The economics of daily natural gas demand in France and in the UK

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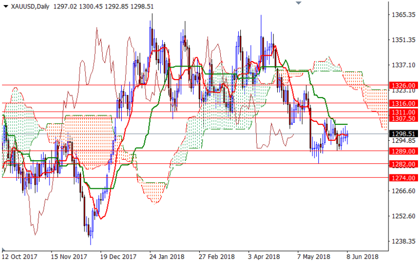
Chair on the Economics of Natural Gas

Background

Changing times for Natural Gas (NG) in the European Energy System:

- Rise of non dispatchable RES
- Demand is uncertain. Large industrial sites are more and more price sensitive



Rising operational challenges for NG TSO's:

- What level of linepack?
- Linepack is costly

The quality of load forecasts is becoming a public policy issue:

- **An increasing attention from regulators**

Litterature on NG demand

- Since the 1980's:
  - Estimation of price income elasticities based on low frequency data
  - This literature is not always based on modern times series techniques
  - Studies on interfuel substitution
- Caveat:
  - The literature predates the emergence of wholesale gas markets
  - A changing role for NG in power generation

$\Longrightarrow$ A lack of recent demand studies based on daily data

Forbes & Zampelli (EJ, 2014)

An idea from electricity literature:

- If day-ahead markets for electricity are efficient, then the day-ahead prices will reflect the processed information and expectation of all market participants
- Test this hypothesis using data for the PG&E aggregation area in the California ISO
- Produce a load forecast based on the day-ahead hourly price
- More accurate than the ISO's day-ahead forecast

Limitations?

- Can we use the studies to gain insights on the magnitude price elasticities?
- An endogeneity issue?

Research questions

- **Are wholesale markets for NG efficient ?**
  - Can we use that information to build good forecast ?
  - Are day-ahead prices and the next day's load exogenous?
- **How is the next day's load sensitive to NG and Elec. prices?**
  - Measure price elasticities in the short - long term
  - Are they symmetric (cf. the works of D. Gately)?
  - Measure cross price elasticities (NG/Elec)

Data

Applications for 2 large markets where transit is not a major concern

- France (North and South) & the UK
- Estimation period: from 31/10/2014 to 31/10/2016
- Out of sample period: from 01/11/2016 to 31/10/2017

Roadmap

Objective:

$$Load_t = f\left(P_{NG_t}, P_{Elec_t}, Seasonal\right)\ \varnothing T,\ \varnothing HDD$$

A time series approach

- Need to check the properties of the times series
- Need to choose an adapted specification

Endogeneity Price vs. Load

Empirical specification

Results & Interpretation

Endogeneity?

	df1	df2	Statistic	Pr(>z)
Northern French zone				
Spark ratio peakload				
Weak instruments	2	510	19.44	$< 10^{-9}$***
Wu-Hausman	1	510	1136.63	$< 10^{-9}$***
Day-ahead gas price				
Weak instruments	2	510	24.24	$< 10^{-9}$***
Wu-Hausman	1	510	805.67	$< 10^{-9}$****

	df1	df2	Statistic	Pr(>z)
UK NTS zone				
Spark ratio peakload				
Weak instruments	1	328	3.06	0.08
Wu-Hausman	1	327	687.50	$< 10^{-9}$***
Day-ahead gas price				
Weak instruments	2	510	25.59	$< 10^{-9}$***
Wu-Hausman	1	510	810.58	$< 10^{-9}$***

	df1	df2	Statistic	Pr(>z)
Southern French zone				
Spark ratio peakload				
Weak instruments	2	510	14.2	$< 10^{-9}$***
Wu-Hausman	1	510	1190.72	$< 10^{-9}$***
Day-ahead gas price				
Weak instruments	2	510	24.97	$< 10^{-9}$***
Wu-Hausman	1	510	822.22	$< 10^{-9}$***

France & UK:

- **Spark ratio peakload** ✓
- **Day-ahead gas price** ✓

Times series properties

	I(0)	I(1)
Northern French zone		
Load		✓
Spark ratio peakload		✓
Day-ahead gas price	✓	
Electricity price		✓
Southern French zone		
Load		✓
Spark ratio peakload	✓	
Day-ahead gas price	✓	
Electricity price	✓	
UK NTS zone		
Load		✓
Spark ratio peakload	✓	
Day-ahead gas price	✓	
Electricity price		✓

Unit root test:

- KPSS test
- Phillips–Perron test

Times series $\neq$ I(1), I(0)

$\Rightarrow$ **An ARDL approach**

An Autoregressive Distributed Lag Modelling Approach
ARDL

$$\ln Load_t = \alpha_0 + \sum_{i=1}^{p} \phi_i \ln Load_{t-i} + \beta' \ln \mathbf{x}_t + \sum_{i=1}^{q-1} \beta_i^{*\prime} \Delta \ln \mathbf{x}_{t-i} + \mathbf{Z} + u_t$$

$$\Delta \ln \mathbf{x_t} = \mathbf{P_1} \Delta \ln \mathbf{x_{t-1}} + \mathbf{P_2} \Delta \ln \mathbf{x_{t-2}} + \cdots + \mathbf{P_s} \Delta \ln \mathbf{x_{t-s}} + \mathbf{Z} + \varepsilon_t$$

- $\mathbf{Z}$ include some dummies
- $\mathbf{x_t}$ is a vector of regressor: vec(Spark ratio peakload, Day-ahead gas price)
- Pesaran, M., Shin, Y.,(1997), An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis. Chapter 11 in Econometrics and Economic Theory in the 20^{th} Century: The Ragnar Frisch Centennial Symposium, Strom S (ed). Cambridge University Press: Cambridge.

Asymmetric issues

NARDL

A decomposition:

$$y_t = \beta^+ x_t^+ + \beta^- x_t^- + u_t$$
$$\Delta x_t = \nu_t$$

where y_t and x_t are at least I(1) variable and x_t is decomposed as $x_t = x_0 + \beta^+ x_t^+ + \beta^- x_t^-$ with :

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} max(\Delta_j, 0)$$
$$x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j=1}^{t} min(\Delta_j, 0)$$

- Schorderet (2003) and Shin, Yu and Greenwood-Nimmo (2013) the robustness of the asymmetric estimator for ARDL and the bound testing approach based on the partial sum decomposed of regressors

Diagnostic tests

ARDL

	Statistic	Pr(>z)
Northern French zone		
A: Serial correlation LB(5)	8.95	0.25
B: Functional form RESET	0.09	0.76
C: Normality JB	2.79	0.09
D: Heteroscedasticity $LB^2(5)$	1.34	0.09
Southern French zone		
A: Serial correlation LB(5)	1.31	0.25
B: Functional form RESET	1.08	0.30
C: Normality JB	0.40	10^{-5}***
D: Heteroscedasticity $LB^2(5)$	0.35	0.55
UK NTS zone		
A: Serial correlation LB(5)	1.90	0.16
B: Functional form RESET	0.16	0.56
C: Normality JB	0.43	10^{-5}***
D: Heteroscedasticity $LB^2(5)$	0.29	0.58

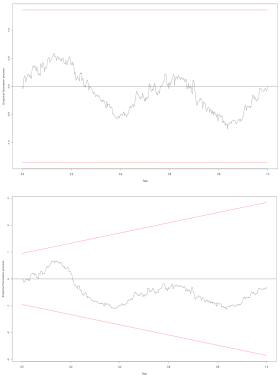
NARDL

	Statistic	Pr(>z)
Northern French zone		
A: Serial correlation LB(5)	8.95	0.25
B: Functional form RESET	0.09	0.76
C: Normality JB	2.95	0.08
D: Heteroscedasticity $LB^2(5)$	0.27	0.59
Southern French zone		
A: Serial correlation LB(5)	0.28	0.25
B: Functional form RESET	1.08	0.30
C: Normality JB	0.41	10^{-5}***
D: Heteroscedasticity $LB^2(5)$	0.49	0.55
UK NTS zone		
A: Serial correlation LB(5)	0.77	0.37
B: Functional form RESET	0.16	0.56
C: Normality JB	0.43	0.05*
D: Heteroscedasticity $LB^2(5)$	2.6	0.10

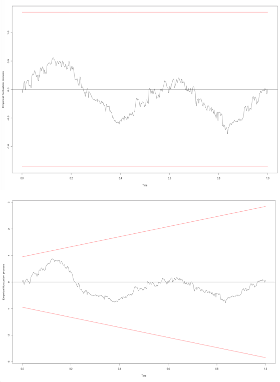
Results

- **Serial correlation** ✓
- **Functional form** ✓
- **Heteroscedasticity** ✓
- **Normality** ∅

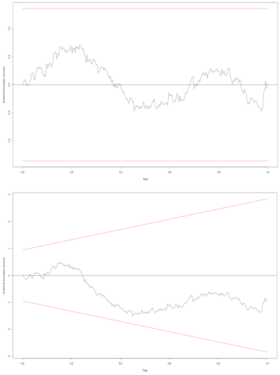
CUSUM & CUSUM^2 tests



Northern French zone



Southern French zone



UK NTS zone

Is there a long run relationship ?

Wald test: see the Bound testing procedure in Pesaran et al. (1997)

ARDL

- **Northern French zone** ✓
- **Southern French zone** ✓
- **UK NTS zone** ✓

NARDL

- **Northern French zone** ✓
- **Southern French zone** ✓
- **UK NTS zone** ✓

Long-Run parameters estimation of ARDL model

	Estimate	Std.Err	Z value	Pr(>z)
Northern French zone				
Spark ratio peakload	0.64	0.15	4.23	$< 10^{-5}$***
Day-ahead gas price	0.25	0.22	1.12	0.07 .
Winter	0.86	0.10	8.35	$< 10^{-9}$***
Tuesday	0.25	0.12	1.97	0.04*
Southern French zone				
Spark ratio peakload	0.87	0.16	5.37	$< 10^{-8}$***
Day-ahead gas price	0.14	0.25	0.58	0.55
Winter	0.77	0.10	7.30	$< 10^{-9}$***
Tuesday	0.40	0.13	3.09	0.001***
UK NTS zone				
Spark ratio peakload	1.79	0.45	3.90	$< 10^{-5}$***
Day-ahead gas price	1.21	0.31	3.84	0.0001***
Winter	0.41	0.08	4.77	$< 10^{-6}$***
Monday	0.86	0.19	4.50	$< 10^{-6}$***
Tuesday	0.57	0.14	3.91	$< 10^{-5}$***
Wednesday	0.59	0.15	3.89	$< 10^{-5}$***
Thursday	0.45	0.13	3.36	0.0007***

Long-Run parameters estimation of NARDL model

	Estimate	Std.Err	Z value	Pr(>z)
Northern French zone				
Spark ratio peakload	0.64	0.14	4.49	$< 10^{-6}$***
Day-ahead gas price	0.39	0.22	1.80	0.07 .
Winter	0.85	0.09	8.64	$< 10^{-9}$***
Southern French zone				
Spark ratio peakload	0.88	0.16	5.58	$< 10^{-8}$***
Day-ahead gas price	0.20	0.24	0.83	0.40
Winter	0.77	0.10	7.59	$< 10^{-9}$***
UK NTS zone				
Spark ratio peakload	0.22	0.14	1.51	0.13
Day-ahead gas price	0.08	0.09	0.94	0.34
Winter	0.35	0.03	9.42	$< 10^{-9}$***

Assymetric issue: a short term reality

Use Likelihood Ratio test (LR test): statistical test used for comparing the goodness of fit of two statistical models — a symmetric model against an Short / Long asymmetric model

Short-term asymmetric

- **Northern French zone** ✓
- **Southern French zone** ✓
- **UK NTS zone** $\varnothing$

Long-term asymmetric

- **Northern French zone** $\varnothing$
- **Southern French zone** $\varnothing$
- **UK NTS zone** $\varnothing$

ARDL-NARDL vs. TSO's Forecast

	AR(1)	ARDL	NARDL	TSO's
	Mean Square Error D-1 5pm			
Northern French zone	0.04123	0.00284	0.05272	0.01121
Southern French zone	0.03378	0.00051	0.02916	0.00158
UK NTS zone	0.01694	0.00161	0.00540	0.00713

Table 1: Table forecasting errors metrics out of sample

Conclusion

- The studies document the informational efficiency of day ahead wholesale prices
- We have gain insights on magnitude price elasticities
- For policy makers, the regional comparison of quality forecast between the UK and France show that the quality of the forecast produces by the TSO's is better when a dedicated incentive policy is implemented

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Appendix

I(0) Stationary test

	Kpss Level	Kpss Trend	Kpss Level (5%)	Kpss Trend (5%)	PP Level	PP Trend	PP Level (5%)	PP Trend (5%)
Northern French zone								
Day-ahead gas price	6.13	0.90	0.01**	0.01**	-4.25	-4.25	0.13	0.87
Electricity price	0.70	0.70	0.01**	0.01**	-124.32	-124.31	0.99**	0.01**
Spark ratio peakload	4.02	0.47	0.01**	0.01**	-218.21	-218.21	0.99**	0.01**
Load	0.68	0.59	0.01**	0.01**	-6.35	-6.35	0.24	0.75
Southern French zone								
Day-ahead gas price	6.13	0.90	0.01**	0.01**	-579.87	-579.87	0.99**	0.01**
Electricity price	0.69	0.70	0.01**	0.01**	-558.57	-558.57	0.99**	0.01**
Spark ratio peakload	0.009	0.01	0.1	0.1	-575.36	-575.36	0.99**	0.01**
Load	0.11	0.074	0.1	0.1	-427.48	-427.48	0.99**	0.01**
UK NTS zone								
Day-ahead gas price	5.50	0.52	0.01**	0.01**	0.91	0.91	0.01**	0.99**
Electricity price	2.90	0.32	0.01**	0.01**	-76.25	-76.25	0.99**	0.01**
Spark ratio peakload	5.58	0.32	0.01**	0.01**	-139.58	-139.58	0.99**	0.01**
Load	0.63	0.59	0.01**	0.01**	-16.05	-16.05	0.78	0.21

Table 2: I(0) test

I(1) Stationary test

	Kpss Level	Kpss Trend	Kpss Level (5%)	Kpss Trend (5%)	PP Level	PP Trend	PP Level (5%)	PP Trend (5%)
Northern French zone								
Day-ahead gas price	0.21	0.10	0.1	0.1	-530.20	-530.20	0.99**	0.01**
Electricity price	0.01	0.01	0.1	0.1	-558.57	-558.57	0.99**	0.01**
Spark ratio peakload	0.010	0.01	0.1	0.1	-573.71	-573.71	0.99**	0.01**
Load	0.12	0.08	0.1	0.1	-433.25	-433.25	0.99**	0.01**
Southern French zone								
Day-ahead gas price	0.21	0.10	0.1	0.1	-579.87	-579.87	0.99**	0.01**
Electricity price	0.019	0.01	0.1	0.1	-558.57	-558.57	0.99**	0.01**
Spark ratio peakload	0.001	0.010	0.1	0.1	-575.36	-575.36	0.99**	0.01**
Load	0.11	0.07	0.1	0.1	-427.48	-427.48	0.99**	0.01**
UK NTS zone								
Day-ahead gas price	0.29	0.14	0.1	0.048*	-328.86	-328.86	0.99**	0.01**
Electricity price	0.27	0.12	0.1	0.081*	-324.25	-324.25	0.99**	0.01**
Spark ratio peakload	0.02	0.02	0.1	0.1	-310.24	-310.24	0.99**	0.01**
Load	0.30	0.13	0.1	0.06*	-325.33	-325.33	0.99**	0.01**

Table 3: I(1) test

Wald test
NARDL

	I(0)	I(1)
10%	2.45	3.52
5%	2.86	4.01
1%	3.74	5.06

Table 4: Wald test statistic bounds co-integration test for Northern French zone: F-stat 31.02

	I(0)	I(1)
10%	2.45	3.52
5%	2.86	4.01
1%	3.74	5.06

Table 5: Wald test statistic bounds co-integration test for Southern French zone: F-stat 27.70

	I(0)	I(1)
10%	2.45	3.52
5%	2.86	4.01
1%	3.74	5.06

Table 6: Wald test statistic bounds co-integration test for UK: F-stat 14.24

Wald test

ARDL

	I(0)	I(1)
10%	3.17	4.14
5%	3.79	4.85
1%	5.15	6.36

Table 7: Wald test statistic bounds co-integration test for Nothern French zone: F-stat 13.32

	I(0)	I(1)
10%	3.17	4.14
5%	3.79	4.85
1%	5.15	6.36

Table 8: Wald test statistic bounds co-integration test for Southern French zone: F-stat 16.93

	I(0)	I(1)
10%	2.17	3.19
5%	2.72	3.83
1%	3.88	5.30

Table 9: Wald test statistic bounds co-integration test for UK: F-stat 8.91

Parameters estimation of ARDL model (1/3)

	Estimate	Std.Err	Z value	Pr(>z)
(Intercept)	1.29	0.25	5.02	$< 10^{-7}$***
Δ Load $_{t-1}$	0.04	0.04	1.12	0.26
Δ Day-ahead gas price	0.80	0.13	5.87	$< 10^{-9}$***
Δ Spark ratio peakload	0.13	0.01	8.40	$< 10^{-9}$***
Winter	$3.8.10^{-4}$	$7.6.10^{-4}$	0.05	0.95
Cointegration$_{t-1}$	-0.06	0.01	-5.05	$< 10^{-7}$***

Table 10: North Short-Run Coefficients. Dependent variable is $\Delta Load$

	Estimate	Std.Err	Z value	Pr(>z)
Spark ratio peakload	0.64	0.15	4.23	$< 10^{-5}$***
Day-ahead gas price	0.25	0.22	1.12	0.07 .
Winter	0.86	0.10	8.35	$< 10^{-9}$***
Tuesday	0.25	0.12	1.97	0.04*

Table 11: North Long-Run Coefficients. Dependent variable is Load

Parameters estimation of ARDL model (2/3)

	Estimate	Std.Err	Z value	Pr(>z)
(Intercept)	1.36	0.24	5.47	$< 10^{-8}$***
Δ Load $_{t-1}$	0.06	0.04	1.46	0.14
Δ Day-ahead gas price	0.41	0.14	2.82	0.004**
Δ Spark ratio peakload	0.13	0.01	7.92	$< 10^{-9}$***
Cointegration$_{t-1}$	-0.07	0.01	-5.49	$< 10^{-8}$***

Table 12: South Short-Run Coefficients. Dependent variable is $\Delta Load$

	Estimate	Std.Err	Z value	Pr(>z)
Spark ratio peakload	0.87	0.16	5.37	$< 10^{-8}$***
Day-ahead gas price	0.14	0.25	0.58	0.55
Winter	0.77	0.10	7.30	$< 10^{-9}$***
Tuesday	0.40	0.13	3.09	0.001**

Table 13: South Long-Run Coefficients. Dependent variable is Load

Parameters estimation of ARDL model (3/3)

	Estimate	Std.Err	Z value	Pr(>z)
(Intercept)	-0.03	0.02	-1.56	0.11
Δ Load $_{t-1}$	-0.08	0.05	-1.61	0.10
Δ Day-ahead gas price	0.69	0.11	5.91	$< 10^{-9}$***
Δ Spark ratio peakload	0.34	0.05	6.06	$< 10^{-6}$***
Cointegration$_{t-1}$	-0.04	0.01	-2.32	0.01*
Monday	0.06	0.02	2.56	0.01*

Table 14: UK Short-Run Coefficients. Dependent variable is $\Delta Load$

	Estimate	Std.Err	Z value	Pr(>z)
Spark ratio peakload	1.79	0.45	3.90	$< 10^{-5}$***
Day-ahead gas price	1.21	0.31	3.84	0.0001***
Winter	0.41	0.08	4.77	$< 10^{-6}$***
Monday	0.86	0.19	4.50	$< 10^{-6}$***
Tuesday	0.57	0.14	3.91	$< 10^{-5}$***
Wednesday	0.59	0.15	3.89	$< 10^{-5}$***
Thursday	0.45	0.13	3.36	0.0007***

Table 15: UK Long-Run Coefficients. Dependent variable is Load

Parameters estimation of NARDL model (1/3)

	Estimate	Std.Err	Z value	Pr(>z)
(Intercept)	1.48	0.14	9.90	$< 10^{-9}$***
Δ Load $_{t-1}$	-0.02	0.04	-0.56	0.56
Δ Day-ahead gas price^{+}	0.71	0.16	4.32	$< 10^{-9}$***
Δ Day-ahead gas price^{-}	0.58	0.17	3.44	$< 10^{-4}$***
Δ Spark ratio peakload^{+}	0.28	0.02	10.76	$< 10^{-9}$***
Δ Spark ratio peakload^{-}	0.09	0.02	3.70	$< 10^{-4}$***
Winter	$4.8.10^{-4}$	$7.5.10^{-4}$	0.06	0.94
Cointegration$_{t-1}$	-0.08	$6.6.10^{-4}$	-12.05	$< 10^{-9}$***

Table 16: North Short-Run Coefficients. Dependent variable is $\Delta Load$

	Estimate	Std.Err	Z value	Pr(>z)
Spark ratio peakload	0.64	0.14	4.49	$< 10^{-6}$***
Day-ahead gas price	0.39	0.22	1.80	0.07 .
Winter	0.85	0.09	8.64	$< 10^{-9}$***

Table 17: North Long-Run Coefficients. Dependent variable is Load

Parameters estimation of NARDL model (2/3)

	Estimate	Std.Err	Z value	Pr(>z)
(Intercept)	1.55	0.16	9.50	$< 10^{-9}$***
Δ Load $_{t-1}$	-7.4.10^{-4}	0.04	-0.18	0.85
Δ Day-ahead gas price^{+}	0.38	0.17	2.16	0.03*
Δ Day-ahead gas price^{-}	0.40	0.17	2.30	0.02*
Δ Spark ratio peakload^{+}	0.29	0.03	9.72	$< 10^{-9}$***
Δ Spark ratio peakload^{-}	0.10	0.03	3.74	$< 10^{-4}$***
Cointegration$_{t-1}$	-0.09	7.5.10^{-4}	-11.59	$< 10^{-9}$***

Table 18: South Short-Run Coefficients. Dependent variable is Δ*Load*

	Estimate	Std.Err	Z value	Pr(>z)
Spark ratio peakload	0.88	0.16	5.58	$< 10^{-8}$***
Day-ahead gas price	0.20	0.24	0.83	0.40
Winter	0.77	0.10	7.59	$< 10^{-9}$***

Table 19: South Long-Run Coefficients. Dependent variable is Load

Parameters estimation of NARDL model (3/3)

	Estimate	Std.Err	Z value	Pr(>z)
(Intercept)	0.83	0.23	3.537	$< 10^{-4}$***
Δ Load $_{t-1}$	-0.05	0.05	-0.94	0.34
Δ Day-ahead gas price^{+}	0.68	0.12	5.57	$< 10^{-8}$***
Δ Day-ahead gas price^{-}	-0.02	0.18	-0.10	0.91
Δ Spark ratio peakload^{+}	0.37	0.08	4.79	$< 10^{-6}$***
Δ Spark ratio peakload^{-}	0.04	0.07	0.55	0.57
Cointegration$_{t-1}$	-0.18	0.03	-6.72	$< 10^{-9}$***

Table 20: UK Short-Run Coefficients. Dependent variable is $\Delta Load$

	Estimate	Std.Err	Z value	Pr(>z)
Spark ratio peakload	0.22	0.14	1.51	0.13
Day-ahead gas price	0.08	0.09	0.94	0.34
Winter	0.35	0.03	9.42	$< 10^{-9}$***

Table 21: UK Long-Run Coefficients. Dependent variable is Load

ARDL-NARDL vs. AR(1)

	ME	RMSE	MAE	MPE	MAPE	MASE	ACF1
AR(1)							
UK NTS zone	0.04	0.13	0.07	0.17	0.33	6.13	0.87
Northern French zone	0.02	0.02	0.02	0.43	0.43	∞	
Southern French zone	-0.05	0.06	0.05	-0.26	0.27	6.89	0.58
ARDL							
UK NTS zone	-0.05	0.05	0.05	-0.86	0.86	∞	
Northern French zone	0.07	0.13	0.08	0.35	0.39	14.24	0.85
Southern French zone	0.20	0.26	0.22	1.01	1.08	4.82	0.78
NARDL							
UK NTS zone	-0.05	0.05	0.05	-1.01	1.01	∞	
Northern French zone	0.12	0.13	0.12	0.57	0.57	5.80	0.82
Southern French zone	0.09	0.14	0.10	0.43	0.52	8.07	0.91

Table 22: Table forecasting errors metrics

Northern French zone

	ARDL	NARDL	GRT GAZ
Mean Square Error D-1 5pm	0.00284	0.05272	0.01121
Mean Square Error D-2	0.01050	0.01581	0.00353
Mean Square Error D-3	0.01899	0.02317	0.00399
Mean Square Error D-4	0.02597	0.03015	0.00614
Mean Square Error D-5	0.03210	0.03576	0.00834
Root Mean Square Error D-1 5pm	0.05332	0.22960	0.03492
Root Mean Square Error D-2	0.10249	0.12576	0.05940
Root Mean Square Error D-3	0.13779	0.15222	0.06317
Root Mean Square Error D-4	0.16114	0.17364	0.07833
Root Mean Square Error D-5	0.17916	0.18911	0.09134
MAPE D-1 5pm	0.00228	0.00372	0.00132
MAPE D-2	0.00390	0.00484	0.00232
MAPE D-3	0.00529	0.00586	0.00253
MAPE D-4	0.00625	0.00680	0.00300
MAPE D-5	0.00687	0.00723	0.00331

Table 23: TSO forecast vs ARDL-NARDL forecast quality for Northern French zone

	ARDL	NARDL	GRT GAZ
Mean Square Error D-1 5pm	0.00284	0.05272	0.01121
Mean Square Error D-2	0.01050	0.01581	0.00353
Mean Square Error D-3	0.01899	0.02317	0.00399
Mean Square Error D-4	0.02597	0.03015	0.00614
Mean Square Error D-5	0.03210	0.03576	0.00834
Theil's Bias component D-1 5pm	0.00130	0.00561	0.00085
Theil's Bias component D-2	0.00251	0.00308	0.00145
Theil's Bias component D-3	0.00337	0.00372	0.00155
Theil's Bias component D-4	0.00394	0.00425	0.00192
Theil's Bias component D-5	0.00438	0.00463	0.00223
Theil's σ component D-1 5pm	0.00261	0.01124	0.00171
Theil's σ component D-2	0.00502	0.00616	0.00291
Theil's σ component D-3	0.00675	0.00745	0.00309
Theil's σ component D-4	0.00789	0.00850	0.00384
Theil's σ component D-5	0.00877	0.00926	0.00447

Table 24: TSO forecast vs ARDL-NARDL forecast quality for Northern French zone: Theil's decomposition

Southern French zone

	ARDL	NARDL	GRT GAZ
Mean Square Error D-1 5pm	0.00051	0.02916	0.00158
Mean Square Error D-2	0.01123	0.01639	0.00477
Mean Square Error D-3	0.01937	0.02295	0.00747
Mean Square Error D-4	0.02663	0.03028	0.01493
Mean Square Error D-5	0.03394	0.03671	0.01610
Root Mean Square Error D-1 5pm	0.02267	0.17076	0.03975
Root Mean Square Error D-2	0.10599	0.12804	0.06909
Root Mean Square Error D-3	0.13918	0.15150	0.08643
Root Mean Square Error D-4	0.16320	0.17400	0.12217
Root Mean Square Error D-5	0.18422	0.19161	0.12688
MAPE D-1 5pm	0.00097	0.00276	0.00159
MAPE D-2	0.00374	0.00466	0.00267
MAPE D-3	0.00525	0.00595	0.00330
MAPE D-4	0.00625	0.00681	0.00467
MAPE D-5	0.00707	0.00748	0.00502

Table 25: TSO forecast vs ARDL-NARDL forecast quality for Southern French zone

	ARDL	NARDL	GRT GAZ
Mean Square Error D-1 5pm	0.00051	0.02916	0.00158
Mean Square Error D-2	0.01123	0.01639	0.00477
Mean Square Error D-3	0.01937	0.02295	0.00747
Mean Square Error D-4	0.02663	0.03028	0.01493
Mean Square Error D-5	0.03394	0.03671	0.01610
Theil's Bias component D-1 5pm	0.00058	0.00437	0.00102
Theil's Bias component D-2	0.00271	0.00328	0.00177
Theil's Bias component D-3	0.00357	0.00388	0.00221
Theil's Bias component D-4	0.00418	0.00446	0.00313
Theil's Bias component D-5	0.00472	0.00491	0.00325
Theil's σ component D-1 5pm	0.00116	0.00875	0.00204
Theil's σ component D-2	0.00543	0.00656	0.00354
Theil's σ component D-3	0.00713	0.00776	0.00443
Theil's σ component D-4	0.00836	0.00891	0.00626
Theil's σ component D-5	0.00944	0.00982	0.00650

Table 26: TSO forecast vs ARDL-NARDL forecast quality for Southern French zone: Theil's decomposition

UK NTS zone

	ARDL	NARDL	National Grid
Mean Square Error D-1 5pm	0.00161	0.00540	0.00713
Mean Square Error D-2	0.00760	0.01214	0.00241
Mean Square Error D-3	0.01123	0.01518	0.00327
Mean Square Error D-4	0.01359	0.01700	0.00345
Mean Square Error D-5	0.01530	0.01800	0.00379
Root Mean Square Error D-1 5pm	0.04018	0.07346	0.08443
Root Mean Square Error D-2	0.08716	0.11017	0.04909
Root Mean Square Error D-3	0.10597	0.12320	0.05720
Root Mean Square Error D-4	0.11659	0.13038	0.05876
Root Mean Square Error D-5	0.12369	0.13418	0.06153
MAPE D-1 5pm	0.01098	0.01098	0.00859
MAPE D-2	0.01591	0.01591	0.00739
MAPE D-3	0.01805	0.01805	0.00861
MAPE D-4	0.01883	0.01883	0.00895
MAPE D-5	0.01955	0.01955	0.00922

Table 27: TSO forecast vs ARDL-NARDL forecast quality for UK NTS zone

	ARDL	NARDL	National Grid
Mean Square Error D-1 5pm	0.00161	0.00540	0.00713
Mean Square Error D-2	0.00760	0.01214	0.00241
Mean Square Error D-3	0.01123	0.01518	0.00327
Mean Square Error D-4	0.01359	0.01700	0.00345
Mean Square Error D-5	0.01530	0.01800	0.00379
Theil's Bias component D-1 5pm	0.00370	0.00675	0.00453
Theil's Bias component D-2	0.00802	0.01013	0.00553
Theil's Bias component D-3	0.00976	0.01133	0.00528
Theil's Bias component D-4	0.01074	0.01199	0.00542
Theil's Bias component D-5	0.01140	0.01234	0.00568
Theil's σ component D-1 5pm	0.01344	0.01344	0.00906
Theil's σ component D-2	0.01601	0.02017	0.00987
Theil's σ component D-3	0.01947	0.02257	0.01056
Theil's σ component D-4	0.02144	0.02390	0.01084
Theil's σ component D-5	0.01140	0.02462	0.01135

Table 28: TSO forecast vs ARDL-NARDL forecast quality for UK NTS zone: Theil's decomposition