volatility, namely asymmetry, and persistence of shocks.

i. **ARCH effects.** The model shows a positive and significant ARCH parameter with a value of 0.253. This confirms the fact that larger shocks increase SGP returns volatility, regardless of their signs, to a greater extent than smaller shocks. The term that measures the magnitude of the effect. i.e. $\left[\frac{\varepsilon_{t-1}}{\sigma_{t-1}} - E \left\{ \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right\} \right]$ determines the size of the new innovation into the series.

ii. **GARCH effects.** These are determined by GARCH coefficients commonly named β_i , i.e., those determining the influence of the past conditional volatilities on the current conditional variance. In our case since $|\sum \beta_i| < 1^{140}$ and the EGARCH model is always stationary (if ε_t has a Normal Distribution). Moreover, all ARCH and GARCH parameters are highly significant

¹⁴⁰ | $|\sum \beta_i| < 1$ shows that the necessary stationary condition is met and establishes the conditions for covariance stationarity of the EGARCH model under particular specifications of the error distribution.

whereas the leverage coefficient is not. Persistence (determined by $|\sum \beta_i|$) is lower than one reflecting no restrictions in the second moment although its value of 0.802 is not far from the nonstationarity boundary allowed by EGARCH models. Results of the Ljung-Box and ARCH tests on returns and residuals square respectively, using standardized innovations of the estimated model, indicate acceptance ($h=0$ with highly significant p-values) of their respective null hypotheses and confirm the validity of the selected EGARCH model. By the above, it is safe to say that volatility of SGP returns is fairly persistent, with the estimated $|\sum \beta_i|$ parameter¹⁴¹ controlling the decay of the autocorrelation function. An alternative measure of volatility persistence is the half-life of a volatility shock (HLS), which is the time it takes for the volatility to move halfway back towards its unconditional variance after it receives a shock. HLS can be measured as $HLS = \ln 0.5 / \ln \beta$ Nelson (1991). In our case, and to be able to compare the results with existing literature on oil price volatility persistence, we consider the β value from our EGARCH (1, 1) specification of 0.781 implying HLS of about 2.8 months or approximately 85 days. Interestingly, the evidence found for high volatility persistence in the Brent market of HLS about 87 days (Wei et al., 2010), 95 days (Narayan and Narayan, 2007) or even 128 days (Mohammadi and Su, 2010) also using EGARCH (1, 1) specifications for Brent returns, reflect the high level of persistence inherited by long-term gas prices from Brent although balanced by other variables included in the gas price formula.

iii. **Asymmetric leverage.** Reported results for the asymmetric leverage coefficients show consistent effects: the EGARCH coefficient is positive in agreement with negative coefficients found in all the GJR-GARCH models analysed, this indicating that positive shocks would increase volatility more than negative shocks. However, none of the leverage parameters in the variance equation are significant at either 5% or 10% levels indicating that evidence of asymmetric response to good and bad news appears mixed in line with results found in the literature for Brent returns Mohammadi and Su (2010). This despite asymmetry coefficient found significant in other research also using EGARCH models Wei et al. (2010). The potential for positive leverage effects is somehow unexpected as it is in contradiction with negative asymmetric leverage effects sometimes reported for the Brent market, i.e., downward movements (shocks) that raise oil prices are more often followed by greater volatilities than upward movements of the same magnitude that reduce the oil price Narayan and Narayan (2007). In our case, the small value of the leverage coefficients and the fact that parameters are always non-significant would lead to rejecting the hypothesis of asymmetry effects on conditional volatility overall.

¹⁴¹ The sum of α and β quantifies the persistence of shocks to conditional variance only for GARCH models. The shock persistence in the EGARCH (p, q) model is measured by $\sum \beta_i$ implying that the volatility process does return to its long-run level with the magnitude of $\sum \beta_i$ controlling the speed of the mean reversion.

8.2.2.3. Quantitative evaluation of volatility clustering

Among all the properties analysed before, the phenomenon of volatility clustering has intrigued many researchers and oriented in a major way the development of stochastic models in financial forecasting and derivatives pricing. Observation of this feature in financial time series has led primarily to the use of GARCH models as in essence these models are able to reflect the fact that fluctuations in the current period will impact on expected fluctuations in the future. However, quantification of volatility clustering effects using autoregressive heteroscedastic models is not generally sufficient since this property is not intrinsically linked to a GARCH specification (Cont, 2005). Therefore other methodologies such as the analysis of autocorrelation of absolute returns (Niu and Wang, 2013) or the copula approach (Ning et al., 2015) have been developed. Following this line of work, not necessarily linked to ARCH-type modelling but also specific research based on rolling analysis of financial time series¹⁴² (Tseng and Li, 2012; Alexander, 2001; Dacorogna et al., 2001; Zivot and Wang, 2006) we introduce an index (R_n) as a quantitative measure of volatility clustering that can be used to compare the degree of volatility clustering along SGP and Brent time series. This index is calculated over a rolling window of reference to obtain valid estimates of volatility clustering stability. The process is simple: we begin by putting a window in the first month of the whole series and count the number of months over a p% threshold fluctuations within an n-month window. We then move on to the second month of the entire series and again count the number of months over the p% threshold fluctuations within this next n-month window. We repeat the same procedure until we finish scanning through the whole time series. Finally, we calculate the ratio R_n , mathematically defined as $R_n = \sigma_e / \sigma_G$, where σ_e and σ_G are the standard deviation of the number of days of the largest (1-p) % fluctuations within an n-month period for the empirical and for the simulated Gaussian data sets respectively. The larger the ratio, the larger the degree of clustering is. As a preliminary step to selecting the best size of the rolling window, a detailed analysis reveals that window size of 20 months delivers maximum visibility of clustering effects over a wider range of p% largest fluctuations. Moreover, for different time periods considered, the relationship between crude oil and gas prices established by the R_n index is a unique parameter connecting crude oil and gas price volatility clustering characteristics.

Figure 59 shows for the different p% threshold options (expressed as a rate over one), how standard deviation (SD) and R_n vary from one period to another. Two different periods to be covered by our investigation are identified. The first period, i.e., 2002-2013 (top row) mainly

¹⁴² Rolling analysis is commonly used in modelling to back test the proposed model on historical data to evaluate stability and predictive accuracy. In our case we use rolling analysis to assess scale of volatility clustering effects a methodology that reveals itself to be ideal for the proposed analysis within selected border zones.

characterized by the credit crunch in 2008 and the second period extended from 2002 until 2016 (bottom row) to include the collapse of oil prices since late 2014 and the current oversupply situation.

Figure 59_Scope of R_n ratio over 2002-2013 (top) and 2002-2016 (bottom)

It is apparent from Figure 59 that for SGP returns $p=20\%$ shows the highest R_n values (implying maximum clustering visibility) whereas Brent returns show maximum R_n values at about $p=40\%$ for both periods. Certainly most relevant to our investigation is the fact that when taking into account the 10% largest fluctuations ($p=90\%$), R_n values for Brent returns are consistently higher than for SGP returns, indicating that SGP prices do not reflect Brent volatility clustering dimension entirely, as it was to be expected from effects from other factors embedded into gas prices.

Examining the results more closely, we can evaluate how clusters of volatility evolve incrementally. The calculation shows that the increase in the clustering index R_n between the first and the second study periods is about 19% for gas whereas for Brent is about 58%, always considering the $p=90\%$ threshold. Consequently, it can be said that the amount of volatility effectively reflected by SGP gas is only about a 33% of the total, this resulting in the diminished

influence of oil price indexations since 2013 until 2016. As mentioned earlier, future updates on the evolution of the R_n index could serve as a reference to quantify progress made by liberalization measures or at least evaluate the resilience of oil indexed structures in long-term gas contracts.

In order to expand our investigation to advance patterns of behaviour for clustering in both series effectively, we simply compare results obtained for $p=20\%$ (SGP) and $p=40\%$ (Brent), with those obtained with a similar random Gaussian series. See left chart in Figure 60.

Figure 60_Clustering distribution (left) and SGP vs. Brent frequency (right)

As it can be seen, both SGP returns and Brent returns (solid) display a broader spread of occurrence over the threshold than corresponding normally distributed returns (dash) implying a R_n higher than one in each case.

Figure 60 (right) shows that when plotting Brent vs. SGP returns clustering behaviour, SGP clustering pattern although rather similar, seems to be lagging behind crude oil within a band of 3 to 6 months (solid circle) as it would be expected from the lagging effects in the gas price formula. Interestingly, the scale of volatility clustering variation is very similar on average despite sporadic opposite effects (dash circle), possibly reflecting balancing of traders' portfolios on an occasional basis.

Figure 61 below represents conventional absolute crude oil, and SGP returns series against clustering dimension, i.e., number of peaks over 40% and 20% threshold respectively.

Figure 61_Brent (left) and SGP (right) returns vs. clustering frequency

As it can be seen, bumps shaping volatility clustering from the analysis (dash) tend to be aligned with heights and valleys in returns (solid) this being an indication that volatility clustering is intimately related to largest and smallest changes over the time series Mandelbrot (1963). Moreover, a manifestation of maximum volatility clustering effects coincides with a sharp decrease of returns in 2008.

8.3 Conclusion

In this chapter, we investigate into the fundamental relationship between oil prices and long-term gas contract prices using a novel approach to provide appropriate information and quantify the level of influence reached by oil prices into gas prices. Consequently, we provide a tool to facilitate an objective assessment of liquid gas hub penetration and underlying gas market implications.

In the first place, we analyse stylized facts of long-term gas prices characterizing the model that best fit our reality to conclude on the EGARCH (2, 1) class as the optimum fit. In turn, we investigate into the extensive academic research on oil price volatility to derive meaningful conclusions. As a result, we find conditional volatility of gas prices to be modestly persistent, with a volatility half-life of about 85 days against evidence found for higher volatility persistence in the Brent market up to 128 days using a similar EGARCH (1, 1) specification for comparison. Mixed effects on the leverage influence affecting conditional volatility are found for gas prices, this different from negative asymmetric leverage effects frequently reported for Brent oil prices.

Supported by modelling results, in the second part of the study, we propose a novel approach to quantify volatility clustering characteristics of crude oil prices against those of long-

term gas prices. To measure the extent of the impact, we introduce an index, i.e., R_n , which allows to evaluate and compare volatility clustering effects over a rolling window of a fixed size through the sample. In the light of these results, it can be seen that the average gas price clustering of volatility relative to crude oil prices is dynamic and in fact is decreasing since 2013 as it would be expected from a more open and traded gas market in Spain.

Broadly speaking, the analysis performed provides a quantitative benchmark to assess oil price influence on gas price structures and in turn, it reveals the degree of penetration of other price mechanisms rather than oil-indexed in an objective manner. Given the importance of oil-indexed contract structures in understanding the level of penetration of liquid hub pricing, regular updates on the size of the effects observed should facilitate a precise assessment of the extent of liberalization of the Spanish gas market and improve the level of transparency, these matters of great interest to both policy makers and gas market agents.

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CHAPTER 9. RESULTS, CONCLUSIONS AND FUTURE LINES OF RESEARCH

This chapter is organized into a logical sequence of introductory facts and an executive summary of results and conclusions from the research as follows:

9.1 Introductory considerations

The conclusions of this thesis focus on the most important points which, the authors believe, emerge from the evaluation about how Brent oil price influence Spanish gas prices with the ultimate objective to facilitate tools to monitor open gas market developments in Spain. In this sense, our results have been brought together within a structured framework to provide a long-term view of Spanish gas market fundamentals as well as views on short term dynamics to evaluate real gas hub aspirations in markets dominated by long-term gas contracting practices, not only in Spain.

9.2 Preliminary results and initial premises

- Inherent properties of Spanish wholesale gas prices confirm the high degree of dependency on oil prices as it was to be expected from long Spanish tradition to secure long-lived gas supply assets in their portfolios. As a result of this strategy, although the Spanish gas market is regarded as well-supplied, traded gas within the country is highly exposed to the direct indexation of long-term supply agreements to the price of crude oil and other refinery products. In turn, this fact leads to gas pricing rigidities away from the genuinely competitive market practice for traded gas in other countries.
- It is recognized that limited gas interconnectivity with Europe through the French border and the small dimension of the Portuguese gas market significantly constrain the successful implementation of liquid and deep gas hub in Spain. On the other hand, the excellent geographical location of Spanish LNG terminals opens scope for a wider range of trading alternatives based on LNG spot opportunities that could increase balancing flexibility of Spanish traders on a temporary basis.
- Aside from gas infrastructure limitations for gas trade, one of the main market-related factors affecting gas pricing in Spain is the need for optimization of gas portfolios and electricity generation activity where gas supply competes against coal at the margin. In this sense, power generation activities are at the heart of the Spanish gas market dynamics.
- Following on the reasoning above and considering coal an important factor determining imported gas volumes at the margin, we draw a plan in Chapter 4 to unveil which would be the true coal price benchmark to be used in the thesis. Our research reveals that,

based on the reality of the domestic coal sector in Spain and the likely picture of coal-fired plants operations in the future, international coal price markers will render the reference price (import parity price) that can be compared with the price of gas on electricity equivalent basis. In line with this, it seems reasonable to use international coal price benchmarks for our analysis.

9.3 Main results and conclusions

9.3.1 Basic findings

- Although Spanish gas prices (SGP) do not automatically reflect oil price movements due to the lagging effect of monthly average oil indexation formulas, the direct link to Brent oil and other prices makes linear regression a valid element to initially investigate on cross-correlated characteristics. Not surprisingly, a first attempt to calibrate the best regression model on SGP reveals that B613, i.e., a moving average Brent over six months is the Brent series that correlate best showing that other contracts signed on a 3 and 9 months rolling average basis are probably less frequent.
- Regarding the statistical distribution of price levels, both SGP and Brent prices reflect the same statistical properties. Both price series exhibit mild positive skewness implying that the right tail is particularly extreme than in the normal case. The estimated kurtosis values for both prices in levels are smaller than 3 (the kurtosis for a standard normal random variable) indicating some evidence of platykurtosis for both. However, as a result of rolling average calculation, Spanish gas prices display lower variability than crude oil prices.
- From the comprehensive process to select the optimum set of regressors on SGP, we find that Brent oil price, gasoil price (these two lagged 6 months) and NBP are the predictors that contribute most. The F-ratio from the ANOVA table indicates that the slope of the regression on each of them is significantly different from zero. Doubts about the economic logic behind SMP resulting negatively correlated reduces its role to a mere adjusting parameter.
- The analysis of Principal Components (PCA) following regression investigations shows that Brent and gasoil prices influence is of a different nature than NBP influence. The analysis also shows the clear dependency between Brent and gasoil prices, this relationship arising through downstream operations what could reduce the number of predictors further in practical forecasting applications.

9.3.2 Fundamental analysis

- Results from the first area of the investigation on stochastic properties reveal that once trend breaks are accounted for, the unit root hypothesis, which could not be rejected using generic (no-break) ADF and KPSS tests for any of the series analysed, is rejected for fuel oil and NBP. These results confirm findings of previous research revealing the high degree of long-term persistence shown by crude oil prices that are in turn transmitted into SGP but also the different long-term nature of both NBP and fuel oil prices. This would also be an indication that contrary to gas market fundamentals Spanish gas prices are mostly driven by oil prices in the long term.
- Stationarity inference provided by two-break tests is in general similar than that of the one-break unit root tests except for SGP prices as the null is rejected using Lumsdaine and Papell (1997) (LP) Mixed model test. This test indicates a significant change of slope in October 2013 altering the decision about nonstationarity previously reached. From these results, it can be derived that for SGP prices the analysis finds arguments to consider events at the end of 2013 significant enough to induce stationarity on the series in the long run. In spite of this, LM tests results determine unambiguously stochastic properties for SGP while weakens previous stationarity assessment of fuel oil. NBP stationary is reinforced on the understanding of the ability of the two-break test to expand insight within a long-run context.
- Results from all tests performed confirm that testing for unit root endogenously maintains the difficulty in rejecting the unit root hypothesis in finite samples but also stronger support for convergence using LM unit root tests. Moreover, we could not find under the scope of our investigation a significant difference when using pre-testing methods.
- In regards to the second objective at this stage, i.e., to examine in detail timing and characteristics of the effects of events over the period, we need to highlight that as exposed in the literature, we corroborate that LS tests have serious difficulties regarding break date detection capabilities. Therefore we do not consider those results in the analysis.
- On the other hand, LP tests methodology provides a strong indication about similarities regarding the underlying trend in each regime and by variable. Regarding the specific relationship SGP-Brent oil, results show that the relative impact of 2008 and 2014 was different for each of these two variables. Taking into account changes in the slope, it can be seen that whereas in 2008 only 62% of the Brent shift is found in SGP, in 2014 as much as 86% of Brent shift is reflected by SGP and even more importantly resulting in a significant change of slope and stationarity as a consequence of this. This is a fascinating result and does not derive from the pure evolution of base price indexation standards over a four year period. Rather, ample LNG market oversupply conditions in addition to proportional oil market effects were at the heart of the extreme reaction in this case. These results show that in the case of SGP,

combined effects of the strong decline in oil prices together with the significant LNG oversupply situation in 2014 may lead to stationary conditions overall.

- Probing the intense influence of Brent prices in SGP, one-break testing methods, allowing for a changing intercept show a similar breakpoint for the Brent related variables, i.e., SGP, Brent, GO and LSFO in 2014 whereas allowing for a changing intercept and slope break all dates move backwards as early as 2010, this advancing the intensity of changes in both price level and slope as a consequence of the 2014-15 price crash. Similarly, considering two breaking points, we find that using the Crash model a regime ending in 2005 and another in 2014 set up the evolution of SGP in line with Brent dynamics. When analysing SGP prices using the Mixed model, 2009 and 2013 are plausible dates for slope changing regimes also exactly coinciding with Brent prices shifts. This results support the importance of the immediate stabilization of oil prices occurring around March 2012, common to oil and Spanish gas prices and before the severe downturn post-2014. Even more importantly, it can be inferred that Brent oil supply-demand fundamentals were the main driver of SGP dynamics since 2002 until the end of 2016 and despite gas market fundamentals or spillover effects from the global economy.

- In general, results reveal the additional advantage of the two-break test regarding detection of a second breaking point stressing the similarities and differences relevant for understanding time series behaviour. Both LP and LS procedures, give more importance systematically to changing-slope events (Mixed model) than to level variations (Crash model) except in the case of NBP prices. This is an indication that NBP prices are less affected by cycles and more by regular gas hub market events influencing price levels. In this sense, it can be said that SGP prices dynamics follow Brent prices cycles away from traded gas hub patterns being less affected by shift changes in level. Similarly, the influence of coal on SGP, looking at the effects of outside events is negligible also as a reflection that gas-coal competition affecting gas prices in Spain is very limited.

- Overall, it can be concluded that using endogenous testing models produce statistical inference that is substantially similar for Brent prices and Spanish gas prices, independently of the optimization sequence and the parameterization of the structural break under the null and the alternative. Moreover, of all the variables analysed, Brent and SGP, maintain the highest degree of similarity regarding the response to structural changes even when compared to other refinery products. It can be observed that gasoil is second closer and fuel oil third.

- We conclude that in general, a random walk process, possibly with drift, may be more accurate to represent the evolution of SGP over time. Moreover, considering that SGP

seem to follow Brent oil patterns even more clearly than gasoil or fuel oil, high persistence inherited might be better represented by a single approximation of crude oil evolution, this especially interesting for modelling and forecasting. In regards to SGP assessment, performance reflects that although shocks associated with the price collapse in 2008 were of crucial importance over the period analysed, that was not enough to consider those shocks as deterministic breaks rather than a great negative realization. For the events in 2014, the analysis is reversed.

- Our results reveal a high degree of persistence shown by crude oil prices that are transmitted into SGP but even more important that the effects of oil market events may be considering overlapping other gas market effects. As an example of this, we find that oil market effects resulting from the drop in oil prices since 2012 were rather more important for SGP than for Brent oil or refined products. This feature arises as a result of the additional decline of natural gas prices at the margin globally as the LNG industry was becoming increasingly concerned about oversupply conditions already in 2014. Moreover, in that period, considerations for different supply contract pricing standards with a view for contract hub price linkage set to increase, were also particularly important in helping sudden drop of gas prices to develop.

- Using multivariate Johansen tests allowed us to investigate into cointegration properties of the selected variables. Our results indicate that there is a long-run relationship between the prices of crude oil, gasoil, NBP, and SGP but no clear relationship can be established between the prices of any of those variables with fuel oil or coal. Therefore it seems that the production and market fundamentals of fuel oil and coal markets are not affected by demand for crude oil-related products. This is an interesting result which also reveals that in spite of fuel oil being included in the first contracts awarded for Spanish wholesalers this variable seems not to be influential in the long-term path of SGP.

9.3.3 Market dynamics

- Regarding the second core challenge within the research framework, we investigate the shorter-term relationships between oil prices and long-term gas contract prices in order to quantify this influence and provide an objective assessment of hub penetration in Spain. As a result, we find conditional volatility of gas prices to be modestly persistent, with a volatility half-life of about 85 days against evidence found for higher volatility persistence in the Brent market up to 128 days using a similar EGARCH (1, 1) specification for comparison. Mixed effects on the leverage influence affecting conditional volatility are found for gas prices, this different from negative asymmetric leverage effects frequently reported for Brent oil prices.

- Supported by modelling results, in the second part of the study, we propose a novel approach to quantify volatility clustering characteristics of crude oil prices against those of long-term gas prices. To measure the extent of the impact, we introduce an index, i.e., R_n , which allows to evaluate and compare volatility clustering effects over a rolling window of a fixed size through the sample. The calculation shows that the increase in the clustering index between the first and the second study periods is about 19% for gas whereas for Brent is about 58%, always considering the $p=90\%$ threshold. Consequently, it can be said that the amount of increasing volatility effectively reflected by SGP gas is only about a 33% of the total, this resulting in the diminished influence of oil price indexations since 2013 until 2016. As mentioned earlier, future updates on the evolution of the R_n index could serve as a reference to quantify progress made by liberalization measures or a least evaluate the resilience of oil indexed structures to traded gas influence.

- In the light of these results, it can be seen that the average gas price clustering of volatility relative to crude oil prices is dynamic and in fact is lower since 2014 as it would be expected from steadily decreasing EU gas hub prices keeping below long-term average import prices (ACER, 2016).

9.3.4 Energy policy consequences

Results from our thesis have significant implications for economic analysis, forecasting, and policy-making decisions. In particular, the prediction of oil and oil products prices are shown to depend critically on whether series are modeled as differenced or trend stationary. In this sense, Spanish gas prices embed a large amount of persistence as a consequence of the direct indexation with Brent oil prices. On the other side, traded NBP volumes seem to follow a mean-reverting business cycle, this consistent with this commodity being sold according to supply-demand conditions where prices typically revert to a long-run marginal cost reference. In the case of Spain, it would be expected that given the prevalence of transitory, short-terms effects of NBP traded gas, increasing penetration into oil-driven local markets should result in stronger mean reverting properties in MIBGAS market. From a market point of view, these results are promising and could provide a ground for further assessment of near-term gas trade in a traditionally long-term gas market as Spain. At the other end of the spectrum, coal reveals itself as strongly difference-stationary implying a more difficult proposition regarding price modelling and policy stabilization measures as price shocks are mostly permanent, reinforcing the idea of an efficient market.

Broadly speaking, the analysis performed in the second part, provides a quantitative benchmark to assess oil price influence on gas price structures and in turn, it reveals the degree of penetration of other price mechanisms rather than oil-indexed in an objective manner. Given the importance of oil-indexed contract structures in understanding the degree

of penetration of liquid hub pricing, regular updates on the size of the effects observed should facilitate a precise assessment of the extent of liberalization of the Spanish gas market and improve the level of transparency, these matters of great interest to both policy makers and gas market agents.

Although results from our investigation resolve some of the open questions, dangers of using a categorical view for unit root properties, especially for Brent and oil-related variables remain. In this sense, our investigation should be seen as a positive and enabling process for model-building. On the more theoretical level, we would recommend exploring further whether shocks to the data series analysed were also related to the magnitude of the post-shock growth rates, to anticipate a potential response to similar events in the future.

9.4 New lines of research

As open lines for future research, this thesis should open scope for a regular evaluation of open trade hubs dynamics in markets with a majority of gas imports linked to oil and refinery prices, based on hard facts. Moreover, additional routes for quantification of marginal gas penetration at regional level, either from pipeline gas flows or from LNG spot volumes could be expanded based on the current work.

More specifically two main areas of research follow logically in exploring alternatives for proper gas market assessment when considering dynamic and fast changing gas market conditions. As a matter of fact, this thesis has been organised from the start with the intention to consolidate a strong base of experience on which to build further evidence towards proper market liberalization assessment overall. These two specific areas are:

- For Spain, it is proposed to follow up regularly, both the analysis of stochastic properties of SGP allowing for structural breaks but also a detailed monitoring of the R_n factor over different periods to evaluate how clusters of volatility evolve incrementally. In this manner, the assessment of new sources of supply at the margin, affecting pricing conditions overall can be significantly improved. In so doing, an objective evaluation of the evolution of new MIBGAS organized market can also be achieved leading to assess, in an objective manner, competitiveness and competition in the sector. We believe that all these issues are of great interest for the future energy policy in Spain but also for the Regulator and gas traders.
- Although results from our investigation resolve some of the open questions, dangers of using a categorical view for unit root properties, especially for Spanish gas prices and Brent remain. In this sense, our investigation should be seen as a building block leading to improve forecasting and modelling concerning gas pricing overall. Furthermore, we would recommend exploring further whether shocks to the data series analysed were

also related to the magnitude of the post-shock growth rates, to anticipate a potential response to similar events in the future and in this manner improve accuracy and understanding of market effects on gas prices.

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APPENDIX 1. DATA GENERATING PROCESS

Following Perron's (1989) testing framework, we consider a univariate process $\{y_t\}$ generated by either additive or innovational outlier models. The Data Generating Processes (DGP) of the additive outlier (AO) models are:

$$y_t = z(T_1)'_t \phi + u_t = z'_{t,1} \phi_1 + z(T_1)'_{t,1} \phi_2 + u_t$$

where, $z'_{t,1} = (1, t)'$, $\phi_1 = (\mu, \beta)'$,

$$z(T_1)'_{t,1} = \begin{cases} DU_t & \text{for Model A1} \\ B_t & \text{for Model A2} \\ (DU_t, B_t)' & \text{for Model A3} \end{cases}, \quad \phi_2 = \begin{cases} \mu_b & \text{for Model A1} \\ \beta b & \text{for Model A2} \\ (\mu_b, \beta b)' & \text{for Model A3} \end{cases}$$

with $DU_t = B_t = 0$ if $t \leq T_1$ and $DU_t = 1, B_t = t - T_1$ if $t > T_1$.

The noise $\{u_t\}$ is such that $A(L) u_t = B(L) \varepsilon_t$ where $\varepsilon_t \sim \text{i.i.d. } (0, \sigma^2)$, and $A(L)$ and $B(L)$ are polynomials in L of order $p+1$ and q , respectively.

The DGP of the innovational outlier (IO) models under the alternative are given by:

$$y_t = z'_{t,1} \phi_1 + \varphi^*(L)(d(T_1)'_{t,2} \phi_2 + \varepsilon_t)$$

where,

$$z(T_1)'_{t,2} = \begin{cases} DU_t & \text{for Model I1} \\ (DU_t, B_t)' & \text{for Model I3} \end{cases}, \quad \phi_2 = \begin{cases} \mu_b & \text{for Model I1} \\ (\mu_b, \beta b)' & \text{for Model I3} \end{cases}$$

with $\phi^*(L)$ and $\phi(L)$ such that $\phi^*(L) = A^*(L)^{-1} B(L)$ and $(1 - \alpha L)^{-1} \phi^*(L) = \varphi(L)$.

Models A1 and I1 are called 'level shift' or 'crash' models, A2 'changing growth' model, and A3 and I3 are 'mixed' models. A changing growth model of the IO type is typically not considered because it is necessary to assume that no break occurs under the null hypothesis which imposes an asymmetric treatment in Perron's framework Perron and Rodriguez (2003).