Two Markets and a Weak Link

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November 10, 2004

Abstract

We characterise the relationship between two network based oligopoly markets when local players share the interconnection’s ownership. To that purpose, we analyse the case of the Bacton (UK)-Zeebrugge (Belgium) natural gas pipeline using Vector Auto-regressive Representation techniques. We conclude that there is a threshold of capacity deployment after which the two local markets split. As a result, the relationship between local price differentials and capacity utilisation is increasing and convex. We also show that the local prices’ dynamic structure is characterised both by convergence features and leader-follower processes, with the more developed market taking a dominant role.

JEL classification: D43, F15, L95

Keywords: Interconnectors, natural gas

*We thank Albert Banal, Nektaria Karakatsani, Tarjei Kristiansen and Karsten Neuhoff for useful comments and discussions.
1 Introduction

As network-based infrastructure industries are liberalized around the world, interconnectors have become important competitive linkages between otherwise isolated markets, and thus have the potential to mitigate local market power. Still, a number of empirical questions remain open concerning how the operations of these interconnectors influence prices. These include whether congestion can be created strategically so as to split the local markets, and how flow disruptions influence their price dynamics. This paper analyses these two questions using data from the Bacton (UK)-Zeebrugge (Belgium) natural gas pipeline.

Strategically created congestion has been studied primarily in the electricity context and rationalized through models of physical capacity withholding (Bushnell, 1999; Joskow and Tirole, 2000). A firm’s price setting ability depends on the degree of market competition at the margin so, in these models, one usually finds a direct link between the degree of capacity utilization and its marginal price, which should result in the local markets splitting before the interconnection reaches technical congestion levels.

In contrast, models based on the Law of One Price (LOOP) often conclude that market splitting would not occur unless the interconnection is constrained (e.g. Hogan, 1992). Their reasoning is as follows: the interconnectors’ main cost component is typically fixed and sunk, while marginal transportation costs are close to zero. Hence, if those holding rights and those interested in excising them traded competitively, arbitrage would tend to equalize the local prices and interconnector charges would be low. Thus, in the absence of transportation costs, congestion and restrictions to trade, the commodity should be uniformly priced, making arbitrage impossible.
Further, a somewhat surprising corollary follows: as long as interconnector capacity is large enough, no output might actually flow along the interconnector (Borenstein et al., 2000). The threat of competition and arbitrage will be all that is needed for effective integration of the two markets and the infrastructure may appear to be under-utilised.

Some of these results have been phrased as testable hypotheses. If the LOOP were to hold between the two markets, their price differences would be stationary and the interconnector would remain either idle or totally constrained (Bower, 2002). "One great attraction of this perspective is that there is no need to define transmission at all: users of the network never transmit power across the network, they merely sell at some nodes and buy at others. All transmission is implicit." (Hogan, 1992). The mere threat of competitive entry becomes a restraining influence on the dominant sellers in each local market, causing them to become more competitive, even though the threatened imports are never realised. (Borenstein et al. 2000).

Moreover, arbitrage would homogenize the two prices’ dynamic structure, for example with "convergence to the mean" (Cremer and Laffont, 2002) and leader-follower processes.

If there were some form of market power inefficiencies (as in Joskow and Tirole, 2000), however, one could expect a significant relationship between the interconnector physical capacity utilization and local price differences and that its full capacity will be seldom utilised. Moreover, the two prices could remain largely independent and their dynamic econometric structures different.

To study empirically these questions, a natural setting in which a number of circumstances concur is desirable: First, it should consist of two oligopolistic markets with a single capacity-constrained transportation in-
terconnection between them. Secondly, the interconnection physical rights’ market would be unregulated and its main owners should be also active in the local markets, so as to have both the opportunity and incentive to withhold capacity. Third, the economic fundamentals of the individual markets should be different, in order to help us determine whether the linkage results in a homogenization of price dynamics. Finally, the link should ideally suffer from unexpected flow disruptions separating the two, so as to provide an exogenous benchmark to assess the effects of market integration. One such natural setting is the liberalized European natural gas market and, specifically, the new situation that emerges around the building of the interconnector between the UK and the Continent.

There are two main wholesale trading gas hubs in Western Europe, Zeebrugge (Belgium) and the National Balancing Point (NBP) in the United Kingdom. The only linkage between them is the recently built "interconnector", whose ownership is shared among some of the largest players in the industry.¹ This pipeline is weak in a double sense: its capacity is limited² and subject to unexpected technical disruption.³ The market for transmission rights is bilateral. Although some capacity is sold on long-term contracts, there is also a day-ahead market that sets marginal prices. These prices are

¹Firms holding interests in the interconnector and their respective percentages follow: Amerada Hess (5%); BP (10%); BG Energy (25%); Conoco-Phillips (10%); DistriGas (25%); Eni (5%); International Power (5%); Gazprom (10%); Ruhrgas (10%); TotalFinaElf (10%). Source: www.interconnector.com.
²It can only carry up to ca. 25% of British or 6% of continental consumption (20 billion cubic metres per annum, bcm/year) towards the Continent. Alternatively, it can carry up to 8.5 bcm/year in the opposite direction.
³Although maintenance operations may be scheduled ahead of time, the interconnector has also suffered a number of unexpected flow interruptions due to system breakdown.
known to the main players but not to external parties.

While continental markets are extremely concentrated and still undergoing a slow liberalization, the UK has been competitive for some years. Before the interconnector opened, it is well documented that NBP prices depended mainly on the value of natural gas for electricity generation (e.g. Stern, 1998). As a result, its dynamics were quite linked to those of the more competitive England and Wales spot electricity market. Features of electricity spot price processes include mean reversion, high volatility and specific seasonal patterns.

In contrast, prices in the Zeebrugge area have traditionally been linked to long-term take-or-pay (TOP) agreements even before the liberalization started. TOP contracts are established between large national incumbents and indexed using different formulae that usually reflect the net-back principle, pricing gas at a discount with respect to its competitors (mainly oil products), which are generally less volatile, mean reverting and seasonal than electricity (Pilipovic, 1997).

Hence, at the outset, both the market structure and the economic fundamentals of gas prices in the European continent were very different from those in the UK and one could expect that they still differentiated their dynamic specification. Whether that is the case or not after the opening of the interconnector is an open question.

In other words, the first issue that we address in this paper is whether the arbitrage or market splitting logic dominates. The second question concerns the influence of the degree of interconnector utilisation on the local markets, both in terms of price levels and their dynamic structure. More synthetically, the research questions that we answer are:

Q. 1: Is there a relationship between market splitting and the degree of
Q. 2: What is the mediating role of the interconnector utilization on the dynamic relationship between the local prices?

The paper is organised as follows: Part 2 is an outline of how the capacity withholding and arbitrage principles relate to the research questions. In Part 3 we discuss the data set. Part 4 includes the empirical results. Finally, a discussion and some concluding remarks are presented in Part 5.

2 Arbitrage and Interconnection Market Power

Consider two markets, A and B, linked by a single weak interconnection, whose access rights are controlled by some players and discretionally sold on a daily basis (time indexed as $t$) to those wishing to transport the commodity.

Now, suppose that there is no market power in the interconnection and transportation costs are very low. If utilized capacity were to be below maximum capacity ($C_{U,t} < C_{MAX}$), arbitragers hold some capability to react instantly to price differences by engaging in three simultaneous transactions: purchase the commodity in the low price market, buy physical transportation rights and sell in the high price market. Thus, one would expect the two prices to be equal, $P_{A,t} = P_{B,t}$ and therefore that $C_{U,t} \approx 0$. If the interconnection were congested ($C_{U,t} = C_{MAX}$), on the other hand, one would expect local prices to diverge. This simple theory leaves little room for cases in which capacity is only partially used but the two prices are not equal.

However, in practice there are a number of reasons for congestion to arise for some $C_{U,t} < C_{MAX}$, with a subsequent increase in the shadow price of the interconnection ($P_{s,t} = |P_{A,t} - P_{B,t}|$). Those include not only the use
of contingency constraints by the interconnector operator, but also other causes related to the economics of the system. For example, given that gas and access to capacity are bought separately, incomplete information and uncertainty might result in situations in which market players anticipate that the interconnection will be constrained but it is not.

Moreover, the flow should always circulate from the low to the high price market. However, in the natural gas case, flow reversals are not instantaneous but require 24 hours once the sign of $P_{S,t}$ changes. It is therefore likely that, in the one or two days preceding that change, the flow will be directed “against market forces”, from the expensive to the cheap market, which will provide no incentive for arbitrage trading and, hence, lead to low $C_{U,t}$.

Finally, the logic in Borenstein et al. (2000) assumes that the linkage is "operated by an entity that attempts to maximise social welfare by providing price signals to induce efficient use" of the infrastructure. However, market power on the available capacity might allow Cournot-type withholding.\footnote{That is, under tighter capacity, it is possible that fewer firms will hold unsold physical rights (i.e. are residual suppliers), which increases their price setting ability.} If the oligopoly were able to exert that market power, there would be a positive link between $C_{U,t}$ and the extent of the two markets’ splitting (i.e. $P_{S,t}$) that for example, in the simple Cournot case, could be postulated as convex quadratic:\footnote{The quadratic functional form would follow from the standard Cournot oligopoly model (e.g. Tirole, 1988) where $b$ is the slope of a linear (inverse) demand function, $P_t = a + bQ_t$, and $q_t$ is the quantity sold by an individual firm in time period $t$.}

$$P_{S,t} = -\frac{b}{q_t} \left( \frac{C_{U,t}}{C_{MAX}} \right)^2$$ (1)
In this formulation, $P_{S,t}$ depends on the market share of each individual firm in the margin. If this were the case, agents holding both physical interconnection rights and positions in the local markets could benefit in at least two ways (Bushnell, 1999; Joskow and Tirole, 2000): a/ Increasing the selling value of the commodity in the local markets; b/ Increasing the value of the transportation rights.

It is therefore plausible in general that market power will become exercisable above a level of capacity, $\bar{C}$, at which point there is sufficient concentration in the residual market for oligopoly capacity reductions to occur. One could expect a zero relationship between $C_{U,t}$ and $P_{S,t}$ while arbitrage holds (i.e. up until $\bar{C}$) and a quadratic thereafter, when market concentration applies. With collusion, $P_{S,t}$ would increase more steeply against $C_{U,t}$ and $\bar{C}$ would be lower, unless $C_{MAX}$ was reached first.

To round up, one important difference between the ”efficient arbitrage” and ”capacity withholding” models is that the latter predicts increasing market splitting as $C_{U,t}$ grows. Moreover, if the relationship between $C_{U,t}$ and $P_{S,t}$ followed this pattern, it would seem appropriate to investigate not only whether locational market dynamics are different but also whether there are different econometric regimes that govern these dynamics, depending on $C_{U,t}$. In this paper, we contrast empirically the withholding and arbitrage models in the case of the Zeebrugge - NBP natural gas interconnector.

3 Data

Wholesale natural gas prices are extracted from daily Heren indices in the UK (NBP) and continental Europe (Zeebrugge), denominated in British
pence per therm. The indices are assembled with data by traders in both markets, collected and made available daily by Heren, a newsletter provider. They reflect the price range of the commodity on the day, weighted for volume of the transactions and are considered the standard indices in both hubs. Their reported cut-off time is 5:30pm GMT.

The interconnector daily flows were downloaded from the pipeline operator’s web-site. Daily electricity prices in the UK were taken from UKPX, the main power exchange for the NETA England and Wales bilateral market. The continental reference was obtained from the Dutch APX spot market web site. The Zeebrugge and APX data-sets encompass observations from 12-Mar-1999 to 20-Dec-2002. Brent prices were downloaded from the Datasstream database. Finally, weather data in the UK is based on average daily temperatures in Southeast England and measured in degrees Celsius by the Met Office.\textsuperscript{6}

The data set has been modified in three ways: First, observations for the day before any changes in flow direction were excluded since they would mis-represent the economics of the system. Second, capacity utilization ratios are measured against the historically maximum rather than nominal capacity values. That is in order to reduce the effect of technical contingency measures taken by the pipeline operator. Finally, interconnector shadow prices are confidential. Therefore, following the method used by the UK energy regulator (e.g. Ofgem, 2004), these are substituted by their absolute value equivalent:

\[ \rho_t = |P_{NBP} - P_{ZEEB}|_t \] (2)

\textsuperscript{6}The exact location of the temperature observations is London Heathrow airport.
4 Results

4.1 Interconnector Utilization and Local Price Differences

In order to consider the possibility of simultaneity in the determination of prices and capacity utilization under open interconnection, we estimated a two-lag Vector Auto-regressive Representation (VAR):

\[
\begin{bmatrix}
C_{U,t} \\
\rho_t
\end{bmatrix}
= \begin{bmatrix}
\alpha_1 \\
\alpha_2
\end{bmatrix}
+ \begin{bmatrix}
\beta_{11} & \beta_{12} \\
\beta_{21} & \beta_{22}
\end{bmatrix}
\begin{bmatrix}
C_{U,t-1} \\
\rho_{t-1}
\end{bmatrix}
+ \begin{bmatrix}
\gamma_{11} & \gamma_{12} \\
\gamma_{21} & \gamma_{22}
\end{bmatrix}
\begin{bmatrix}
C_{U,t-2} \\
\rho_{t-2}
\end{bmatrix}
+ \begin{bmatrix}
u_{1,t} \\
u_{2,t}\end{bmatrix}
\]

(3)

Table 1 includes the estimation for \(C_{U,t}\) and \(\rho_t\) for \(C_{U,t} \neq 0\). All lagged variables are significant suggesting an intertwined relationship between capacity utilization and market splitting. The explanatory power of the two models indicates that \(C_{U,t}\) is determined by its own lagged variables and market splitting, and that the opposite is also a large and significant influence. Moreover, the \(R^2\) values (99.96% vs. 18.48%) indicate that price differences (arbitrage) drive the reciprocal relationship. A Granger causality test is consistent with this assessment, rejecting the null hypotheses of non-causality from \(\rho_t\) to \(C_{U,t}\) (sig. 0.02832) but not for \(C_{U,t}\) to \(\rho_t\). Hence, the evidence confirms the conventional wisdom, which identifies arbitrage as the main driving force linking the two markets.
Table 1: Dynamic Model of Capacity Utilisation and Price Differences

<table>
<thead>
<tr>
<th>( C_U )</th>
<th>( \rho_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{U,t-1} )</td>
<td>1.2451</td>
</tr>
<tr>
<td>( C_{U,t-2} )</td>
<td>-0.2451</td>
</tr>
<tr>
<td>( \rho_{t-1} )</td>
<td>0.0024</td>
</tr>
<tr>
<td>( \rho_{t-2} )</td>
<td>-0.0004</td>
</tr>
</tbody>
</table>

\( \text{Adj. } R^2 \) 0.9996 0.1849

Characterizing the shape of the relationship between \( \rho_t \) and \( C_{U,t} \) involves determining its sign and rationale. As a first step, we estimate linear and, following the capacity withholding model, quadratic expressions for \( C_{U,t} \neq 0 \):

\[
\rho_t = \alpha + \beta_1 C_{U,t} + u_t \quad (4)
\]

\[
\rho_t = \alpha + \beta_1 C_{U,t} + \beta_2 C_{U,t}^2 + u_t \quad (5)
\]

Alternatively, inspired by popular regime switching models of price forecasts in electricity and natural gas markets, successive tests of structural stability are undertaken. These include dummy parameters (D) that influence the intercepts and slopes of the relationship pre- and post-threshold:

\[
\rho_t = \alpha_1 + D\alpha_2 + \beta_1 C_{U,t} + D\beta_2 C_{U,t} + u_t \quad (6)
\]
Where $\alpha_1$ and $\beta_1$ are the intercept and slope coefficients before each threshold, $\bar{C}$, assumption, while $\alpha_2$ and $\beta_2$ are the differentials between the pre- and post-$\bar{C}$ situations. A structural change would be suggested if significant post-threshold values were found.

The linear model elicits a positive relationship between $\rho_t$ and $C_{U,t}$ (sig. 0.0000), indicating that, as the splitting between NBP and Zeebrugge grows, more interconnector capacity is used (Table 2). The quadratic specification suggests convexity: an increase in $\rho_t$ results in marginally decreasing larger $C_{U,t}$ values. The estimations of possible capacity thresholds, indicate that $0.50 \leq \bar{C} \leq 0.60$ with maximum explanatory power for $\bar{C} = 0.57$ ($F = 698.474$).

Table 2: Interconnector Utilisation and Local Price Differences, $C_{U,t} \neq 0$

<table>
<thead>
<tr>
<th>Linear Model</th>
<th>Quadratic Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Coeff. Sig.</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>.1004 .3267</td>
</tr>
<tr>
<td>$C_{U,t}$</td>
<td>1.0711 .0000</td>
</tr>
<tr>
<td>$C_{U,t}^2$</td>
<td>- -</td>
</tr>
<tr>
<td>Adj.$R^2$</td>
<td>.0477</td>
</tr>
<tr>
<td>$F - value$</td>
<td>38.2946</td>
</tr>
</tbody>
</table>

In addition, we consider a model including linear pre-threshold and quadratic post-threshold specifications (Table 3). All parameters are significant and the fit improves visibly ($R^2 = 16.4\%$ vs. $4.77\%$ and $5.34\%$).
Table 3: Linear Pre-Threshold and Quadratic Post Threshold, $C_{U,t} \neq 0$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff.</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>4.7620</td>
<td>.0000</td>
</tr>
<tr>
<td>$D$</td>
<td>10.6751</td>
<td>.0000</td>
</tr>
<tr>
<td>$C_U$</td>
<td>-21.9240</td>
<td>.0000</td>
</tr>
<tr>
<td>$DC_U$</td>
<td>-18.4862</td>
<td>.0000</td>
</tr>
<tr>
<td>$DC_U^2$</td>
<td>27.8913</td>
<td>.0000</td>
</tr>
<tr>
<td>Adj. $R^2$</td>
<td>.1640</td>
<td></td>
</tr>
<tr>
<td>$F$ value</td>
<td>44.1552</td>
<td></td>
</tr>
</tbody>
</table>

The combination of these findings indicates that arbitrage is the main driving force between $\rho_t$ and $C_{U,t}$. However, there are also traces of inefficiencies, including market power. In high interconnector utilization days, those holding rights manage to split the two markets to some extent, so the relationship between the two variables is increasing and convex after a threshold estimated around $\bar{C} = 0.57 \times C_{MAX}$.

4.2 The Relative Behaviour of NBP and Zeebrugge Prices

In this section, we investigate whether the regimes governing the $\rho_t$ vs. $C_{U,t}$ relationship also mediate in the econometric linkage between $P_{NBP}$ and $P_{ZEEB}$. To that effect, the data is separated into three subsets, depending on whether the interconnector was closed (i.e. Regime 1 (R1): $C_U = 0$) or open ($C_U > 0$) and, for the latter, whether capacity utilisation was below (Regime 2 (R2): $0 \leq C_U \leq 0.57$) or above (Regime 3 (R3): $0.57 \leq C_U \leq 1$) the estimated threshold.

We proceed sequentially for the three subsets, starting with tests of simple static integration relationships, followed by slightly more elaborated
dynamic specifications, towards full vector auto-regressive representation (VAR) and vector error correction (VEC) models, in which general causality and long-term equilibrium insights are revealed.

First, to measure the degree of co-movement, the following expression is tested:

\[ P_{ZEEB,t} = \alpha + \beta P_{NBP,t} + u_t \]  

(7)

In these models, \( \alpha \) provides an estimate of the systematic differences between prices in the UK and Belgium caused by the different interconnector status. In addition, \( \beta \) measures the relative volatility of the two series.

Table 4: Static Models

<table>
<thead>
<tr>
<th>Variable</th>
<th>( R1 : C_{U,t} = 0 )</th>
<th>( R2 : 0 &lt; C_{U,t} \leq \bar{C} )</th>
<th>( R3 : C_{U,t} \geq \bar{C} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>16.1272</td>
<td>.0000</td>
<td>2.6428</td>
</tr>
<tr>
<td>( NBP_t )</td>
<td>.3571</td>
<td>.0000</td>
<td>.8759</td>
</tr>
<tr>
<td>( Adj. R^2 )</td>
<td>( M985 )</td>
<td>.9040</td>
<td>( M449 )</td>
</tr>
<tr>
<td>( Prob.F − stat. )</td>
<td>.0000</td>
<td>.0000</td>
<td>.0000</td>
</tr>
</tbody>
</table>

The static models linking \( P_{NBP} \) and \( P_{ZEEB} \) present significantly positive intercepts, suggesting that continental prices are consistently above those in Britain and \( 0 > \beta > 1 \) throughout (Table 4).

We observe substantial differences depending on whether the interconnector is open or not, i.e. between \( R1 \), on the one hand, and \( R2 \) and \( R3 \) on the other. First, \( \alpha \) is substantially larger under \( R1 \). Second, \( \beta \) is considerably smaller under \( R1 \) than under \( R2 \) or \( R3 \) (0.3571 vs. 0.8759 and 0.8317).
That suggests not only that prices are as expected positively correlated but also that the natural volatility of $P_{ZEEB}$ is smaller than that of $P_{NBP}$ and that an open connection results in larger volatility in Zeebrugge. This may be due to the transmission of $P_{NBP}$’s electricity-based fundamentals through the interconnector.

Also as one would expect, the model’s fit is at its lowest point under $R1$. However, the parameters are highly significant and the adjusted-$R^2$ and $F$-values are high ($adj.R^2 = 0.5985; F = 85.96$). Moreover, it is interesting to note that both $adj.R^2$ and $F$ are higher under low capacity utilisation values, $R2$, than when the interconnector is more congested, under $R3$.

Nevertheless, low Durbin-Watson (DW) statistics suggest mis-specification in the models as a result of auto-correlations. Hence, as a second step, the reciprocal dynamic adjustment between the two prices is tested through:

$$\rho_t = \alpha + \chi \rho_{t-1} + u_t$$  \hspace{1cm} (8)

The integration hypothesis is checked through a unit root test of $\chi$: if the LOOP holds, $\rho_t$ should be stationary. The estimated results shown in Table 5 support market integration in all cases. Finally, the one-lag term is very significant but further lags were not, which is consistent with inter-temporal efficiency arising from continuous trading.
Table 5: Dynamic Models Pre- and Post-Threshold: $\rho_t$ is Dependent Variable

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>-.6036</td>
<td>.3372</td>
<td>-.0669</td>
<td>.0001</td>
<td>-.1710</td>
<td>.0001</td>
</tr>
<tr>
<td>$\rho_{t-1}$</td>
<td>-.1434</td>
<td>.0466</td>
<td>-.0669</td>
<td>.0001</td>
<td>-.1710</td>
<td>.0001</td>
</tr>
</tbody>
</table>

Further, a set of more complete dynamic models could include exogenous determinants of the natural gas demand in the two markets:

$$\rho_t = \alpha + \chi \rho_{t-1} + \phi_1 APX_t + \phi_2 NETA_t + \phi_3 TEMP_t + \phi_4 BRENT_t + u_t$$ (9)

The new variables are lagged $\rho$ values, electricity prices (APX in the Netherlands and NETA in England and Wales), temperatures and oil prices, all relating to economic fundamentals. The lagged price difference, $\rho_{t-1}$, seems to capture the dynamic structure of $\rho_t$ so that no other variable is significant to explain $\rho_t$ (Table 6). This underlines again the importance of arbitrage between the two hubs and suggests that it is executed on their interface through the interconnector, rather than across the local natural gas, electricity and oil markets.
Moreover, in order to evaluate whether there is a link in the arbitrage opportunities between electricity and natural gas across the two regions, we consider the regression of the differences against one another:

\[ \rho_t = \alpha + |NETA - APX|_t + u_t \]  \hspace{1cm} (10)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coeff.</th>
<th>Sig.</th>
<th>Coeff.</th>
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<td>( \alpha )</td>
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<td>( \rho_{t-1} )</td>
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<td>.0000</td>
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<td>.0000</td>
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<td>( DW )</td>
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<td>( Adj. R^2 )</td>
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Table 7: Electricity Links

<table>
<thead>
<tr>
<th>Variables</th>
<th>$R1: C_{U,t} = 0$</th>
<th>$R2: 0 &lt; C_{U,t} \leq \bar{C}$</th>
<th>$R3: C_{U,t} \geq \bar{C}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>$-6.6954$</td>
<td>$.000$</td>
<td>$-1.0250$</td>
</tr>
<tr>
<td>$\text{apx} - neta$</td>
<td>$-0.0038$</td>
<td>$.7459$</td>
<td>$.0071$</td>
</tr>
<tr>
<td>$DW$</td>
<td>$.2091$</td>
<td>$.1020$</td>
<td>$.1843$</td>
</tr>
<tr>
<td>$\text{Adj. } R^2$</td>
<td>$.0000$</td>
<td>$.0192$</td>
<td>$.0110$</td>
</tr>
<tr>
<td>$Prob.F - stat.$</td>
<td>$.7459$</td>
<td>$.0062$</td>
<td>$.0570$</td>
</tr>
</tbody>
</table>

Results are presented in Table 7. One can notice that electricity price differences between the Continent and the UK are not econometrically significant under $R1$ ($sig. 0.7459$), very significant under $R2$ ($sig. 0.0062$) and only approximately so under $R3$ ($sig. 0.057$). When the interconnector is open, there is an arbitrage link between the two electricity prices, which becomes weaker with more capacity utilisation.

In summary, the separate consideration of three sub data-sets is both a simple and useful way to understand some of the dynamics between $P_{NBP,t}$ and $P_{ZEEB,t}$. When the interconnector is open, $P_{NBP,t}$ is higher and $P_{ZEEB,t}$ more volatile. Relative congestion, as defined by $R3$, makes arbitrage more difficult but, in general, the two markets are econometrically integrated and long-lasting inefficiencies small. Finally, we have been able to identify an electricity link in the Zeebrugge series that could indicate a migration in the econometric structure $P_{NBP,t}$ of towards $P_{ZEEB,t}$. The study of this possibility is the purpose of the following part.
4.3 Transmission of Dynamic Structures

We estimate Vector Auto-regressive Representation (VAR) and Vector Error Correction (VEC) models including $P_{NBPl,t}$, $P_{ZEEB,t}$, $ZEEB_t$ and $BRENT_t$. 

Migration might be suggested by evidence of a causal relationship between the UK electricity and Zeebrugge prices and / or the existence of a Brent oil linkage in the UK natural gas market:

$$\begin{bmatrix}
P_{NBPl,t} \\
P_{ZEEB,t} \\
NETA_t \\
BRENT_t \\
\end{bmatrix} = \begin{bmatrix}
\alpha_1 \\
\alpha_2 \\
\alpha_3 \\
\alpha_4 \\
\end{bmatrix} \begin{bmatrix}
\gamma_{11} & \cdots & \cdots & \gamma_{14} \\
\cdots & \cdots & \cdots & \cdots \\
\cdots & \cdots & \cdots & \cdots \\
\gamma_{41} & \cdots & \cdots & \gamma_{44} \\
\end{bmatrix} \begin{bmatrix}
P_{NBPl-1} \\
P_{ZEEB,t-1} \\
NETA_{t-1} \\
BRENT_{t-1} \\
\end{bmatrix} + \begin{bmatrix}
u_{1,t} \\
u_{2,t} \\
u_{3,t} \\
u_{4,t} \\
\end{bmatrix}$$

(11)

Firstly, assuming no particular equilibrium relationship between the four variables, the VAR (1) is considered (Table 8). The results reflect the existence of different economic linkages between $P_{NBPl,t}$ and $P_{ZEEB,t}$ depending on the interconnector utilization. We note that $P_{NBPl,t}$ is related to $NETA_t$ under R1 and R3 ($R1: t-value = 1.49664$; $R3: t-value = 1.51812$) while the oil link to the Continent emerges only under the R2 ($t-value 1.7729$). This vertical relationship between electricity and natural gas prices in the UK was confirmed by its mirror image relationship between $P_{NBPl-1}$ and $NETA_t$. 

19
Table 8: VAR (1) considering all interconnector status options

<table>
<thead>
<tr>
<th></th>
<th>$R_1: C_U = 0$</th>
<th>$R_2: 0 &lt; C_U \leq \bar{C}$</th>
<th>$R_3: C_U \geq \bar{C}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$NBP_t$</td>
<td>$ZEEB_t$</td>
<td>$NBP_t$</td>
</tr>
<tr>
<td>$NBP_{t-1}$</td>
<td>.9861</td>
<td>-.0505</td>
<td>.9663</td>
</tr>
<tr>
<td>t-values</td>
<td>9.2694</td>
<td>.6585</td>
<td>37.9296</td>
</tr>
<tr>
<td>$ZEEB_{t-1}$</td>
<td>.1588</td>
<td>.9268</td>
<td>.0035</td>
</tr>
<tr>
<td>t-values</td>
<td>1.0737</td>
<td>8.6918</td>
<td>.1092</td>
</tr>
<tr>
<td>$NETA_{t-1}$</td>
<td>.0349</td>
<td>-.0102</td>
<td>.0007</td>
</tr>
<tr>
<td>t-values</td>
<td>1.4966</td>
<td>.6045</td>
<td>.4540</td>
</tr>
<tr>
<td>$BRENT_{t-1}$</td>
<td>.0992</td>
<td>.0269</td>
<td>-.0425</td>
</tr>
<tr>
<td>t-values</td>
<td>1.9731</td>
<td>.2902</td>
<td>1.7729</td>
</tr>
<tr>
<td>const</td>
<td>-1.3012</td>
<td>1.6018</td>
<td>1.4967</td>
</tr>
<tr>
<td>t-values</td>
<td>.2395</td>
<td>.4089</td>
<td>2.0806</td>
</tr>
<tr>
<td>Adj. $R^2$</td>
<td>.8589</td>
<td>.7388</td>
<td>.9425</td>
</tr>
<tr>
<td>$Prob.F$</td>
<td>46.6440</td>
<td>22.2111</td>
<td>1186.539</td>
</tr>
</tbody>
</table>

Concerning $P_{ZEEB,t}$, the pricing structure includes some traces of $P_{NBP,t}$ on top of oil prices under $R_2$ and also of $NETA_t$ under $R_3$ ($t-value = 1.8539$). Moreover, the oil link emerges in the absence of integration to the UK ($R_1: t-value = 1.9739$; $R_3: t-value = -2.9064$) and dissolves under $R_2$ ($t-value = -0.2938$).

Overall, the VAR (1) model provides solid support for the hypothesis of different regimes depending on whether arbitrage is possible or not along the interconnector. When the interconnector is open, $P_{NBP,t}$ and $P_{ZEEB,t}$ receive the influence of each other and their economic determinants, identified by the existence of oil linkages in the UK and NETA in Zeebrugge. In cases
of market splitting, though, each series reverts to its traditional dynamics. Finally, we find a relevant econometric relationship between oil prices and NETA via $R^2$.

To complement this analysis, a VEC model is defined with the following specifications:

$$
\begin{bmatrix}
NBP_t \\
ZEEB_t \\
NETA_t \\
BRENT_t
\end{bmatrix} =
\begin{bmatrix}
\alpha_1 \\
\alpha_2 \\
\alpha_3 \\
\alpha_4
\end{bmatrix} +
\begin{bmatrix}
\gamma_{11} & \cdots & \gamma_{14} \\
\cdots & \ddots & \cdots \\
\cdots & \cdots & \cdots \\
\gamma_{41} & \cdots & \gamma_{44}
\end{bmatrix}
\begin{bmatrix}
\Delta NBP_{t-1} \\
\Delta ZEEB_{t-1} \\
\Delta NETA_{t-1} \\
\Delta BRENT_{t-1}
\end{bmatrix}
+ \begin{bmatrix}
\delta_{11} & \cdots & \delta_{14} \\
\cdots & \ddots & \cdots \\
\cdots & \cdots & \cdots \\
\delta_{41} & \cdots & \delta_{44}
\end{bmatrix}
\begin{bmatrix}
\rho_{t-1} \\
(ZEEB - NETA)_{t-1} \\
(NETA - BRENT)_{t-1}
\end{bmatrix}
+ \begin{bmatrix}
u_{1,t} \\
u_{2,t} \\
u_{3,t} \\
u_{4,t}
\end{bmatrix}
$$

In which the $\gamma$’s are measuring short-term movements resulting from previous changes in the market, while the $\delta$ parameters indicate the strength of changes in the relative position of the two variables that help restore the market equilibrium.
Table 8: VEC (1) considering all interconnector status options

<table>
<thead>
<tr>
<th></th>
<th>$R_1: C_{U,t} = 0$</th>
<th>$R_2: 0 &lt; C_{U,t} \leq \bar{C}$</th>
<th>$R_3: C_{U,t} \geq \bar{C}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$NBP_t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$ZEEB_t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t-value$</td>
<td>(.1650) (.10080)</td>
<td>(.7817) (.7920)</td>
<td>(.2584) (.6709)</td>
</tr>
<tr>
<td>$\rho_{t-1}$</td>
<td>1.1169 .9800</td>
<td>1.4908 1.3287 1.5682 1.6743</td>
<td></td>
</tr>
<tr>
<td>$t-value$</td>
<td>(.1169) (.9800)</td>
<td>(.4909) (.3287) (.5682) (.6742)</td>
<td></td>
</tr>
<tr>
<td>$(ZEEB -)$</td>
<td>- .2465 .1761</td>
<td>.0141 .0551 .0525 .0848</td>
<td></td>
</tr>
<tr>
<td>$(NETA -)$</td>
<td>(.0294) (.9659)</td>
<td>(.4512) (2.0809) (.7788) (1.5954)</td>
<td></td>
</tr>
<tr>
<td>$(BRENT -)$</td>
<td>(1.0294) (2.0018)</td>
<td>(.0038) -.0016 -.0019 -.0008 .0009</td>
<td></td>
</tr>
<tr>
<td>$\Delta NBP_{t-1}$</td>
<td>-.4250 .1278</td>
<td>.1065 -.0240 .4274 .3397</td>
<td></td>
</tr>
<tr>
<td>$t-value$</td>
<td>(1.3312) (.5258)</td>
<td>(.9872) (.2642) (3.3459) (.3742)</td>
<td></td>
</tr>
<tr>
<td>$\Delta ZEEB_{t-1}$</td>
<td>.4028 .1844</td>
<td>-.1149 -.0316 -.3549 -.1406</td>
<td></td>
</tr>
<tr>
<td>$t-value$</td>
<td>(.7192) (.4323)</td>
<td>(.9353) (.3049) (2.7267) (1.3712)</td>
<td></td>
</tr>
<tr>
<td>$\Delta NETA_{t-1}$</td>
<td>.0294 .0089</td>
<td>.0046 .0023 -.0065 -.0097</td>
<td></td>
</tr>
<tr>
<td>$t-value$</td>
<td>(1.1214) (.4489)</td>
<td>(2.2387) (1.2970) (1.5580) (2.9658)</td>
<td></td>
</tr>
<tr>
<td>$\Delta BRENT_{t-1}$</td>
<td>-.3612 .5703</td>
<td>.0024 -.0886 .0887 .0417</td>
<td></td>
</tr>
<tr>
<td>$t-value$</td>
<td>(.7412) (1.5370)</td>
<td>(.0103) (.4449) (.3348) (.1997)</td>
<td></td>
</tr>
<tr>
<td>$Adj.R^2$</td>
<td>.2886 .0987</td>
<td>.0274 .0152 .0947 .1421</td>
<td></td>
</tr>
<tr>
<td>$F-stat$</td>
<td>2.2752 1.3443</td>
<td>2.0247 1.5601 3.6884 5.2605</td>
<td></td>
</tr>
</tbody>
</table>

22
Electricity prices are shown to influence the long-term adjustment relationship between $P_{NBP,t}$ and $P_{ZEEB,t}$ under all regimes (Table 8). $P_{ZEEB,t}$ also affects that relationship, as well as the $NETA_t - P_{ZEEB,t}$, when the interconnector is operational, indicating that traders at NBP might be indeed playing an arbitrage game between the two markets.

Moreover, the model indicates the existence of a dynamic equilibrium relationship between $\rho_{t-1}$ and the determination of $P_{NBP,t}$ and $P_{ZEEB,t}$ under $R2$ ($t-values$ 1.4908 and 1.3287) that is present to a lesser extent under splitting specifications. We also find evidence of double-sided arbitrage under $R2$ in that there is an equilibrium relationship between $NETA_t$ and $P_{ZEEB,t}$ determining the latter that also becomes less influential under the $R3$ and, particularly, $R1$ assumptions.

To summarise, the VAR and VEC models provide general evidence of the migration in dynamic econometric structures between $P_{NBP,t}$ and $P_{ZEEB,t}$ depending on the degree of interconnector utilisation as defined in the three separated data sets. We found an oil link to $P_{NBP,t}$ under $R2$ and $NETA_t$ and $P_{NBP,t}$ links to $P_{ZEEB,t}$ under $R2$ and $R3$, respectively. Moreover, we identified some evidence of structural integration between the two gas prices under $R2$.

5 Discussion and Concluding Remarks

The economic value of the Zeebrugge-Bacton natural gas interconnector should be determined by the price divergence between the two hubs, $\rho_t$. Without capacity constraints and under an efficient markets hypothesis, no arbitrage would occur, the interconnector would remain idle and both $P_{ZEEB,t}$ and $P_{NBP,t}$ would move within the boundaries of marginal trans-
portation costs (i.e. close to zero). If that is not the case, one expects the pipeline to operate regularly and that those holding both transportation and local market positions obtain arbitrage rents.

We have found that the relationship between $\rho_t$ and $C_U$ is convex, and that market splitting emerges at a lower level than anticipated, with a threshold, $\bar{C}$, around 55-60%. Hence, the separate consideration of interconnector closures ($R_1$, ”technical splitting”), low ($R_2$, ”integration”) and high interconnector utilisation ($R_3$, ”economic splitting”) cases has proven to be a step in the direction of establishing the mediating role of congestion in the operation of the LOOP. Moreover, the dynamic results provided subtle insights about the actual interrelationships, which were influenced by splitting and market power.

Firstly, arbitrage is very effective in forcing convergence in the European gas market but prices diverge under ”technical splitting”. The static models indicate that interruptions in the pipeline service lead to systematic increases in the differential between the two local prices. When the interconnector closed, $P_{ZEEB_t}$ grew and $P_{NBP,t}$ decreased, as foreseen by market players:

”The scheduled shut down of the UK-Belgium gas Interconnector has had the predicted effect on the NBP prompt and prices have dropped on Monday, traders said” (Platts, 8-Sept-2003).

The LOOP operates as a process of convergence to the mean in levels so the interconnector has so far resulted in a price subsidy from British to continental European wholesale buyers. Factors that favour the emergence of more competition (and lower prices) in the UK include a larger number of buyers and sellers, larger volumes of free natural gas at the electricity
generation margin, more market transparency and Ofgem’s behaviour as successful industry watchdog. Thus, the British government idea of the interconnector providing the means by which they could export both their gas and their liberalisation philosophy to the Continent (Stern, 1998) has been replaced in recent years by purchasing cartels (Financial Times, 2000), and official allegations of anti-competitive firm behaviour (Financial Times, 2001).

Second, arbitrage influences not only the absolute $P_{NBP,t}$ and $P_{ZEEB,t}$ levels but also their structural formation. Traditionally, prices in the UK depended on the dynamics of the wholesale electricity market while in the Continent they were pegged to those of oil. Now, commentators refer to the interconnector becoming a channel of an "oil linkage" to British natural gas prices. Its logic is conventional wisdom among industry experts:

"A higher oil price acts as an incentive to develop associated fields, which automatically brings more gas as well as more oil onto the market. In the interests of fostering the healthy growth, which continues to characterize the gas market, the gas industry will always have to remain alert to the price differential between gas and alternative oil products. Oil indexation is no more than an expression in mathematical terms of what is an economic fact of life" (Verberg, 2000)\(^7\)

The argument works in the long run and also as a justification for the existence of indexed contractual arrangements in the Continent. It might

\(^7\)The reference to market players that are able and, indeed, should manage the “healthy growth” in the gas industry evidences of the degree of market power still available to incumbents.
explain why Brent price should influence Zeebrugge but not why it should influence day-ahead UK prices, unless the interconnector funnels the linkage. We found evidence of a migration of price structures that largely homogenizes their dynamics and that depends upon the existence of arbitrage opportunities. Consistent with economic theory, the effect emerges only when physical and economic market integration occur and there is sufficient idle capacity. If that is the case, \( P_{NBP,t} \) and \( P_{ZEEB,t} \) become very interrelated. When either technical (\( R1 \)) or economic splitting (\( R3 \)) takes place, though, they separate. A relatively low capacity utilisation threshold results on \( P_{NBP,t} \) and \( P_{ZEEB,t} \) not being arbitraged as well as one would have learned to expect.

A third general lesson concerns the causality relationship between the two prices. There is substantial evidence of \( P_{NBP,t} \) driving \( P_{ZEEB,t} \) but not the other way around. A number of factors might explain this dependence: 1. The UK trading mechanism is more mature and liquid; 2. Information is more reliable and easier to access in the UK; 3. The connection between electricity and natural gas markets is stronger there, and; 4. Blending capacity is limited in the Zeebrugge area. These explanations fit well the empirical data and suggest that, in general, when a well-developed market integrates with another that is embryonic, the former tends to take the driving causality role.

Moreover, although logically the two should be determined simultaneously, we found that \( \rho_t \) preceded \( C_{U,t} \). A possible explanation for this effect might have to do with the timing of information availability. Real time interconnector data is more difficult to obtain than local market information and might become, as a consequence, subordinate in the price determination process. If that were the case, more interconnector information would not
only facilitate market scrutiny but local competition, too.

Finally, if prices had been found to be econometrically equivalent during disruptions, it would have been plausible to argument against the economic rationale for having an interconnector in the first place. One would have expected the LOOP to hold at all times so the interconnector’s economic value would not have depended upon its arbitrage role but simply as balancing instrument. Congestion (and the economic value of the interconnector) would have been very small under these circumstances (Bower, 2002). In general, though, it was found that the interconnector has sufficient capacity to integrate the two markets.

To our knowledge, there is no previous empirical literature examining the relationship between transportation capacity utilisation and locational prices. Hence, we believe that the above results provide new insights on the management of interconnection infrastructures, which are pertinent to understand the dynamics of the European competitive energy industry and, in general, of inter-related markets.

6 Appendix: Empirical sources

UK Gas demand, natural gas prices at Zeebrugge and NBP.
Heren (http://www.heren.com).
Interconnector flows: http://www.interconnector.com
Platts daily email update on international gas markets (www.platts.com).
Electricity prices:
England and Wales:
http://www.elexon.co.uk/elexon/publications/index.html
References


