Resources Policy 82 (2023) 103546

Contents lists available at ScienceDirect

Resources Policy

journal homepage: www.elsevier.com/locate/resourpol

Energy prices in Europe. Evidence of persistence across markets[☆]

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ARTICLE INFO

JEL classification:
C22
G15

Keywords:
Energy consumption
Energy prices
Long memory
Fractional integration
Persistence

ABSTRACT

This paper deals with the behavior of energy price changes and how their shocks exert an impact on suppliers and consumers in different markets. For this purpose, a fractional integration model is used to evaluate the persistence and mean reversion in prices across the major European markets (Germany, France, Italy, UK, Spain). We compare the results with other major players as the US and Japan, to understand, first, if the European behavior is different, and second, if geopolitical shocks that are affecting this market are expected to be permanent. Empirical results show evidence of mean reversion properties in European prices, though some minor differences arise from market to market that apparently, are not associated with the energy generation strategies followed by each country. Thus, it will likely be expected following the current energy shocks the series will recover due to natural market forces, without the need for additional policies.

1. Introduction

Energy is today one of the primary elements used by most industries to manufacture intermediate products and final goods. Thus, understanding the behavior of price changes and how these shocks impact suppliers and consumers is very important. Authors such as Gil-Alana et al. (2020) investigated the persistence of the spot and futures energy market in the Iberian region, finding evidence of long memory and mean reverting behavior in the period under study (2007–2017). Later, and after the Covid crisis and before the Ukranian war, Martin-Valmayor and Gil-Alana (2022) studied the hourly intraday market from November 2020 to October 2021, with evidence of high persistence, with shocks having permanent effects with non–mean reversion properties, and no month-specific effects on the data series. The difference between the two studies can be related to the different frequency employed (intraday, weekly, and monthly), the different spans of data and the momentum (with or without shocks).

In any case, it is clear that over the last two years, energy prices in European countries have raised from nearly 50€/MWh in November 2020 to 400–600 €/MWh by the end of May 2022. Major reasons appear to be the increase in gas prices (post-Covid bottlenecks and Ukrainian war tensions), the CO_2 rights market with growing tensions in the acquisition of rights by the European power companies, and the European legal framework of marginal prices (Pacce et al., 2021). In all the European countries, the growing energy prices along with the inflation generated in 2021 have produced tensions and fears regarding economic growth. During 2022, The EU adopted several policy measures to reduce the impact of this crisis, which included the diversification of supply, reducing dependency on Russia, investment in alternative forms of energy, reinforcing efforts in energy demand reduction, and in some cases capping energy prices as with the Iberian Gas exception or the inframarginal market revenue cap (Dhand et al., 2023).

The energy pricing strategy is similar across all European countries, with a fixed day-ahead market system (single day-ahead coupling, SDAC), and with a mechanism of marginal prices (least efficient fixed the whole price) to enhance competition and favor energy investment over the most efficient production technologies. The current environment with underlying geopolitical tensions poses an interesting question regarding whether this market can be naturally adjusted in the long term or if current shocks will be permanent. In other words, the relevant

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[☆] Luis A. Gil-Alana and Miguel Martín-Valmayor gratefully acknowledges financial support from the Grant PID2020-113691RB-I00 funded by MCIN/AEI/ 10.13039/501100011033, from 'Ministerio de Ciencia e Innovación' (MICIN), 'Agencia Estatal de Investigación' (AEI) Spain and 'Fondo Europeo de Desarrollo Regional' (FEDER).

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https://doi.org/10.1016/j.resourpol.2023.103546
Received 5 February 2023; Received in revised form 1 April 2023; Accepted 1 April 2023

Table 1
Primary energy consumption by fuel (in exajoules) in chosen countries.

	Oil	Natural gas	Coal	Nuclear energy	Hydro	Renewables	TOTAL
GERMANY	4.18	3.26	2.12	0.62	0.18	2.28	12.64
	33%	26%	17%	5%	1%	18%	
FRANCE	2.91	1.55	0.23	3.43	0.55	0.74	9.41
	31%	16%	2%	36%	6%	8%	
UK	2.50	2.77	0.21	0.41	0.05	1.24	7.18
	35%	39%	3%	6%	1%	17%	
ITALY	2.35	2.61	0.23	0.00	0.41	0.76	6.36
	37%	41%	4%	0%	6%	12%	
SPAIN	2.45	1.22	0.16	0.51	0.28	0.97	5.59
	44%	22%	3%	9%	5%	17%	
JAPAN	6.61	3.73	4.80	0.55	0.73	1.32	17.74
	37%	21%	27%	3%	4%	7%	
US	33.24	29.71	10.00	7.71	2.16	9.36	92.18
	36%	32%	11%	8%	2%	10%	

Source: BP Statistical Review of World Energy 2022

Table 2
European gas dependency on Russian natural gas imports. Germany, France, Italy and Spain data (2016–2020) taken from Eurostat. UK (2021)

	Natural gas consumption 2021	Russian gas consumption in ExaJoules average (2020–2016)	Expected Russian dependency over 5-year average	5 year average Russian gas consumption (mil. cubic m) (2020–2016)
Germany	3.26	1.891	58.0%	52,514.48
France	1.55	0.337	21.8%	9366.55
UK (from 2021)	2.77	0.122	4.4%	n.d.
Italy	2.61	1.116	42.7%	30,989.94
Spain	1.22	0.053	4.4%	1484.60

Source: Germany, France, Italy and Spain Eurostat 2021; UK Department for Business, Energy and Industrial Strategy 2021

Table 3
Share of gas supply from Russia in Europe in 2021.

Bosnia and Herzegovina	100%
Moldova	100%
North Macedonia	100%
Latvia	92%
Serbia	89%
Austria	86%
Bulgaria	79%
Finland	75%
Slovakia	68%
Greece	64%
Hungary	61%
Slovenia	60%
Czechia	55%
Poland	50%
Germany	49%
Italy	38%
Lithuania	27%
Romania	24%
Croatia	16%
France	15%
Belgium	14%
Estonia	12%
Georgia	6%

Source: Agency for the Cooperation of Energy Regulators

question is to determine if European energy markets are mean reverting through natural forces or not. Public aid and exemption of CO_2 emission rights on green energy boosted the installation of these technologies after 2018, leaving a great surplus of unused capacity of traditional coal and combined-cycle plants. However, current European tensions with Russia regarding gas and coal supply are leading to the retargeting of these objectives. The European Commission adopted the target to achieve 32% by 2030, seeking a decarbonization process in the EU's energy system and a long-term strategy of achieving carbon neutrality by 2050 (EC, 2021), but these objectives are now in question due to the inflation provoked by the energy crisis.

In this paper we evaluate the persistence and mean reversion behavior in energy prices in large Western European markets (Germany, France, Italy, UK, Spain), comparing these results with other global players such as the US and Japan to understand, first, if the European behavior is different, and second, if geopolitical shocks that are affecting this market are expected to remain permanent. From a methodological perspective, we use fractional integration methods, which seem to be appropriate since with a single parameter, the order of integration, we will be able to determine these features in the data.

The structure of the paper is as follows: Section 2 includes a short description about the different energy mix strategies in the countries under analysis. Section 3 presents the literature review on energy persistence issues, while Section 4 is devoted to the data description and the methodology used in the paper. Section 5 displays the main empirical results and finally, Section 6 concludes the manuscript with the main implications of this study.

2. European energy markets

We describe in the following the different energy markets under analysis. We have chosen the major Western European countries (Germany, France, Italy, Spain, and the UK), along with Finland, which is a country which features strongly in previous NordPool studies (Haldrup et al., 2010; Ergemen et al., 2016), and with other two larger markets, these being the US and Japan, for comparison purposes.

Table 1 summarizes the primary energy consumption breakdown in these selected countries, while Table 2 shows the specific Russian natural gas dependency of these countries in terms of the Eurostat Russian average gas imports in the period 2016–2020.

In addition, Table 3 shows the dependency but according to the Agency for the Cooperation of Energy Regulators in 2021. The results show major differences due to the consequences of the Ukrainian war on imports of Russian gas. Some countries such as Bosnia, Moldova or Macedonia are fully exposed as in 2021 the entirety of their gas supply depended on Russian sources, but others such as France, Belgium or Croatia had less than 15% dependency and were using alternative sources. In our study, the most exposed countries are Germany and Italy which import around 50% of their gas consumption from Russian sources.

Regarding energy consumption technology, all countries under study except France still show a very large dependency on fossil fuels. Oil and gas are the largest energy sources in total final consumption (TFC), accounting for more than 69% in Spain, 74% in Germany, 77% in the UK and 82% in Italy. In the US this percentage is around 80% and is approximately 86% in Japan. Nevertheless, renewable energy sources, including bioenergy, wind and solar, are making fast progress while nuclear power remains at low levels. It is important to underline the important role that coal plays in the German strategy (still 17%). Regarding the TFC breakdown, in Germany, the residential and commercial sectors together consumed 40% of TFC, the industry sector 35% and the transport sector 25%, with levels being similar in the other countries (IEA International Energy Agency, 2019). On the other hand, France produced about half of its total energy supply domestically with a very large dependency on nuclear power (36%), and with less development of renewable technologies.

Regarding the rest of the countries being studied, Finland has vast resources of forest-based biofuels, which account for most of the energy production in the country, along with an important contribution from nuclear power generation. Therefore, total primary energy supply (TPES) is dominated by domestic biofuels and nuclear power as well as by oil, which is imported mainly from Russia. Electricity and oil account for the largest share of total final consumption (TFC) in the country, but direct use of biofuels and district heating also represent significant shares. Industry is the largest energy-consuming sector, accounting for nearly half of TFC (IEA International Energy Agency, 2019). In the case of Japan, the 2011 events have had a significant impact on Japan's energy system. The Fukushima accident led to a total suspension of the nuclear power fleet, which has only partially restarted. This has made Japan more dependent on fossil fuels (86%) with only 7% of electricity generation being through renewal energy. In 2019, total primary energy supply (TPES) is the second highest in the IEA after the US and the fifth largest in the world. Japan's energy sector is also dominated by fossil fuels, which account for 88%. As a major difference, Japan has a large energy-intensive industry sector, which accounts for 41% of TFC (IEA International Energy Agency, 2019). Finally, the US is the largest energy producer in the world. The shale revolution, led by technological breakthroughs in hydraulic fracturing and horizontal drilling, has resulted in an unprecedented increase in production, and made the country the world's largest producer of oil and gas. In 2020, the US is accounted for 18% of total world production of crude oil and 44% of natural gas liquid production (BP Statistical Review of World Energy 2021). Thanks to this growth in oil and gas production, the US is becoming more self-sufficient in energy, as only one third of oil is imported. Thus, the US energy sector is heavily dominated by fossil fuels (81%).

3. Literature review

Regarding persistence and energy prices, Escribano et al. (2011) examined spot prices of deregulated electricity markets from Argentina, Australia (Victoria), New Zealand (Hayward), the Nordic Power Market (NordPool), and Spain using daily data. The authors found evidence of mean-reversion with orders of integration ranging between 0.5 and 0.6 in all the markets under analysis except for the NordPool that returned a value of 0.93. Moreover, they found strong volatility and jumps of time-dependent intensity even after adjusting for seasonality.

Dealing with the NordPool market, Haldrup and Nielsen (2006) employed a Markov switching fractional integration model, originally proposed in Haldrup et al. (2010), to analyze the NordPool for the time period January 2000–October 2003 using daily data. These authors found evidence of abrupt and generally unanticipated changes in spot electricity prices, suggesting fat-tailed distributions with a very strong seasonal behavior, and levels of integration in the range 0.31–0.52 in all the series under their analysis. Ergemen et al. (2016) examined the NordPool loads and spot prices for the period 2000–2013. They found evidence that both prices and loads contain common factors with long memory and loadings that vary considerably during the day. The integration factor grew, ranging in the interval (0.50, 0.83) in all series; however, these series still exhibit non-stationarity and mean-reversion properties.

Table 4
Summary of integration factor results calculated in previous energy pricing studies.

Source	Market	Frequency	Integration factor	Period
Escribano et al. (2011)	Argentina, Australia, New Zealand	Daily	0.50–0.60	1996–1999
Escribano et al. (2011)	NordPool	Daily	0.93	1993–1999
Haldrup et al. (2010)	NordPool	Daily	0.31–0.52	2000–2003
Ergemen et al. (2016)	NordPool	Hourly	0.50–0.83	2000–2013
Koopman et al. (2007)	NordPool, EEX, Powernext, APX	Daily	<0.5	1993–2005
Gianfreda and Grossi (2012)	Italy (IES)	Daily	0.45	2005–2008
Fanone et al. (2013)	EPEX	Daily	0.47	2007–2010
Pereira et al. (2019)	MIBEL	Hourly	0.68–0.92	2007–2014
Gil-Alana et al. (2020)	MIBEL	Daily	0.52–0.70	2007–2017
Martin-Valmayor and Gil-Alana (2022)	MIBEL	Hourly	1.30–1.53	2020–2021
Gil-Alana et al. (2017)	Kenya	Monthly	1.05	2008–2015

Source: own elaboration

Koopman et al. (2007) investigated with ARFIMA-GARCH models the NordPool market, plus the EEX in Germany, the Powernext in France, and the APX in the Netherlands. These authors considered values between January 1993 to April 2005 and found evidence of a different dynamic behavior depending on the mix of power generation from market to market. Their results showed that EEX, Powernext and APX were less persistent than NordPool, but all of them had a significant periodicity and integration orders smaller than 0.5. Gianfreda and Grossi (2012) considered the Italian Electricity Spot, with daily samples from January 2005 to December 2008, and using an ARFIMA-GARCH (7, 0) model with a one-lag autoregressive term. They found evidence of mean reversion, having values of the integration order of around 0.45. Fanone et al. (2013) analyzed the EPEX market (joint venture of German EEX and French Powernext) with a Lévy-based fractional autoregressive (FAR) model applied to daily data from January 2007 to September 2010. The order of integration based on the Whittle function (1953), was in this case about 0.47.

Pereira et al. (2019) examined the persistence of electricity prices in the MIBEL (Iberian electricity market) by using series of day-ahead hourly prices for Portugal and Spain between July 2007 and December 2014. They investigated the presence of structural breaks using the Hassler and Meller (2014) approach. According to these authors, the order of integration of the series ranged between 0.68 and 0.92 before breaks, observing a decrease afterwards with an order of about 0.35. Gil-Alana et al. (2020) studied the July 2007–July 2017 period in the same Iberian market, also finding evidence of mean reversion with an integration order in the range of (0.52, 0.70) on the spot market. For these authors, the observed behavior was like a typical micro-economic price-elasticity dynamics, where higher prices induce lower consumption and vice-versa, in a feedback process that is temporally persistent. Finally, Martin-Valmayor and Gil-Alana (2022) analyzed the intraday behavior of this market with 12 monthly series from November 2020 to October 2021, i.e., just before the Ukrainian war, finding evidence of high levels of persistence and values of d in the interval (1.30, 1.53). Table 4 summarizes the results in terms of the integration order in all the above-mentioned contributions.

Table 5
Detail of data set followed in the study.

Country	BLOOMBERG data	Monthly sampling data	Daily sampling data
Germany	FDB1Y Comdty	July 2018–September 2022	July 2018–September 2022
Spain	OMLPDAHD Index	January 1998–September 2022	August 2014–September 2022
France	PWNXFRAV Index	November 2001–September 2022	August 2014–September 2022
Finland	ENNSHEPK Index	July 2009–September 2022	August 2014–September 2022
Italy	ELIO1MON TPGE Index	November 2011–September 2022 (Break between December 02, 2020February 04, 2015)	Nov 2011–September 2022 (Break between December 02, 2020February 04, 2015)
UK	UKPSPIR Index	March 2001–September 2022	August 2014–September 2022
Japan	JPXS1700 Index	March 2005–September 2022	August 2014–September 2022
US-1	STO7M1 Index	October-2012-September 2022	n.d.
US-2	FRED data APU000072610	Monthly sampling data Nov 1978–September 2022	Daily sampling data n.d.

Source: own elaboration

4. Data description and methodology

The data set of this paper is built with data taken from Bloomberg in Germany, Spain, France, Italy, the UK, Finland, and Japan, based on daily and monthly data; for the US we use two different data sets with monthly data, one based on Bloomberg, and the other one based on the average Prices of US city average from the St. Louis FRED database. Table 5 details the sources of the data, the frequency and the sample period examined, while Table 6 presents some descriptive statistics, revealing that European markets have greater volatility than Japan and the US, and that this volatility differs from country to country.

As far as the methodology is concerned, we use fractional integration widely used in the analysis of energy prices. Nevertheless, we first performed classical unit root tests on the series. We employed Dickey and Fuller (ADF, 1979), Phillips and Perron (PP, 1988), Elliot et al. (ERS, 1996) and Ng and Perron (NP, 2001) tests and, though not reported, the results supported in all cases the unit root hypothesis. However, it should be taken into account that most of these methods have very low power against fractional alternatives (as shown for example in Diebold and Rudebusch, 1991; Hassler and Wolters, 1994, and Lee and Schmidt, 1996), and because of that, we work in this paper with the fractional integration analysis that includes all the above methods as a particular case of interest if the order of integration is equal to 1.

The applied model in the following section is the following one,

$$y(t) = \alpha + \beta\, t + x(t), (1 - B)^d x(t) = u(t), t = 1, 2, \dots \tag{1}$$

where y(t) refers to the observed data, α and β are unknown parameters referring to an intercept and a linear time trend, and x(t) is integrated of an unknown order that is estimated from the data; u(t) is supposed to be an integrated of order 0 process. This model has been applied separately for each monthly data set, obtaining 12 independent results. The estimation of the differencing parameter d is crucial to determine if shocks in the series have transitory or permanent effects. Thus, if $d = 0$, $x(t) = u(t)$ in (1), and x(t) is said to be short memory as opposed to the case of long memory that takes place when $d > 0$. From a statistical viewpoint, the borderline point is 0.5. Thus, if $d < 0.5$, x(t) is covariance stationary; however, if it becomes asymptotically nonstationary for $d \geq 0.5$, and it is more nonstationary as we increase the value of d, noting that the variance of the partial sum increases in magnitude with d; finally, from a policy perspective, mean reversion occurs if $d < 1$ and shocks will have permanent effects if $d \geq 1$.

5. Empirical results

Based on the model given by Eq. (1), Table 7 reports the estimates of d and their corresponding 95% confidence bands for the monthly data. Due to its seasonal nature, the errors u(t) is supposed to follow a seasonal AR (1) process.

We report the estimates of d under three different scenarios: with no deterministic components (second column); with an intercept (column 3), and with an intercept and a linear time trend (fourth column), marking in the table in bold the selected case for each series. We observe

Table 7
Estimates of d on the monthly data using model (2).

Series	No terms	An intercept	An intercept and a linear time trend
SPAIN	0.55 (0.50, 0.61)	0.55 (0.50, 0.61)	**0.54 (0.49, 0.60)**
FRANCE	0.79 (0.70, 0.90)	0.77 (0.67, 0.88)	**0.77 (0.68, 0.88)**
FINLAND	0.88 (0.75, 1.02)	**0.82 (0.68, 0.98)**	0.83 (0.71, 0.98)
UK	0.70 (0.63, 0.79)	0.67 (0.60, 0.75)	**0.69 (0.61, 0.76)**
JAPAN	0.43 (0.34, 0.53)	**0.36 (0.29, 0.46)**	0.37 (0.29, 0.47)
GERMANY	1.79 (1.44, 2.24)	**1.63 (1.25, 2.11)**	1.59 (1.25, 2.06)
USA	0.96 (0.85, 1.11)	0.71 (0.60, 0.85)	**0.71 (0.60, 0.85)**
ITALY	0.87 (0.70, 1.17)	0.67 (0.52, 1.02)	**0.60 (0.27, 1.02)**
USA-2	1.09 (1.01, 1.18)	1.02 (0.94, 1.11)	**1.02 (0.95, 1.11)**

Source: own elaboration. The values in bold refer to the selected specification. In parenthesis, the 95% confidence bands for the values of d.

Table 6
Descriptive statistics from the data set.

		MIN	MAX	AVERAGE	STDEV	STDEV/AVERAGE
GERMANY	FDB1Y Comdty	35.62	575.00	90.40	98.29	1.09
SPAIN	OMLPDAHD Index	–	258.66	46.14	35.02	0.76
FRANCE	PWNXFRAV Index	2.66	635.63	50.03	62.68	1.25
FINLAND	ENNSHEPK Index	6.98	508.89	55.23	57.82	1.05
ITALY	ELIO1MON TPGE Index	−18.00	320.25	77.54	65.28	0.84
UK	UKPSPIR Index	10.84	313.68	46.20	37.64	0.81
JAPAN	JPXS1700 Index	2.05	34.03	10.54	4.69	0.44
US-1	STO7M1 Index	11.24	13.54	12.25	0.47	0.04
US-2	Avg. Electricity price	0.05	0.17	0.10	0.03	0.25

Source: own elaboration

Table 8
Estimates of d based on the daily data using model (2).

Series	No terms	An intercept	An intercept and a linear time trend
i) White noise errors (Uncorrelated)			
SPAIN	0.77 (0.73, 0.80)	**0.76 (0.73, 0.80)**	0.76 (0.73, 0.80)
FRANCE	0.74 (0.71, 0.78)	0.74 (0.71, 0.78)	**0.74 (0.71, 0.78)**
FINLAND	0.51 (0.48, 0.55)	0.51 (0.48, 0.54)	**0.51 (0.48, 0.54)**
GERMANY	1.04 (0.97, 1.11)	**1.07 (1.00, 1.15)**	1.07 (1.00, 1.15)
JAPAN	0.67 (0.64, 0.70)	**0.67 (0.64, 0.70)**	0.67 (0.64, 0.70)
ITALY	1.00 (0.95, 1.04)	**0.99 (0.95, 1.04)**	0.99 (0.95, 1.04)
UK	0.58 (0.56, 0.61)	0.58 (0.56, 0.61)	**0.58 (0.55, 0.60)**
ii) Bloomfield autocorrelation			
SPAIN	0.61 (0.57, 0.65)	0.60 (0.57, 0.64)	**0.60 (0.56, 0.64)**
FRANCE	0.60 (0.58, 0.63)	0.60 (0.57, 0.63)	**0.60 (0.57, 0.64)**
FINLAND	0.38 (0.35, 0.40)	0.37 (0.35, 0.40)	**0.37 (0.34, 0.39)**
GERMANY	0.81 (0.75, 0.86)	0.80 (0.75, 0.85)	**0.79 (0.74, 0.85)**
JAPAN	0.59 (0.55, 0.64)	**0.59 (0.55, 0.64)**	0.59 (0.55, 0.64)
ITALY	0.99 (0.93, 1.07)	**0.97 (0.91, 1.05)**	0.97 (0.91, 1.05)
UK	0.57 (0.54, 0.60)	0.56 (0.54, 0.59)	**0.55 (0.53, 0.60)**

Source: own elaboration. The values in bold refer to the selected specification. In parenthesis, the 95% confidence bands for the values of d.

that a time trend is required in the cases of Spain, France, the UK, the US, and Italy, while an intercept is sufficient for the cases of Finland, Japan, and Germany. If we look now at the estimated values of d we see that in most cases the values are smaller than 1; in fact, mean reversion (i.e., values of d significantly smaller than 1) are obtained for Japan (d = 0.36), Spain (0.54), Italy (0.60), USA (0.71), France (0.77) and Finland (0.82); for the US (FRED data) d is equal to 1.02 and the unit root null cannot be rejected, while for Germany the value of d is significantly higher than 1 (d = 1.63). It seems however, that this last result might be due to the low number of observations employed in the analysis and should not be taken as representative.[1]

Table 8 refers to the daily data, and here we make two assumptions with respect to the error term. In the upper part of the table, we suppose u(t) is uncorrelated and follows a white noise process; in the lower part, u(t) is autocorrelated and we use here the non-parametric approach of Bloomfield (1973) that approximates AR structures by means of the spectral density function. Starting with the case of white noise errors, the time trend is required in the cases of France, Finland and the UK, and reversion to the mean is found in all cases except Germany and Italy. The lowest orders of integration correspond to Finland (0.51) and the UK (0.58), followed by Japan (0.67) and France (0.74) and Spain (0.78). If autocorrelation is permitted, Italy is the only country showing a lack of mean reversion, and for the rest of the countries, the values range from 0.37 in Finland to 0.79 in Germany, implying transitory though long-lasting shocks.

Table 9
Estimates based on a non-linear deterministic trend. Daily data.

Series	No terms				
SPAIN	0.76 (0.72, 0.80)	84.141 (1.39)	−22.643 (−0.64)	23.919 (1.04)	−21.537 (−1.26)
FRANCE	0.74 (0.70, 0.79)	111.551 (1.32)	−58.806 (−1.19)	47.149 (1.44)	−42.833 (−1.55)
FINLAND	0.50 (0.47, 0.54)	**75.881 (3.02)**	**−32.853 (-2.17)**	**27.198 (2.23)**	**−22.419 (-2.20)**
GERMANY	1.07 (1.00, 1.14)	80.605 (0.26)	−47.024 (−0.25)	42.661 (0.49)	−36.364 (−0.64)
JAPAN	0.67 (0.63, 0.70)	12.923 (0.75)	−0.704 (−0.07)	2.315 (0.32)	−0.805 (−0.14)
ITALY	0.98 (0.94, 1.03)	17.275 (1.55)	30.323 (0.45)	40.107 (1.17)	31.644 (1.37)
UK	0.56 (0.54, 0.59)	**84.312 (3.59)**	**−35.751 (-2.57)**	**32.259 (3.00)**	**−28.353 (-3.23)**

In bold the coefficients which are statistically significant at the 5% level.

As a robustness method, the linear time trend in equation (1) is replaced by a non-linear one and based on the Chebyshev polynomials in time, such that the model becomes now:

$$y_t = \sum_{i=0}^{m} \theta_i P_{iT}(t) + x_t, (1-L)^d x_t, (u_t), t = 1, 2, \ldots, \tag{2}$$

where T is sample size, and *m* is the orthogonal Chebyshev polynomials order in time, which are expressed as:

$$P_{0,t}(t) = 1, \tag{3}$$

$$P_{i,T}(t) = \sqrt{2}\, cos(i\pi(t-0.5)/T,), t = 1, 2, \ldots, T; \quad i = 1, 2, \ldots. \tag{4}$$

These polynomials are well described in Hamming (1973) and Smyth (1998), and Bierens (1997), Tomasevic et al. (2009) and others have pointed out that it is possible to estimate highly non-linear trends with rather low degree polynomials. The estimation here is based on the approach developed in Cuestas and Gil-Alana (2016) that allows for fractional integration in the context of the Chebyshev's polynomials in time as in (2). The results using daily data are displayed in Table 9, and the we observe that the estimated values of d are practically the same as those reported in Table 8, with the unit root null hypothesis being unrejected in the cases of Germany and Italy, and this hypothesis being rejected in favor of mean reversion in the rest of the cases. With respect to the non-linear structure, the non-linear coefficients are only statistically significant in the cases of Finland and the UK.

Table 10 shows the differences between monthly and daily samples, and the impact of the different time span. Time series with smaller sample sizes such as Germany or Italy show large differences between monthly and daily data, probably due to the small number of observations used in the case of monthly data. However, for the rest of European countries (Spain, France, Finland and the UK) plus Japan where the samples are more homogeneous (August 2014–September 2022), the results between the two calculations are very similar, exhibiting a fairly small volatility factor (standard deviation/average) in all these series.

When comparing these results with previous studies represented in Table 4, where all of them show mean reversion independently of the

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[1] In particular, this series had only 50 observations to compute with prices that had been multiplied by 6,5x in the last 10 values (from €75 eur in Aug-21 to €575 in Aug-22) and following a clear growing pattern since July-18 (€43). This small amount of observations and explosive growth in the final period had led to a very large confidence interval (1.25, 2.11) indicating weak consistency of results. In fact, when increasing the sample size using daily frequencies (up to 1059 observations) under the same price limits, the estimated value of d was reduced to 1.07 with a much reasonable confidence interval of (1.00 – 1.15). Thus, results are different than in the rest of countries as only the growing trend is very noticeable in this country (the log series has a linear growing trend in the last 20 observations), while in the rest of countries different periods were considered with no observed trends.

Table 10
Comparison between daily and monthly samples.

Country	d (monthly)	Monthly sampling data	d (daily, white noise)	Daily sampling data
Germany	1.63	July 2018–Sept 2022	1.07	July 2018–Sept 2022
Spain	0.54	Jan 1998–Sept2022	0.76	Aug 2014–Sept 2022
France	0.77	Nov 2001–Sept2022	0.74	Aug 2014–Sept 2022
Finland	0.82	July 2009–Sept 2022	0.51	Aug 2014–Sept 2022
Italy	0.6	Nov 2011–Sept 2022 (Break 12/2020–02/2015)	0.99	Nov 2011–Sept 2022 (Break 12/2020–02/2015)
UK	0.69	Mar 2001–Sept 2022	0.58	Aug 2014–Sept 2022
Japan	0.36	Mar 2005–Sept 2022	0.67	Aug 2014–Sept 2022
US -1 (Bloomberg)	1.02	Oct-2012 - Sept 2022	n.d	n.d.
US -2 (FRED)	0.71	Nov 1978–Sept 2022	n.d	n.d.
Spain, France, Finland, UK and Japan (Homogeneous data Aug 2014–Sept 2022)				
	0.64	Average	0.65	
	0.19	Standard Deviation	0.11	
	0.29	Average/Std. deviation	0.16	

Source: own elaboration

Table 11
Relationship of d and the primary energy consumption.

	Primary energy consumption weight			Integration Factor d
	Oil + Coal (%)	Natural gas (%)	Nuclear + Green (%)	
UK	38%	39%	24%	0.58
Japan	64%	21%	15%	0.67
US	47%	32%	21%	0.71
France	33%	16%	50%	0.74
Spain	47%	22%	31%	0.76
Italy	41%	41%	18%	0.99
Germany	50%	26%	24%	1.07

Source: own elaboration

data frequency, it can be argued that our results are quite similar when including the most recent data. Thus, following the results reported in this work, it may be expected that, in Europe, the current shock associated with gas scarcity and the Ukrainian war will be adjusted by natural market forces without additional policies being implemented.

Regarding the relationship of the energy consumption distribution in terms of the integration order, Table 11 and Fig. 1 show the relationship between these figures and the linear trend between each category and the order of integration. We observe a very small positive slope of the integration order d in terms of the natural gas weight; however, the correlation factor R^2 is very small. Thus, no concluding empirical relationship can be identified on these terms.

6. Conclusions

This paper deals with the behavior of energy price changes and how their shocks exert an impact on suppliers and consumers in different markets. It focuses on major European countries as Germany, France, Italy, the UK and Spain, and the US and Japan to analyze if energy prices in Europe act differently than in other countries. Thus, it has been examined the market persistence and mean reversion properties of the primary energy consumption spot prices, and their relationship with its weight of generation and the impact on natural gas after the recent shocks suffered by the energy market. To this end, we have applied fractional integration methods on monthly and daily data starting from 2014.

The empirical results show evidence of mean reversion in all the European countries, though some differences occur between the different markets. Thus, it would be expected that prices following the recent energy shock should recover themselves by natural market forces, without any additional policies. According to our results, these differences are not associated with the energy distribution strategies followed

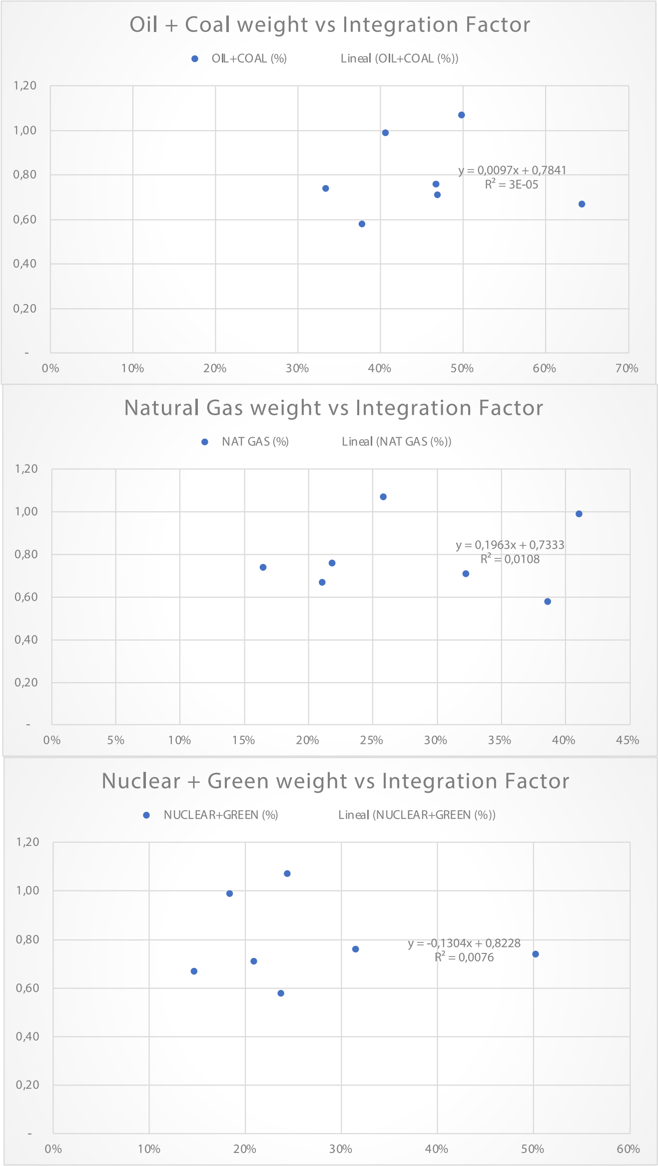

Fig. 1. Relationship of d and the primary energy consumption and associated linear trends.

by each country.

The empirical results reported in this work can be extended by permitting nonlinear structures or even structural breaks in the data. Thus, though we have also used a non-linear model based on Chebyshev polynomials in time, other approaches based on Fourier functions in time (Gil-Alana and Yaya, 2021) or neural networks (Yaya et al., 2021) can be employed. This line of research is interesting since some researchers have argued that fractional differentiation is very much related to these issues. Work in this direction is now under progress.

Author statement

Prof. Miguel A. Martin-Valmayor proposed the original idea. He contributed with the introduction, data sources and conclusions.

Prof. Luis Alberiko Gil-Alana made the computation and interpretation of the results along with the overall revision of the manuscript.

Prof. Juan Infante made the Introduction, Literature review and conclusions.

Declaration of competing interest

There are no competing interests with the publication of the present manuscript.

Data availability

Data will be made available on request.

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