LNG and the Relationship between UK and NW European Natural Gas Markets.

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Main Question:

Has the relationship between UK NBP and AGIP changed since the opening of the UK to global LNG trade?

If it did, how...?

(i) Prices have *permanently* broken away from the old long-term relationship and have entered a new one.

(ii) Prices broke away from the old relationship and no longer maintain a long-term relationship with each other at all.

Key Results:

(i) *Evidence of a price decoupling from old to new, much weaker, long-run relationship from middle of 2006.*

(ii) *From November 2008, the date when UK LNG imports picked up, the long-run relationship appears to break down altogether.*

Contributions

The contributions of this study are threefold:

(i) First study to take account of important UK spot gas market drivers: seasonality, temperature and gas storage injection/withdrawal behaviour.

(ii) The effect of pipeline and LNG import capacity extensions on the long-term relationship between UK NBP and oil-indexed gas prices will be analyzed. Use measure of oil-indexed gas prices in the NW European market, the *Average German Import Price*, rather than price for crude oil.

(iii) Larger dataset compared to previous research, which covered data up until and including 2005, hence import UK gas market events.

Why prices might have decoupled...

Key:

Through LNG the UK natural gas market has opened to international arbitrage for the marginal unit of supply.

Relative *global natural gas prices matter.*

UK NBP and AGIP can reconnect if:

(i) Spot LNG prices are above AGIP.

(ii) High UK demand exceeds available spot LNG - NW European imports balance UK market.

...and why it is important.

Key:

Decoupling of UK NBP and oil-indexed gas increases the friction between the two pricing systems.

The dynamic properties of the AGIP-UK NBP price differential is important for:

(i) Large-scale gas consumers in NW Europe, positioned in long-term oil-indexed supply contracts.

Key: high degree of integration between UK and NW European spot markets.

(ii) Exporters of natural gas into NW Europe - decoupling increases pressure to move away from oil-indexation.

(iii) UK consumers - exposure of UK NBP to oil-price shocks.

Previous research produces conflicting results...

- Commonly held view: arbitrage across the IUK connects UK NBP and oil-indexed prices in the NW European market; Barton and Vermeire (1999), ILEX(2001).
- *Contradicting empirical evidence:*
  - (i) Significant cointegration relationship between UK NBP and Brent for period of physical market isolation (1995-98), cointegration rejected from 1998-2002; Asche et al. (2006).
  - (ii) Cointegration holds between UK NBP and Brent over the entire sample between 1996-2003, *before* opening of the IUK; Panagiotidis and Rutledge (2007).
- Key: No empirical work on long-term relationship using data post 2005.

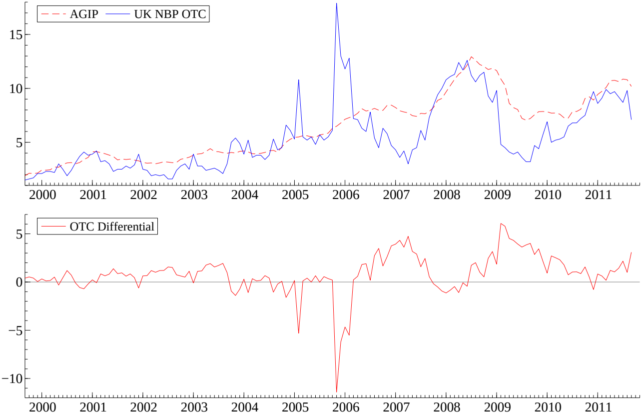

Figure: AGIP, NBP OTC and Differential (in USD/mmbtu): September 1999 to November 2011

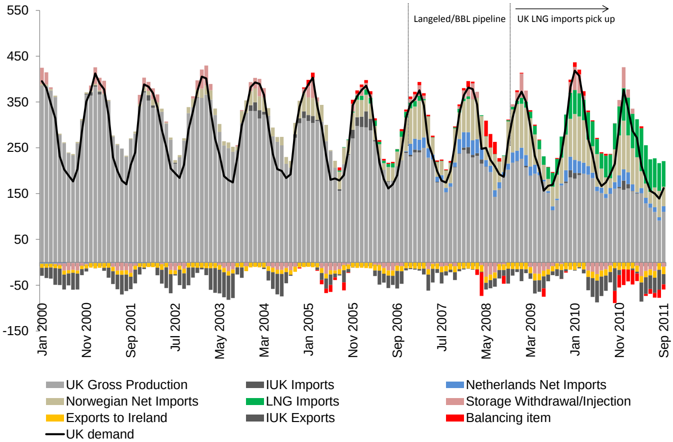

Figure: UK Natural Gas Balance (mcm/day) Jan 2000 - Sept 2011, Source: DECC, National Grid, author's calculation

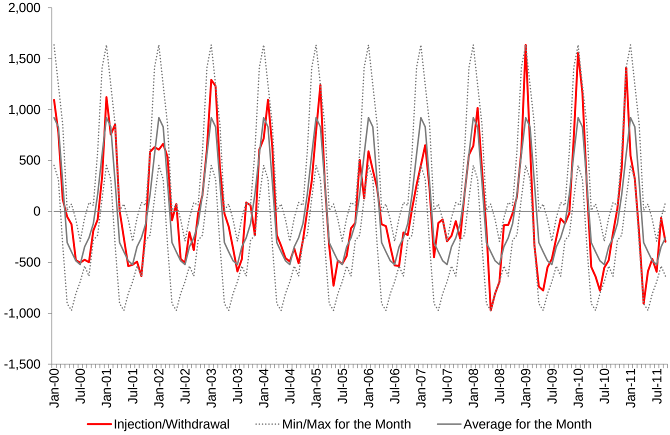

Figure: UK natural gas storage injections (-) and withdrawals (+) (in mcm) - Source: National Grid, author's calculation.

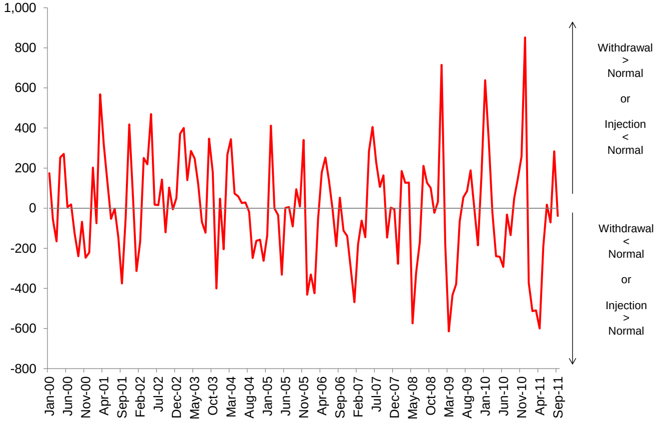

Figure: UK natural gas storage deviations from Normal inj./withdr. (in mcm) - Source: author's calculation.

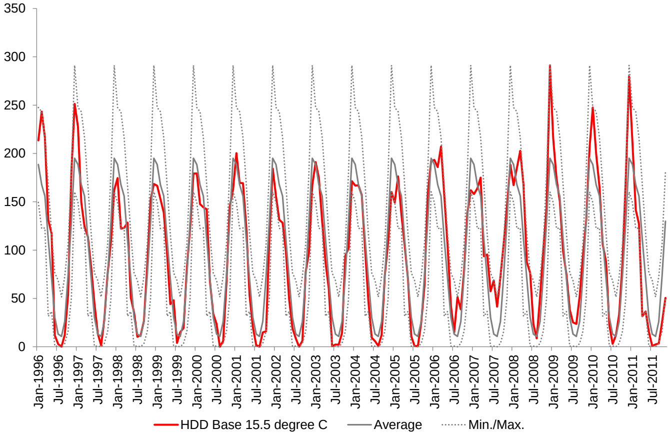

Figure: UK Heating Degree Days (HDD), monthly aggregates - Source: Bloomberg

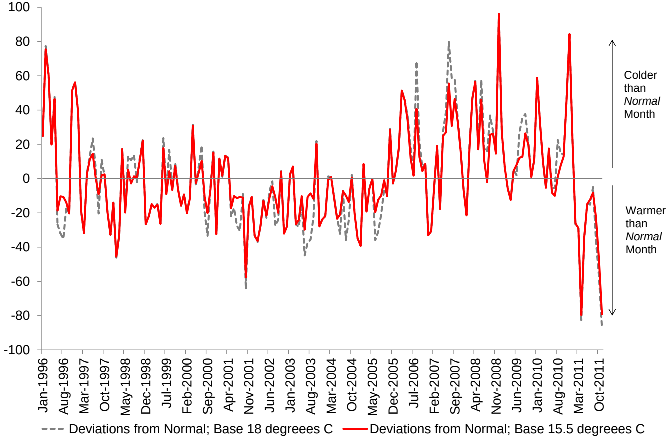

Figure: UK Heating Degree Days (HDD), deviations from normal, monthly aggregates - Source: author's calculation

Is there a break in the cointegrating relationship and have prices decoupled? If so, how?

Following Ramberg and Parsons (2012):

(i) Prices have *permanently* broken away from the old long-term relationship and have entered a new long-term relationship.

Implies: a regime shift in the cointegrating relationship.

(ii) Prices broke away from the old relationship and no longer maintain a long-term relationship with each other at all.

Implies: prices are no longer cointegrated.

Following long-run model between UK NBP and AGIP is proposed:

$$log(nbp_t^m) = \alpha + \beta log(agip_t) + \phi_1 Winter_t^{05/06} + \phi_2 DS_t + \phi_3 DHDD_t + \epsilon_t$$

To test for structural breaks, Gregory and Hansen (1996):

(i) Test for *coupling* while allowing for single break in both constant α and sensitivity β.

(ii) Obtain estimated break-date τ.

(iii) Estimate model on each side of τ separately.

Partition the variation in the AGIP-UK NBP price differential (y_t) into several components:

$$y_t = \mu_t + \gamma_t + \phi_1 Winter_t^{05/06} + \phi_2 DS_t + \phi_3 DHDD_t + \epsilon_t$$

- μ_t stochastic trend component, follows RW.
- γ_t stochastic seasonal, time variant.
- Temperature, storage and winter 05/06 controls.

Test for *structural break* in stochastic trend at two **known** dates: BBL pipeline (December 2006) and the pick-up of UK LNG imports (November 2008).

Table: Cointegration Regressions and Endogenous Breaks

	Dependent: $log(nbp^{otc})$ $m = otc$			Dependent: $log(nbp^{front})$ $m = front$		
Break†	No	$\tau = 2006(5)$	$\tau = 2006(5)$	No	$\tau = 2006(8)$	$\tau = 2006(8)$
Model		C	C/S		C	C/S
$log(agip)$	0.9584***	1.5587***	1.5293***	0.9828***	1.4912***	1.4443***
	(0.1040)	(0.1336)	(0.1473)	(0.1053)	(0.1367)	(0.1487)
$log(agip)*\delta_\tau^m$	-	-	0.1283	-	-	0.2208
			(0.2775)			(0.3053)
Dev. Storage	-0.0001	-0.0001	-0.0002	-0.0002	-0.0002	-0.0002*
	(0.0002)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)
Dev. HDD(b=15.5)	0.0011	0.0027*	0.0029**	0.0004	0.0011	0.0014
	(0.0020)	(0.0015)	(0.0014)	(0.0020)	(0.0016)	(0.0015)
Constant	-0.1684	-0.9029***	-0.8338***	-0.1361	-0.7703***	-0.6768***
	(0.1874)	(0.1950)	(0.2135)	(0.1896)	(0.2040)	(0.2203)
Constant$*\delta_\tau^m$	-	-0.6711***	-0.9661*	-	-0.5743***	-1.0607*
		(0.1189)	(0.5627)		(0.1214)	(0.6311)
R^2	0.6575	0.7611	0.7657	0.6556	0.7332	0.7389
adj.-R^2	0.6499	0.7541	0.7569	0.6480	0.7253	0.7291
N	140	140	140	140	140	140

* = significant at the 10% level, ** = significant at the 5% level,*** = significant at the 1% level.
(...) Standard errors in parentheses. † break dates estimated using Gregory and Hansen (1996).
Model: (C) break only in level, (C/S) break in both level and slope parameter.

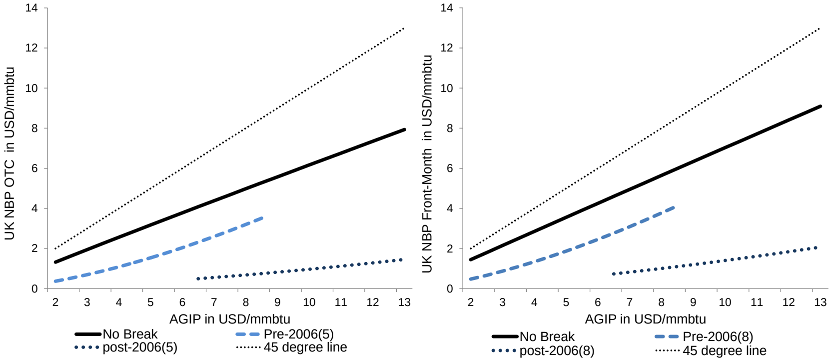

Figure: UK NBP and AGIP Cointegrating Relationships

Unobserved components model

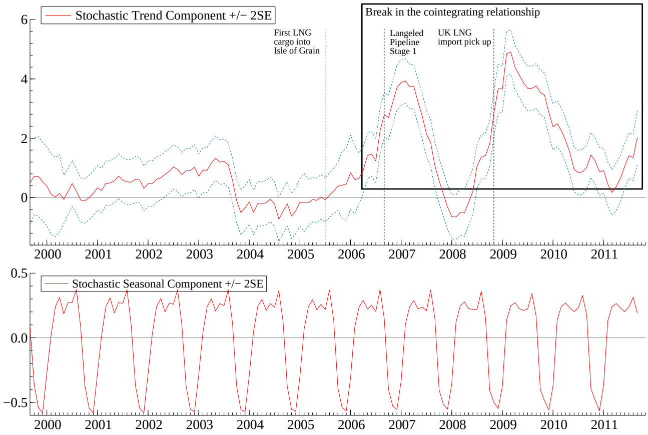

Figure: UC Model 5 (OTC): stochastic trend and break in co-integrating vector

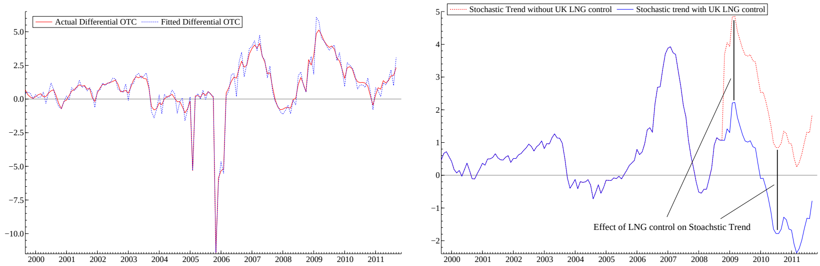

Figure: Final Model: actual and fitted differential, the effect of LNG on the stochastic trend (USD/mmbtu)

Table: Split Cointegration Regressions UK NBP OTC and AGIP

Dependent Variable: $log(NBP - OTC)$

Full sample	N	Constant	$log(AGIP)$	R^2	Engle-Granger τ	Phillips-Ouliaris τ	Hansen‡
1999M10:2011M09	144	-0.2747*	1.0174***	0.6793	-4.6463	-4.65315	
		(0.1489)	(0.0825)		[0.0011]	[0.0011]	[> 0.2]
Break 2006(12)	N	Constant	$log(AGIP)$	R^2	Engle-Granger τ	Phillips-Ouliaris τ	Hansen‡
1999M10:2006M11	86	-0.4961**	1.2335***	0.6655	-4.4270	-4.4915	
		(0.2006)	(0.1368)		[0.0030]	[0.0025]	[> 0.2]
2006M12:2011M09	58	-1.7975***	1.6743***	0.5890	-2.6023	-2.5196	
		(0.4169)	(0.1883)		[0.2505]	[0.2838]	[0.1707]
Break 2008(11)	N	Constant	$log(AGIP)$	R^2	Engle-Granger τ	Phillips-Ouliaris τ	Hansen‡
1999M10:2008M10	109	-0.3108*	1.0680***	0.7058	-4.4115	-4.4578	
		0.175077	(0.1054)		[0.0028]	[0.0024]	[> 0.2]
2008M11:2011M09	35	-1.5206**	1.5541***	0.4738	-1.9869	-1.8954	
		(0.6063)	(0.2767)		[0.5418]	[0.5873]	[0.1343]

(...) Standard errors in parentheses. [...] MacKinnon (1996) p-values in parentheses.

‡ Hansen (1992) p-values in parentheses.

* = significant at the 10% level, ** = significant at the 5% level, *** = significant at the 1% level.

The null-hypothesis of both Engle-Granger and Phillips-Ouliaris tests is: *no cointegration*.

The null-hypothesis of the Hansen test is: *cointegration*.

Table: Split Cointegration Regressions UK NBP Front-Month and AGIP

Dependent Variable: $log(NBP - Front)$

Full sample	N	Constant	$log(AGIP)$	R^2	Engle-Granger τ	Phillips-Ouliaris τ	Hansen‡
1999M10:2011M09	144	-0.2312	1.0364***	0.6798	-4.3488	-3.9463	
		(0.1563)	(0.0866)		[0.0031]	[0.0109]	[0.1379]
Break 2006(12)	N	Constant	$log(AGIP)$	R^2	Engle-Granger τ	Phillips-Ouliaris τ	Hansen‡
1999M10:2006M11	86	-0.6111***	1.3796***	0.7349	-4.4787	-3.8342	
		(0.1953)	(0.1332)		[0.0026]	[0.0171]	[> 0.2]
2006M12:2011M09	58	-1.8862***	1.7390***	0.5975	-2.5399	-2.6611	
		(0.4079)	(0.1842)		[0.2754]	[0.2285]	[> 0.2]
Break 2008(11)	N	Constant	$log(AGIP)$	R^2	Engle-Granger τ	Phillips-Ouliaris τ	Hansen‡
1999M10:2008M10	109	-0.3239*	1.1352***	0.7310	-4.3516	-3.7310	
		(0.1797)	(0.1081)		[0.0034]	[0.0212]	[> 0.2]
2008M11:2011M09	35	-1.3049***	1.4708***	0.4664	-1.9270	-1.8517	
		(0.4646)	(0.2120)		[0.5716]	[0.6087]	[< 0.01]

(...) Standard errors in parentheses. [...] MacKinnon (1996) p-values in parentheses.
‡ Hansen (1992) p-values in parentheses.
* = significant at the 10% level, ** = significant at the 5% level, *** = significant at the 1% level.
The null-hypothesis of both Engle-Granger and Phillips-Ouliaris tests is: *no cointegration*.
The null-hypothesis of the Hansen test is: *cointegration*.

Conlusion...

(a) Conventional cointegration analysis:
   (i) Estimated over the entire sample, AGIP and UK NBP are cointegrated, close to unit elasticity.
   (ii) Endogenous break estimation suggest level and constant change in the middle of 2006.
   (iii) Split estimation provides better fit, explaining between 8-10% more of UK NBP vol.
   (iv) Substantial drop in constant indicates drastically weakened long-run relationship.
   (v) Evidence of a price *decoupling* from old to new, much weaker, long-run relationship from middle of 2006.

...continued.

(b) Unobserved components modelling:
  (i) Continuous decline in seasonal pattern confirms reduced influence of seasonal arbitrage on price differential.
  (ii) Trend departure from zero in middle of 2006 - break in cointegrating relationship.
  (iii) Evidence of a price *decoupling* from old to new, much weaker, long-run relationship from the end of 2006.
  (iv) From 2008(11) LNG, long-run relationship appears to break down altogether. Key: despite tight Asian LNG market!

Problem: low post-break sample size.

Going forward...

(a) Repeat analysis as more data on post-break sample becomes available. Possible results:
   (i) Reject CI in post-break sample. Parameters meaningless. Price no longer maintain long-run relationship.
   (ii) Accept CI in post-break sample and confirm new, much weaker, long-run relationship.

   Both cases suggest the relationship between UK NBP and AGIP is broken.

(b) Include (Asian) spot LNG price. Determine whether the price of spot LNG has taken over from AGIP in setting the UK NBP in periods of peak UK demand.

Thank you!

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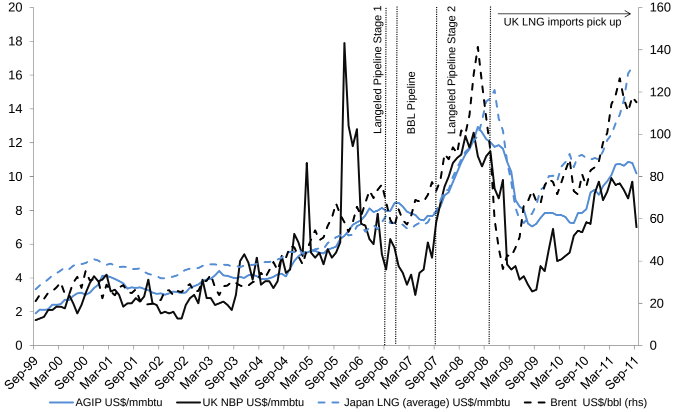

Figure: UK NBP day-ahead, AGIP and Japan LNG import price in USD/mmbtu (lhs), Brent crude oil in USD/bbl (rhs) September 1999-2011, Source: Bloomberg, BAFA

Table: UK LNG Regasification Capacity

Terminal Name	Operator/Developer	Commissioning Date	Landfall in the UK	Capacity in *bcma*
Isle of Grain 1/2	National Grid	2005	Isle of Grain	13.5
Gasport	Excelerate	2007	Teesside	$\approx$ 4
Dragon	BG/Petronas	2009	Milford Haven	6
South Hook 1	QP/ExxonMobil	2009	Milford Haven	10.5
South Hook 2	QP/EcconMobil	2010	Milford Haven	10.5
Isle of Grain 3	National Grid	2010	Isle of Grain	7
			Total existing	$\approx$ 51.5
Isle of Grain 4	National Grid	?	River Medway	?

Source: Heather (2010) and National Grid (2010). QP Qatar Petroleum. BG British Gas (Centrica).

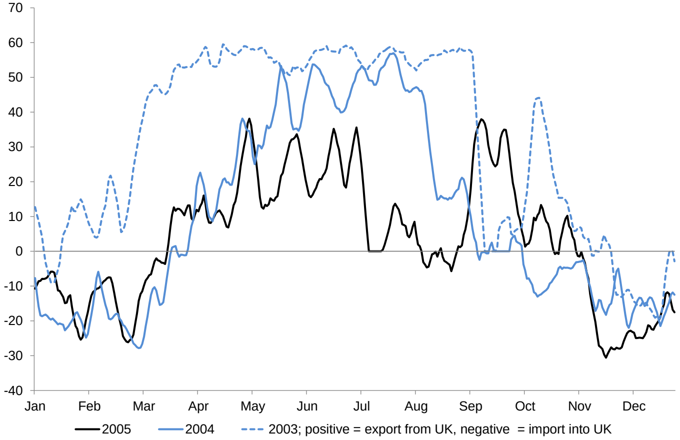

Figure: Interconnector Daily Pipeline Flows pre LNG (Weekly average in mcm/day) 2003-2005, Source: Interconnector

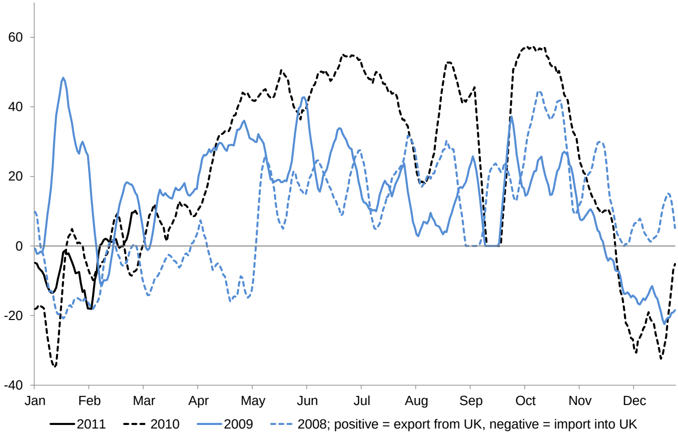

Figure: Interconnector Daily Pipeline Flows post LNG (Weekly average in mcm/day) 2008-2011, Source: Interconnector

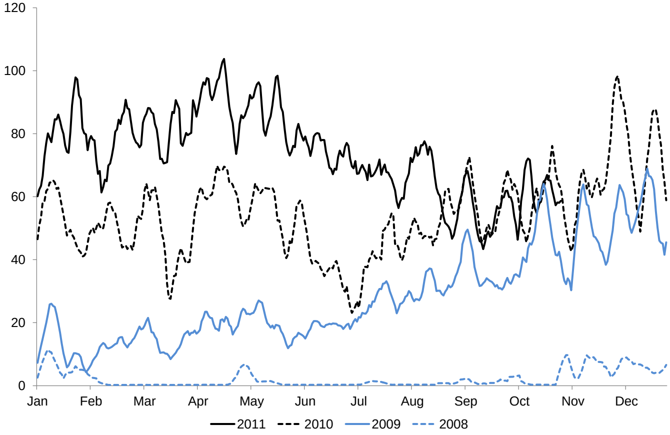

Figure: UK LNG imports (Weekly average in mcm/day) 2011-08, Source: Bloomberg/NationalGrid

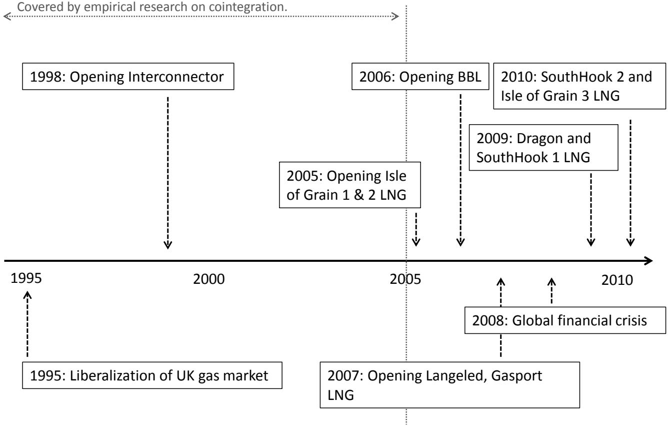

Figure: Major Events in the UK Gas Market, 1995-2010

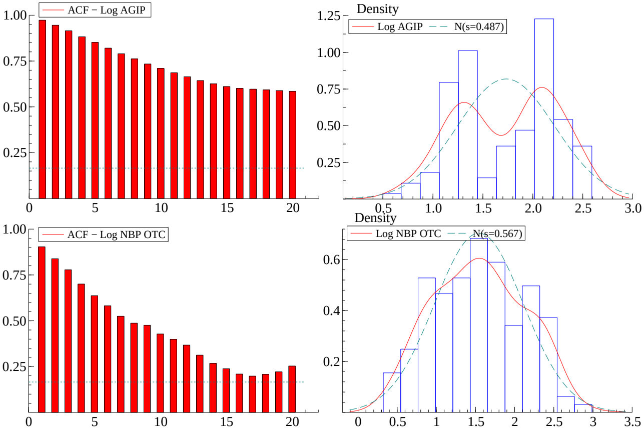

Figure: Distribution and ACF: Log Prices

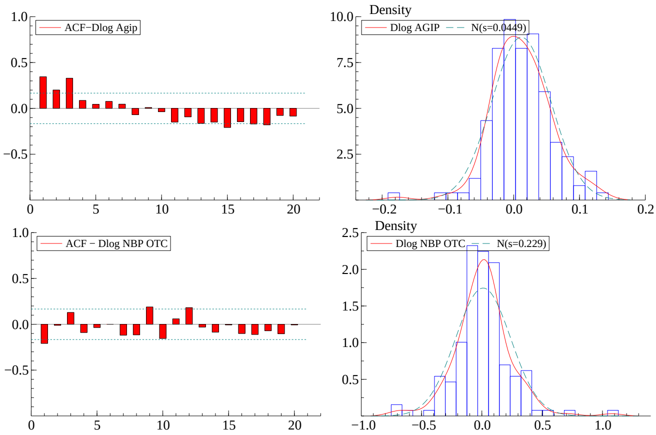

Figure: Distribution and ACF: 1-month difference - Log Prices

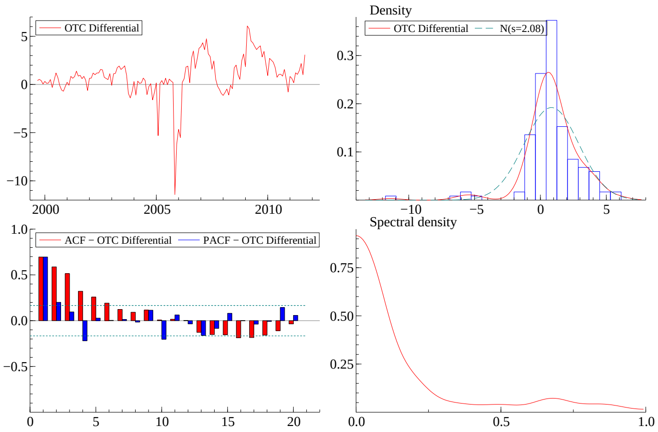

Figure: AGIP-NBP OTC differential, ACF (PACF), distribution and spectral density

Table: UK Natural Gas Storage Injection/Withdrawal, deviations from normal

Deviation	Storage Injection	or	Storage Withdrawal	Count	Hypothesized Effect on UK NBP spot price
$DS_t > 0$:	$<$ *Normal*	or	$>$ *Normal*	71	*Upward pressure*
$DS_t < 0$:	$>$ *Normal*	or	$<$ *Normal*	70	*Downward pressure*

DS = *Actual* Injection (Withdrawal) - *Normal* Injection (Withdrawal)

Table: UK Heating Degree Days (HDD), deviation from normal

HDD Deviation	Count Baseline 18C	Count Baseline 15.5C	Hypothesized Effect on UK NBP spot price
$DHDD_t > 0$:	67	65	*Upward pressure*
$DHDD_t < 0$:	74	76	*Downward pressure*

DHDD = *ActualHDD* for the month - *Normal* (Average) for the month.

Table: Descriptive Statistics

	AGIP	UK NBP Front	UK NBP OTC	Log Differential OTC	Log Differential Front	Dev. Storage	Dev. HDD *base*=15.5	Dev. HDD *base*=18
Observations	141	141	141	141	141	141	141	141
Mean	6.4501	6.0416	5.5943	0.1885	0.1136	-0.9854	0.6733	0.6491
Median	6.4910	5.2880	4.8000	0.1450	0.1028	1.5406	-2.8933	-4.3750
Maximum	12.9362	18.6203	17.9000	0.9471	0.8154	852.0697	96.1067	96.1067
Minimum	2.4154	1.7814	1.6000	-1.0144	-1.0538	-614.3223	-79.7375	-82.7062
Std. Dev.	2.8585	3.3898	3.1503	0.3160	0.3189	260.8423	25.8353	29.9141
Skewness	0.4013	1.0001	1.0546	-0.3037	-0.2354	0.2011	0.6392	0.5510
Kurtosis	2.0250	3.6163	3.7256	4.2352	3.6911	3.4694	4.4921	3.5140
JB (p-value)	0.0092	0.0000	0.0000	0.0038	0.1283	0.3256	0.0000	0.0130

JB is the Jarque-Bera test for normality (null hypothesis: normally distributed). The sample covers September 1999 - September 2011.

$Log\ Differential\ OTC = \ln(AGIP) - \ln(NBP\ OTC)$; $Log\ Differential\ Front = \ln(AGIP) - \ln(NBP\ Front)$

Table: Unit Root Tests

		Levels		First Differences	
		t-Statistic	Prob.*	t-Statistic	Prob.*
Log AGIP	ADF	-1.5847	0.4878	-8.3079	0.0000
	PP	-1.8995	0.3318	-8.6210	0.0000
Log NBP OTC	ADF	-2.8369	0.0557	-14.6156	0.0000
	PP	-2.6473	0.0860	-14.6339	0.0000
Log NBP Front	ADF	-2.5214	0.1125	-9.3982	0.0000
	PP	-1.9917	0.2903	-9.3026	0.0000
Log Differential OTC	ADF	-4.6208	0.0002	-	-
	PP	-4.6237	0.0002	-	-
Log Differential Front	ADF	-4.3322	0.0006	-	-
	PP	-3.9740	0.0021	-	-
Differential OTC	ADF	-3.7060	0.0049	-	-
	PP	-4.9030	0.0001	-	-
Differential Front	ADF	-4.4254	0.0004	-	-
	PP	-4.1584	0.0011	-	-

*MacKinnon (1996) one-sided p-values, including constant. Lag-length selection based on Schwartz information criterion (min-lag=0, max-lag=13)
Null-hypothesis: the series is integrated of order one, $I(1)$.
ADF= Augmented Dickey-Fuller; PP = Phillips-Perron

Table: Cointegration Tests

Johansen System Cointegration Test				
Series: $log(agip)$, $log(nbp^{OTC})$				
Sample (adjusted): 2000M02 2011M09				
Unrestricted Cointegration Rank Test (Trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.1336	22.2187	15.4947	[0.0042]
At most 1	0.0152	2.1398	3.8415	[0.1435]
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.1336	20.0789	14.2646	[0.0054]
At most 1	0.0152	2.1398	3.8415	[0.1435]
1 Cointegrating Equation:		Log likelihood		288.93
Normalized cointegrating coefficients			$log(nbp^{OTC})$	$log(agip)$
			1.0000	-0.9719
				(-0.1008)
Adjustment coefficients			$Dlog(nbp^{OTC})$	$Dlog(agip)$
			-0.3306	0.0219
			(-0.0882)	(-0.0156)

(...) Standard errors in parentheses. Both Trace and Max-Eigen tests indicate
1 cointegrating equation at the 0.05 level. * denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis (1999) p-values

Table: Cointegration Tests

Single-Equation Cointegration Tests

Series: $log(AGIP)$, $log(NBP - OTC)$
Sample: 1999M09 2011M09

Engle-Granger†

Dependent	τ-statistic	Prob.*	z-statistic	Prob.*
$log(UKNBPOTC)$	-4.6463	0.0011	-37.8681	0.0006
$log(AGIP)$	-2.9623	0.1260	-17.9166	0.0746

Phillips-Ouliaris

Dependent	τ-statistic	Prob.*	z-statistic	Prob.*
$log(NBP - OTC)$	-4.6531	0.0011	-37.9991	0.0006
$log(AGIP)$	-3.6469	0.0252	-24.0454	0.0189

Null-hypothesis: Series are not cointegrated. † automatic lags specification based on Schwarz criterion (maxlag=13). *MacKinnon (1996) p-values.

Table: UC Estimation Output - Dependent variable: Differential OTC

Model	1	2	3	4	5	6	7†
Final State							
Level	1.8898	2.2061	2.2508	2.1121	2.0282	-2.1644	-0.7802
(p-value)	(0.0151)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0700)	(0.3912)
Seasonality	*Fixed*	*Fixed*	*Stochastic*	*Stochastic*	*Stochastic*	*Stochastic*	*Stochastic*
Controls							
Outlier 2005(2)	-	-5.4397***	-5.0587***	-4.9687***	-5.1346***	-5.0903***	-5.0826***
		[0.7613]	[0.7579]	[0.7550]	[0.7494]	[0.7333]	[0.7349]
Outlier 2005(11)	-	-5.6266***	-4.9945***	-4.9311***	-5.2699***	-5.3041***	-5.1776***
		[0.8377]	[0.8527]	[0.8481]	[0.8263]	[0.8095]	[0.8085]
Winter 05/06	-	-5.6565***	-5.9881***	-5.9742***	-5.7795***	-5.6249***	-5.6895***
		[0.6633]	[0.6734]	[0.6679]	[0.6486]	[0.6057]	[0.6125]
Dev. Storage	-	-	-0.0007**	-0.0005	-	-	-
			[0.0003]	[0.0003]			
Dev. HDD(b=15.5)	-	-	-	-0.0058	-0.0084**	-0.0083***	-0.0091***
				[0.0037]	[0.0032]	[0.0031]	[0.0031]
Structural Breaks							
BBL/Langeled	-	-	-	-	-	**1.31318**	-
(December 2006)						[0.7627]	
LNG	-	-	-	-	-	**2.6647*** **	**2.6280*** **
(November 2008)						[0.7570]	[0.7689]

[..] Standard errors in parentheses. The sample period for the model analysis is January 2000 through Septemer 2011.
† *break* model that minimizes Bayesian Schwartz Criterion.
* = significant at the 10% level, ** = significant at the 5% level, *** = significant at the 1% level

Table: UC Estimation Output - Dependent variable: Differential Front

Model	1	2	3	4†	5
Final State					
Level	0.9160	1.0348	1.0073	-5.9681	-4.5338
(p-value)	(0.0473)	(0.0073)	(0.0038)	(0.0000)	(0.0013)
Seasonality	*Fixed*	*Stochastic*	*Stochastic*	*Fixed*	*Stochastic*
Controls					
Outlier 2005(11)	-	-4.7233***	-3.9156***	-4.7983***	-4.4283***
		[0.8400]	[0.8492]	[0.8634]	[0.8424]
Outlier 2006(2)	-	3.0367***	2.8976***	3.1720***	2.9215***
		[0.8400]	[0.8165]	[0.8283]	[0.8073]
Winter 05/06	-	-3.6697***	-3.9341***	-3.8325***	-3.7126***
		[0.9039]	[0.9258]	[0.7630]	[0.8609]
Dev. Storage	-	-	-0.0006**	-0.0003	-0.0006**
			[0.0003]	[0.0003]	[0.0003]
Dev. HDD(b=15.5)	-	-	-0.00417	-0.0033	-
			[0.0036]	[0.0036]	
Structural Breaks					
BBL/Langeled	-	-	-	**3.1660*** **	**2.8381*** **
(December 2006)				[0.8411]	0.90554
LNG	-	-	-	**3.4558*** **	**2.5803*** **
(November 2008)				[0.8324]	[0.9063]

[..] Standard errors in parentheses. The sample period for the model analysis is January 2000 through Septemer 2011. † *break* model that minimizes Bayesian Schwartz Criterion. * = significant at the 10% level, ** = significant at the 5% level, *** = significant at the 1% level

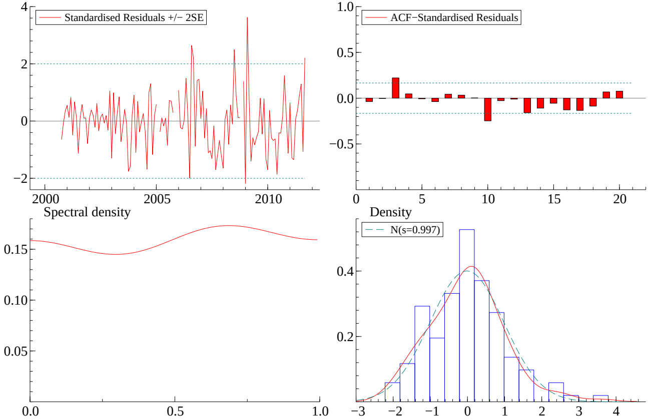

Figure: UC Model 7 (OTC): residual diagnostics

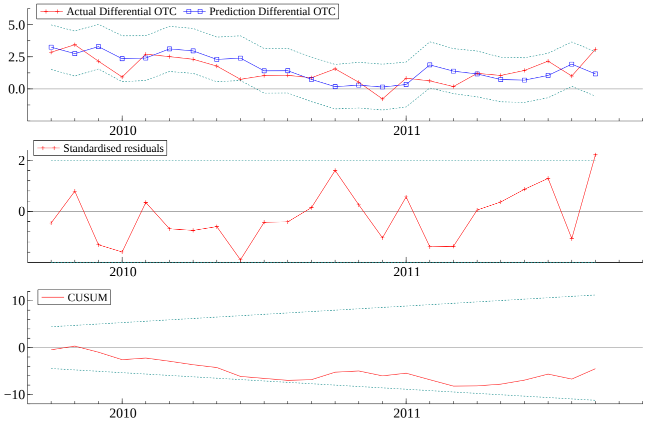

Figure: UC Model 7 (OTC): in-sample predictions