COMPETITION IN THE UK GAS INDUSTRY
An explanation of the events occurred at St Fergus and Bacton in Summer and Autumn 1998

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Abstract

In Summer and Autumn 1998 a series of singular events occurred at the two main gas terminals on the UK mainland. At St Fergus, in Scotland, shippers wanted to input more gas than what was physically possible while at Bacton, in England, input was particularly low. As a consequence Transco had to take balancing operations in order to maintain equilibrium in the transportation system. The balancing operations caused significant costs for the industry. The reasons for this sequence of unusual events are still not completely clear.

The aim of this paper is to study the incentives faced by shippers during Summer and Autumn 1998 and to give a reasonable explanation for the events at St Fergus and Bacton. We model the interaction between shippers as a two stage game in which shippers first decide their "nominations" and then compete on the "Flexibility Mechanism". We find the Nash equilibria in pure strategies of the game and we conclude that a series of exogenous events (expansion programs, new gas fields) may have induced shippers to force significant constraints at the terminals in order to increase profits from Transco balancing operations.

September 2000

1. Background

1.1. The regulatory framework

The regulatory framework of the onshore gas regime is provided by the Gas Act 1986 (as amended by The Gas Act 1995). The Department of Trade and Industry provides for the framework for the offshore industry.

The Public Gas Transporters' Licence states that public gas transporters are responsible for the transportation process and have to maintain balance into the system. Moreover they have to introduce a network code to regulate the use of the pipeline system and must act so that neither public gas transporter or any shipper obtains "unfair" commercial advantage. Transco is the major public gas transporter. Transco balancing decisions are regulated by its network code and Operational Guidelines.

Shippers buy gas from the producers and deliver it to their customers through the pipeline system. The Gas Shippers' Licence gives the guidelines for their activity. Condition 2(1) of The Gas Shippers' License requires that shippers "act in a reasonable and prudent manner" in using the pipeline infrastructure. Condition 2(2) states that shippers shall not pursue any course of conduct which is likely to prejudice the "safety" of the system or the "efficiency of the balancing operations" taken by a public gas transporter. Moreover condition 2(3) requires that the licensee "shall not knowingly or recklessly act in a manner likely to give a false impression to a relevant transporter as to the amount of gas to be delivered by the licensee".

Ofgas (1999b) reports that some of the above requirements were not probably met by some shippers during the extraordinary events occurred at St Fergus and Bacton in 1998.

1.2. Gas fields

There are two kinds of gas fields. In "Dry gas fields" gas is the only output of the extraction process, while in "Associated gas fields" gas can only be extracted together with liquids. Dry gas fields are mainly connected with the Bacton terminal, while associated gas fields are mainly connected with St Fergus.

Extraction of gas in the associated gas fields can not be easily changed following the gas demand (which is highly seasonal). This may cause a difference in the incentives faced by shippers at the two terminals. At St Fergus shippers have incentive to keep quantities within a smaller range which is determined by the technological limits to reinjection of liquids and by the demand of the associated oil.

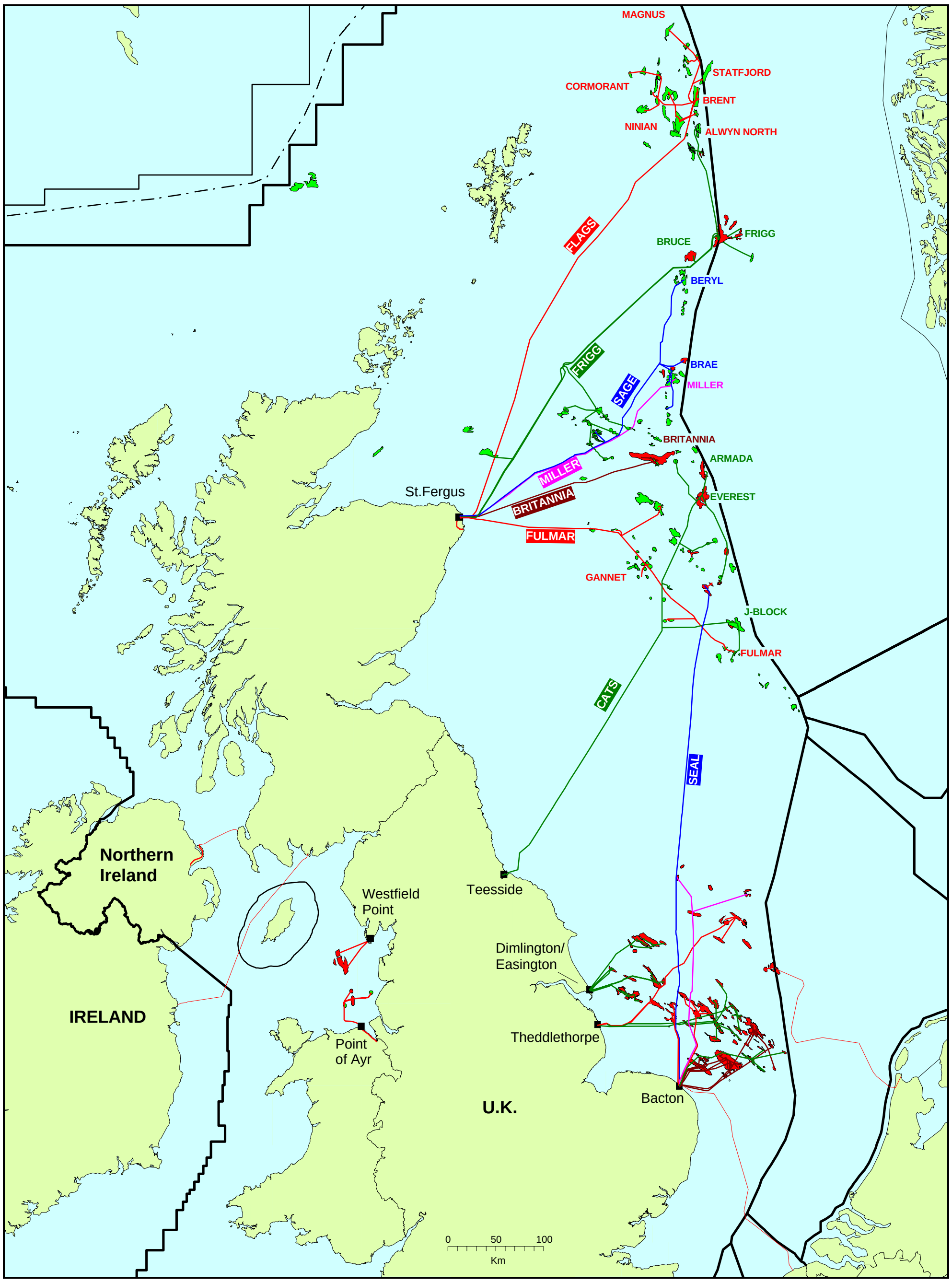
1.3. The gas transportation system

Each field is connected to the onshore transportation system through a single pipeline. In the offshore pipeline infrastructure each pipeline delivers gas to a single terminal on the mainland and it is not possible to switch gas between gas terminals (Fig.1). The onshore pipeline infrastructure is more flexible and there is often more than one way to transfer gas between two terminals.

The gas transportation system is such that a “1 in 20 days peak demand” is satisfied across terminals, that is Transco has to provide enough aggregate capacity to satisfy the aggregate demand except for a few extraordinary cases. It is important to notice that Transco has no obligation to provide enough capacity at single terminals. Thus it may happen that shippers ask to input more gas than the available capacity at a single terminal, even if there is not overall excess of gas input into the system.

The gas transportation system is periodically updated in order to meet the increasing demand of gas in the UK. A major reinforcement project started in Summer 1998 and it was still under way when the unexpected constraints at Bacton and St Fergus took place. It is believed that the National Transportation System Capacity Expansion & Maintenance Programme played a role in determining such unusual events (Ofgas, 1999a).

Fig.1. UK Offshore Pipeline Infrastructure



Source: Wood Mackenzie.

1.4. System balancing

Before the gas day shippers nominate inputs and their customers' offtakes. On the basis of the nominations and the actual available capacity at each terminal Transco evaluates if balancing operations are necessary. There are three typical situations that may cause balancing operations: overall constraints, locational constraints and individual imbalances.

We start with the first two cases. Any difference between aggregate inputs and offtakes (overall constraint) or any difference between inputs and offtakes at a specific terminal (locational constraint) is bought or sold on the Flexibility Mechanism. C*onstraints, in principle, can be deliberately caused by shippers.*

In order to show how this can be possible we have to notice that Transco sells capacity at each terminal in annual tranches and shippers may nominate flows in excess of their booked capacity[1]. It follows that, in principle, shippers could nominate very large or very small quantities of gas in order to force a constraint and then have positive profits on the Flexibility Mechanism. This kind of constraint would have no relation with changes in gas demand and shippers conduct could eventually give a "false impression" to the public gas transporter.

The third situation that may cause balancing operations is when individual imbalances occur. Any difference between shipper's daily input and offtake is bought or sold by Transco using the "cash out system"[2]. The cash out system gives a strong incentive to keep the individual difference between input and offtake within a reasonable scale.

On the Flexibility Mechanism, used to solve overall and locational constraints, shippers can place bids to provide gas (System Buy Bids) or to take gas off the system (System Sell Bids). Transco accepts bids in price order (starting with the lowest for System Buy

[1] The only limitation is that, if the volume allocated exceeds booked capacity, the shipper will incur a capacity overrun charge.

[2] In broad terms, if no overall constraint has occurred, Transco will buy or sell gas to solve any individual constraint at the System Average Price. In case of an overall shortage of gas Transco will sell gas to a shipper who has underdelivered at the System Marginal Price Buy, which is higher than the System Average Price. The opposite happens when an overall excess of gas occurs. Only operations caused by imbalance between overall supply and demand are used for the computation of the System Marginal Price.

Bids and from the highest for System Sell Bids) up to the required volume. If a shipper has one of his bids accepted he will pay (or receive) the bid price. Every bid has a specific location and flow rate. Shippers have different ways to deliver gas to the system or to take gas off the system accordingly to their accepted bids: they can change planned deliveries at the terminals, use their storage facilities or interrupt some of their customers.

Transco balancing operations on the Flexibility Mechanism may give rise to profits or losses. These are charged or rebated to shippers in proportion to their gas throughput. This process is called "Neutrality Charge". Balancing actions may have a significant effect on revenues and costs of shippers. Since Transco is cash neutral the net profit of each player is just a transfer from other shippers.

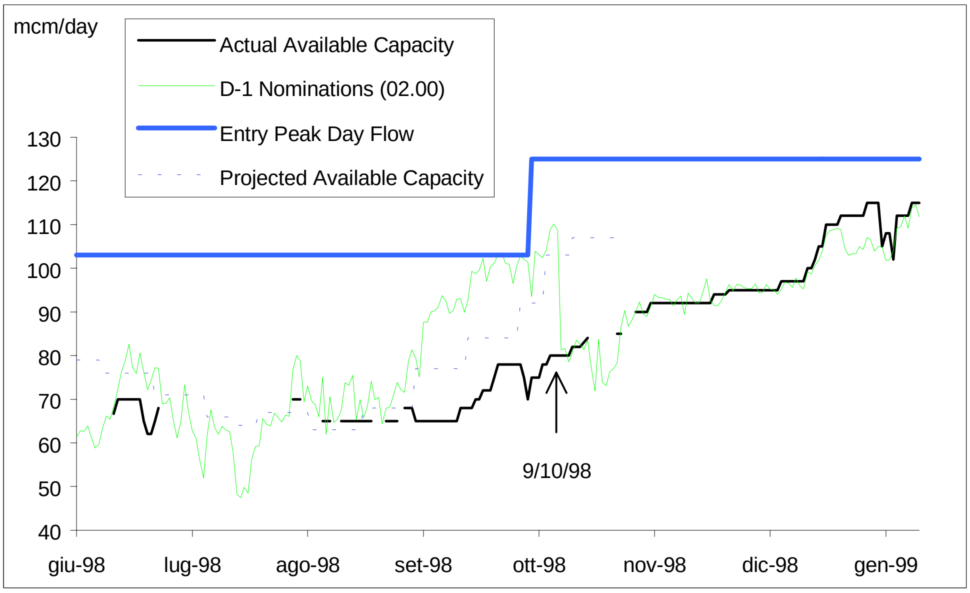
1.5. Events at St Fergus

A series of singular events happened at St Fergus in Summer and Autumn 1998.

1) Transco implemented the National Transportation System Capacity Expansion & Maintenance Programme in order to upgrade the system and increase the available capacity. This program implied significant investments (some £350 million) and had some unwanted effects on the system during the summer (Fig. 2). In particular the available capacity at St Fergus was temporarily reduced more than what was projected in June 1998, when shippers were informed of the likely transitory consequences of the Programme. The effects of the Programme increased the cyclical trough which is normal during the summer, since the available capacity at the terminals is closely related to the gas demand (low during the summer).

2) From the beginning of September until 9 October 1998 the sum of the nominations (see day ahead nominations at 02.00 in Fig.2) was far in excess of the available capacity and of the projected capacity. Nominations were not justified by an increase in the demand of gas (Ofgas, 1999a).

Fig.2. St Fergus nominations and entry capacity. Source: Ofgas (1999a)



3) A major new associated gas field, Britannia, started output in early August 1998. This new gas field is connected only with the St Fergus terminal.

4) Prices on the Flexibility Mechanism at St Fergus fell suddenly at the beginning of September and had remained significantly lower than prices at Bacton until November 1998. Constraints caused the System Marginal Price Sell being set at St Fergus and the System Marginal Price Buy being set at Bacton. System Marginal Prices are reported in Fig. 4.

The consequences of the above events were a series of moderate system sell operations at St Fergus between June and the end of August 1998 and major system sell operations in September 1998. The system sell operations created (at least in part) an overall imbalance in the system, and a significant number of system buy actions were taken to input additional gas at the other terminals, mainly at Bacton.

The concern about the consequences of these events led to a urgent modification of the shippers nomination procedure at St Fergus (modification 271 of Transco Network Code). From 9 October each shipper could not nominate more than his "scaled back capacity", which was proportional to his share of the total booked capacity. The sum of the scaled back capacities had to be equal to the available capacity. This action artificially dampened nominations at St Fergus and gave to the system a semblance of normality reducing the balancing operations and the associated costs. Nevertheless, prices on the Flexibility Mechanism were not affected by this operation and remained "too low" at St Fergus and "too high" at Bacton.

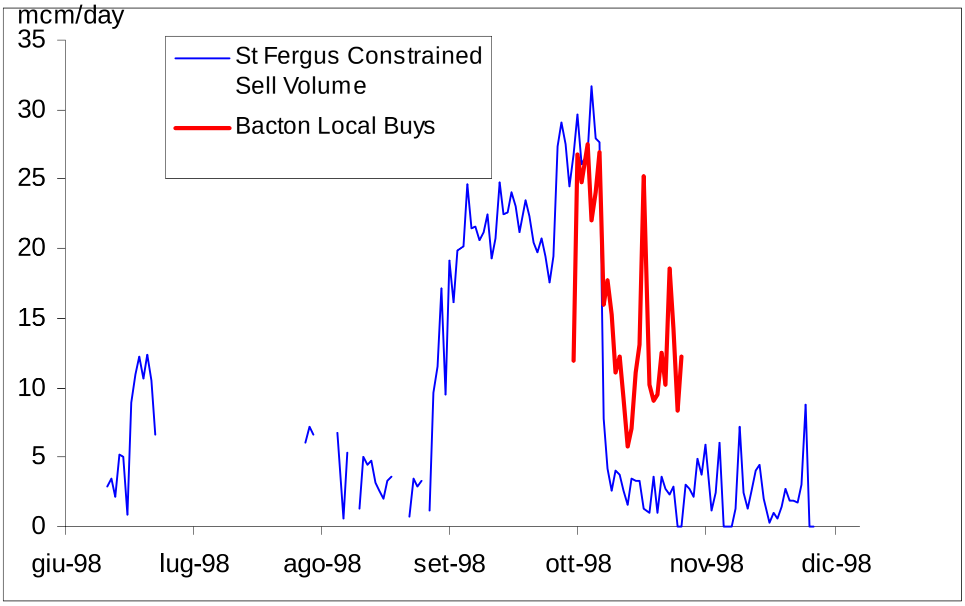
1.6. Events at Bacton

Unusual events happened also at Bacton between September and the end of October 1998. These may have been caused, at least in part, by those at St Fergus.

1) A number of reinforcement projects were under way which precluded Transco from buying gas at any other terminal than Bacton, in consequence of the shortage of gas due to the system sell operations at St Fergus.

2) In September and October 1998 nominations were far below what was anticipated on the basis of the previous year and what seemed to be justified by the gas demand.

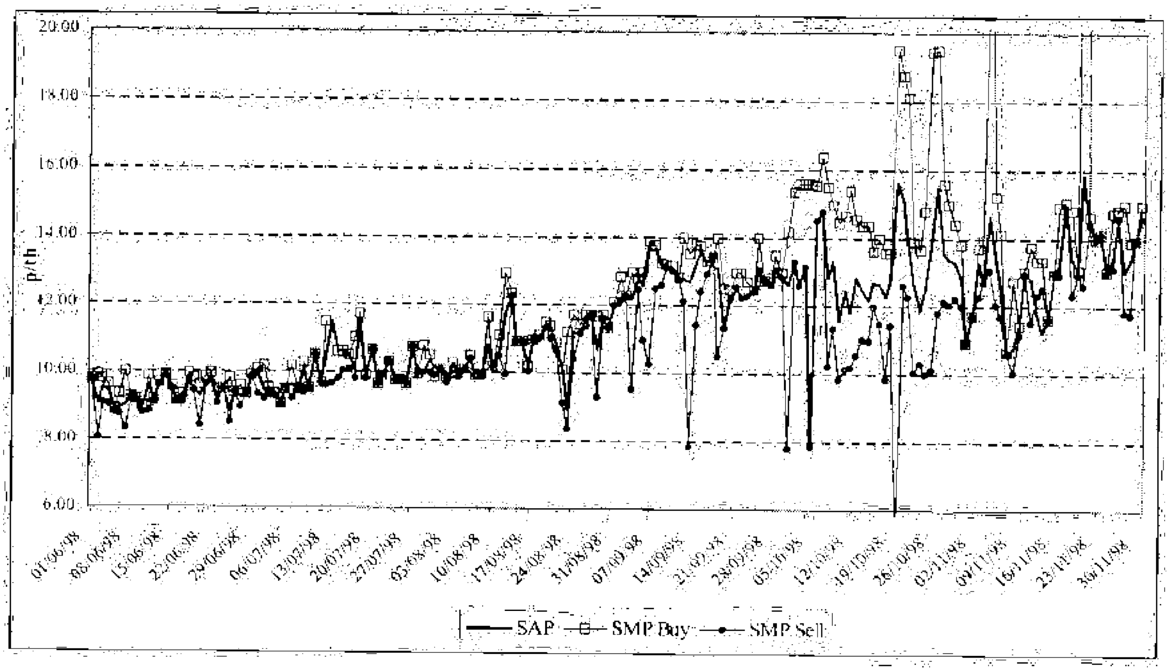
Fig.3. St Fergus and Bacton constrained operations. Source: Ofgas (1999a).



3) Prices on the Flexibility Mechanism at Bacton increased and remained high and volatile until mid November 1998.

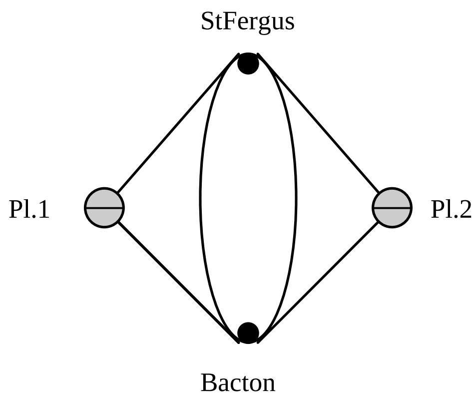
As a consequence of the very low nominations at Bacton, Transco took balancing actions (system buy operations) throughout October (Fig.3). System buy operations were taken even after implementation of modification 271 at St Fergus, which forced nominations to meet the available capacity at St Fergus. No action in the form of modification 271 was implemented at Bacton, because it was considered too difficult to force shippers to input at least a certain amount of gas in order to solve the constraint.

Fig.4. SAP, SMP Buy and SMP Sell: June-November 1998. Source: Ofgas (1999a).



2. The "terminal game"

In the previous paragraph we described some institutional features of the relation between shippers and Transco and between shippers. We also summarised the main events that occurred during the summer 1998. The aim of this paper is to find a reasonable explanation of this succession of events that could shed light on the incentives that shippers faced. From now on we will look at shippers as "players" in a "terminal game".



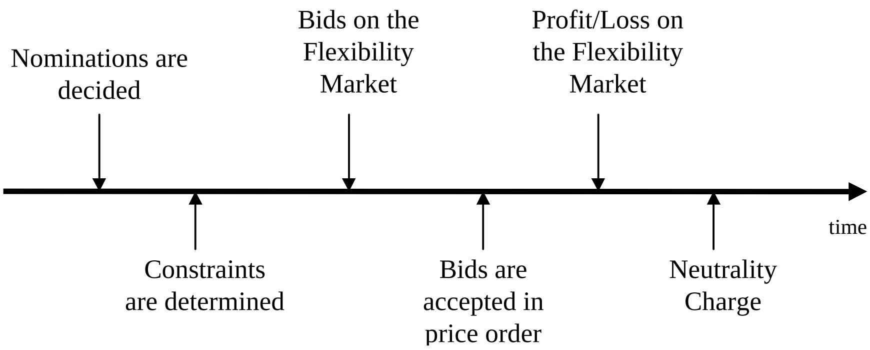
As for the description of any game, we first give a list of players, then a list of actions that players can take and finally we describe what their objectives are.

In the terminal game there are only two players (two shippers), both of them are connected to the two existing terminals (St Fergus and Bacton) and there is no other connection between shippers and their customers (Assumption 1).

At each terminal a quantity X of gas has to be landed. It may not be the same at each terminal ($X_{sf} \neq X_{ba}$). X_{sf} and X_{ba} are set so that

$$D_1 + D_2 = X_{sf} + X_{ba}$$

The total demand is exactly satisfied with the amount of gas that is rigidly put into the system by the shippers. This is equivalent to say that no storage is possible into the system (Assumption 2). This can be considered as a realistic assumption, since the pipeline infrastructure is built so that it is able to accommodate the overall gas demand in most circumstances.



Shippers move twice. First: they decide simultaneously what they want to input into the system at each terminal (SF_1, BA_1 and SF_2, BA_2). These quantities are called nominations. Then nominations are revealed and constraints (*q*) are computed as differences between the total amount of the nominations and the actual available capacity:

$$q_{sf} = SF_1 + SF_2 - X_{sf}$$
$$q_{ba} = X_{ba} - BA_1 - BA_2$$

Second: shippers simultaneously decide what they would like to buy or sell on the Flexibility Market and at what price.The system manager, who buys or sells the constrained quantities on the Flexibility Market, chooses the best price and allocates quantities to be sold or bought (Assumption 3).

Every player must nominate the exact amount of gas which is necessary to satisfy his demand:

$$SF_1 + BA_1 = D_1$$
$$SF_2 + BA_2 = D_2$$

From Assumption 2 and 4 it follows that

$$SF_1 + BA_1 + SF_2 + BA_2 = X_{sf} + X_{ba}$$
$$SF_1 + SF_2 - X_{sf} = X_{ba} - BA_1 - BA_2$$
$$q_{sf} = q_{ba}$$

If the sum of the nominations at one of the terminals (say St Fergus) is larger than the required quantity (X_{sf}), then the sum of the nominations at the other terminal (say Bacton) must be smaller than then required quantity at that terminal (X_{ba}). An excess of gas at St Fergus implies a shortage of gas of the same amount at Bacton. Constraints are symmetric. This is a realistic assumption since symmetry of the constraints is a relevant feature of the events occurred in 1998 (Assumption 4).

In Paragraph 1.4 we observed that shippers can nominate flows in excess of their booked capacity and we did not mention any other constraint. Nevertheless Assumption 4 is not so unrealistic as it might appear. Players can still choose where to input the gas which is necessary to satisfy their demand without any constraint. Moreover the Shippers' License precludes nominations from being clearly too big or too small with respect to the shipper's total demand, since this would be a clear violation of condition 2(3). Finally, in practise, it is very unlikely to observe shippers with a small demand nominating more than shippers with a large demand. By the above assumption we rule out the possibility that a player will openly break the Shippers' Licence but we still allow for the possibility that a player will "cleverly"[3] break it, reallocating strategically his demand across terminals.

If each player nominates the exact amount of his demand then only locational constraints can happen in the terminal game. This is appealing since locational constraints were one of the distinctive features of the events at St Fergus and Bacton. If only locational constraints could happen in the real world, then the price used in the cash out system would be the System Average Price and no player would receive a strong "punishment" for his individual imbalances. Hence the cash out system would have minimum effect on shippers' profits. Since only locational constraints can happen in the terminal game, we assume that there is no cash out system in the game.

It is assumed that an excess of gas happens at the terminal called St Fergus and that a shortage of gas occurs at the other terminal.

$$SF_1 + SF_2 \geq X_{sf}$$
$$BA_1 + BA_2 \leq X_{ba}$$

This is not restrictive, since names are arbitrary (Assumption 5).

[3] Since we are interested in studying the incentives of the players, we have to leave to players the possibility of breaking the rules (in a realistic way). This is unfortunately possible, in practise, and it was one of the reasons for the Ofgas investigation.

In the terminal game, we imagine that the only way to solve a constraint is to increase or reduce the nominated quantities. This is realistic, at least if we model the situation of the market during the summer, when the demand is low and the possibility of interrupting customers is limited.

The events occurred on the Flexibility Mechanism in 1998 are of central interest in studying the anomalies observed at St Fergus and Bacton. The game, in consequence, is centred on the Flexibility Market. The Flexibility Market is the counterpart of the Flexibility Mechanism in the terminal game.

Players buy or extract any quantity of gas at marginal cost *c* and they sell it to customers at the same price *p=c*. Thus shippers can not make any profit from their "ordinary" business. What can be profitable is buying and selling gas on the Flexibility Market when a constraint occurs. It is clear, though, that they can influence the occurrence of a constraint through the nominations (Assumption 6).

Shippers must flow into the system at least a minimum quantity at each terminal:

$$\underline{C}_1^{sf}, \underline{C}_2^{sf}, \underline{C}_1^{ba}, \underline{C}_2^{ba}.$$

This is an economic constraint, not a technological one: it represents in a simple way the incentive for producers to smooth the extraction of gas from associated gas fields (Assumption 7). In fact this constraint turns out to be binding only in the location where the excess of gas occurs. It is assumed that interruption and storage are not feasible and that constraints can always be solved using the Flexibility Market:

$$X_{sf} \geq \underline{C}_1^{sf} + \underline{C}_2^{sf}$$

$$X_{ba} \leq \overline{C}_1^{ba} + \overline{C}_2^{ba}$$

Shippers can not flow into the system more than the given booked capacity at each terminal: ($\overline{C}_1^{ba}, \overline{C}_2^{ba}, \overline{C}_1^{sf}, \overline{C}_2^{sf}$). This constraint happens to be binding only at the terminal with shortage of gas (Bacton) (Assumption 8).

The objective of each player is to maximise his total profit (= profit on the Flexibility Market - Neutrality Charge) given the strategy of the other player.

Assumption 9: on the Flexibility Market

9.1) Shippers can bid only once.

9.2) Shippers do not buy gas at price $p>c$ and do not sell gas at price $p<c$. Since they have no duty to buy or sell gas on the Flexibility Market we assume that they will not deliberately incur into losses that are not necessary. For simplicity we exclude the possibility that shippers deliberately incur into losses at one of the terminals in order to have some sort of gain at the other.

9.3) Losses of the system manager resulting from the Flexibility Market operations are charged to shippers in proportion to their overall gas input (neutrality charge).

9.4) For each terminal, bids are sorted by price and gas is traded at the price specified on every accepted bid for the specified quantity.

9.5) If two bids have the same price and the sum of the bid quantities exceeds the constrained quantity the market will be shared in two equal parts.

9.6) It is assumed that prices on the Flexibility Market are bounded between a minimum (*Min*) and a maximum (*Max*) price. For simplicity it is also assumed symmetry of the minimum and maximum price with respect to the marginal cost ($c - Min = Max - c$).

Finally, in order to simplify the interpretation of some results it is assumed that $X_{sf} \geq X_{ba}$ (Assumption 10). This is not at all a fundamental assumption but it is well supported by data described in the Ofgas report (1999a). In the next paragraphs we will look for the Nash Equilibria in pure strategies.

3. The Flexibility Market Subgame

3.1. Equilibria on the Flexibility Market at St Fergus and Bacton

The terminal game happens to have a single equilibrium outcome in pure strategies. The equilibrium outcome, though, may change if the parameters of the model change.

The analysis of the equilibria of the subgame proceeds as follows: first we define three possible cases imposing restrictions on the parameters. Then for each case we find the Nash Equilibria (in pure strategies) of the Flexibility Market Subgame *at each terminal* for every possible pair of profits at the other terminal. Third, we show that when both terminals are in equilibrium, for every possible pair of profits at the other terminal, then we have equilibrium on the Flexibility Market Subgame and there is no other equilibrium on the Flexibility Market Subgame. In the next paragraph, finally, we will look for equilibria in the complete game.

In the Flexibility Market Subgame *nominations are taken as given*, since they are determined in the first stage of the game. The constrained quantity is then known by Assumption 3. C_1^{sf}, C_2^{sf}, *c*, *Max*, *Min* are exogenous parameters and s*ince only minimum capacities are relevant at St Fergus we will simply use* C_1^{sf}, C_2^{sf} *instead of* $\underline{C}_1^{sf}, \underline{C}_2^{sf}$.

Players bid on the Flexibility Market choosing q_1^{sf}, q_2^{sf} and p_1^{sf}, p_2^{sf} in order to maximise their total profit (P_1, P_2). The total profit function of each player has two components:

a) the direct profit from the Flexibility Market at the two terminals $\left(\Pi_1^{sf}, \Pi_1^{ba}, \Pi_2^{sf}, \Pi_2^{ba}\right)$

b) the neutrality charge: the sum of the terminal profits (equal to the overall loss of the system manager) of the two players is charged back in proportion to their gas input $\left(I_1^{sf}, I_2^{sf}, I_1^{ba}, I_2^{bs}\right)$. Gas input at St Fergus is equal to the nomination less the amount of gas bought back on the Flexibility Market $\left(O_1^{sf}, O_2^{sf}\right)$.

$$P_1 = \Pi_1^{sf} + \Pi_1^{ba} - \left[\Pi_1^{sf} + \Pi_1^{ba} + \Pi_2^{sf} + \Pi_2^{ba}\right] \frac{I_1^{sf} + I_1^{ba}}{I_1^{sf} + I_1^{ba} + I_2^{sf} + I_2^{ba}}$$

where
$$I_1^{sf} = SF_1 - O_1^{sf}$$
$$I_2^{sf} = SF_2 - O_2^{sf}$$

Equilibria at St Fergus

At St Fergus shippers can "buy back" gas on the Flexibility Market (remember that only an excess of gas may happen at St Fergus). Increasing the traded quantity at St Fergus has two different effects on shippers' payoffs: it weakly increases profits at St Fergus (see Assumption 9.2) and it decreases total gas input and thus the share of the costs. The second effect is clear from the definition of profit and gas input. Three different cases may occur.

Case 1) $X_{sf} > C_1^{sf} + C_2^{sf}$

The quantity of gas which has to be entered into the system is larger than the sum of the minimum quantity of gas that shippers can input at St Fergus (see Assumption 7). Changing signs and adding to both sides $SF_1 + SF_2$ and using the definition of constrained quantity at St Fergus we obtain

$q < SF_1 - C_1^{sf} + SF_2 - C_2^{sf}$

The above assumption on the parameters implies that the constrained quantity (q) is less than the sum of the maximum quantities that players can buy on the Flexibility Market at St Fergus. In this situation the incentive to compete is strong: at least one of the players can increase his profit by raising the price at which he is ready to buy back gas and by taking off the system a larger quantity. Strong competition on the Flexibility Market drives profits to zero and the sell price up to the level at which no player has positive profit (the marginal cost) from buying gas. In this situation a **Competitive Equilibrium** is reached (See Appendix 1), with both players bidding the marginal cost and sharing the market 50/50.

Case 2) $X_{sf} < C_1^{sf} + C_2^{sf}$

The available capacity is smaller than the minimum quantity that players can input. In this unlikely case the constraint can not be solved: the gas that can be accepted is less than the minimum that players can flow. In this situation Transco and shippers could use their storage facilities or Transco could curtail the terminal flows by issuing a Transportation Flow Advice. In the terminal game we assume that if capacity falls below this level, then the above actions are automatically taken by the Public Gas

Transporter in order to keep the capacity at the minimum level at which the flexibility market can guarantee to balance the system and thus its safety. This level is clearly the minimum quantity of gas that shippers can land.

Case 3) $X_{sf} = C_1^{sf} + C_2^{sf}$

changing signs and adding to both sides $SF_1 + SF_2$ and using the definition of constrained quantity at St Fergus we obtain

$q = SF_1 - C_1^{sf} + SF_2 - C_2^{sf}$

Given nominations at St Fergus, the maximum quantity that Player *i* can buy on the Flexibility Market at St Fergus is $SF_i - C_i^{sf}$: every player can buy back his whole nomination except for the minimum quantity he has to input. In case 3) the constrained quantity equals the maximum quantity that can be traded on the Flexibility Market at St Fergus. There is no competition between shippers: players can buy back gas at the minimum possible price because they are sure that the other player will not try to have a larger share on the Flexibility Market. This is because both of them are already selling their maximum quantity on the Flexibility Market. In this situation a **Low Price Equilibrium** is obtained (see Appendix 2): players bid the minimum possible price and the maximum quantity they can buy back on the Flexibility Market.

Equilibria at Bacton

The structure of the equilibria at the other terminal is symmetric. At Bacton a shortage of gas occurs (see Assumption 5) and the system manager buys gas on the Flexibility Market. Similarly as before we define the gas input at Bacton for each shipper as

$$I_1^{ba} = BA_1 + i_1^{ba} \leq C_1^{ba} \Rightarrow i_1^{ba} \leq C_1^{ba} - BA_1$$
$$I_2^{ba} = BA_2 + i_2^{ba} \leq C_2^{ba} \Rightarrow i_2^{ba} \leq C_2^{ba} - BA_2$$

Input at Bacton is the *sum* of the nomination and the gas traded on the Flexibility Market (*i*). The gas input can not exceed the booked capacity, thus we define an upper bound to the gas input on the Flexibility Market ($\overline{C}_i^{ba}$). *Since only the maximum capacities are relevant at Bacton we will use* C_1^{ba} *and* C_2^{ba} *instead of* $\overline{C}_1^{ba}$ *and* $\overline{C}_2^{ba}$.

From Assumption 4 we have that

$q = X_{ba} - Ba_1 - Ba_2$

At Bacton the System buys gas to solve the constraint, thus shippers can increase their gas input over the nomination selling gas to the system on the Flexibility Market. As a consequence they make profits $\Pi_1^{ba}, \Pi_2^{ba} \geq 0$ which are charged back through the neutrality charge. Differently from the previous case, *the gas traded on the Flexibility Market increases the total gas input of the shippers and thus raises the share of the costs.*

Case 1) $X_{ba} < C_1^{ba} + C_2^{ba}$

adding to both sides $-BA_1 - BA_2$ and using the definition of q we obtain

$q < C_1^{ba} - BA_1 + C_2^{ba} - BA_2$

In this case the constraint is smaller than the sum of the maximum quantities shippers can sell to the system $\left(C_i^{ba} - BA_i\right)$. Players will harshly compete and competition will lead to a **Competitive Equilibrium**, in which the equilibrium price falls to the marginal cost[4] (see Appendix 3) and players share the market 50/50.

Case 2) $X_{ba} > C_1^{ba} + C_2^{ba}$

The above inequality implies that the gas input of the shippers is always below the amount of gas required at Bacton and the constraint can not be solved on the Flexibility Market. The Public Gas Transporter takes actions, in this case, to keep the constraint down to a manageable size (see Assumption 7).

Case 3) $X_{ba} = C_1^{ba} + C_2^{ba}$

adding to both sides $-BA_1 - BA_2$ we obtain

$q = C_1^{ba} - BA_1 + C_2^{ba} - BA_2$

The constrained quantity is equal to the maximum quantity that players can trade on the Flexibility Market. Then players will sell the maximum possible quantity to the system

[4] At least if there is Competitive Equilibrium at the other terminal, for details see Appendix 3.

at the highest possible price and will not have any incentive to fight (**High Price Equilibrium**) (see Appendix 4).

3.2. Equilibria in the Flexibility Market Subgame

In appendices 1 to 4 it is showed that

a) at St Fergus there is only one equilibrium outcome for any possible Π_1^{ba}, Π_2^{ba}. The equilibrium may be different for different combinations of parameters, as we described in the previous paragraph.

b) at Bacton there is only one equilibrium outcome for any possible Π_1^{sf}, Π_2^{sf}. The equilibrium may be different for different combination of parameters.

These propositions are relevant for individual terminals. In order to look for Nash equilibria in the Flexibility Market Subgame we have to consider all terminals together. If each of the two terminals is in equilibrium for any possible profit at the other terminal then it can be showed that

c) the Flexibility Market Subgame is in equilibrium[5].

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[5] Take the strategies such that (s_{sf}, v_{sf}) are the equilibrium strategies of Pl.1 and Pl.2 respectively at St Fergus for any Π_1^{ba}, Π_2^{ba}, and (s_{ba}, v_{ba}) are the equilibrium strategies of Pl.1 and Pl.2 at Bacton for any Π_1^{sf}, Π_2^{sf}. Then $(s_{sf}, s_{ba}, v_{sf}, v_{ba})$ is a Nash Equilibrium of the Flexibility Market Subgame.

Proof:
Π_1^{sf}, Π_2^{sf} are function of (s_{sf}, v_{sf}) only.
Π_1^{ba}, Π_2^{ba} are function of (s_{ba}, v_{ba}) only.
Assume that $(s_{sf}, s_{ba}, v_{sf}, v_{ba})$ is not a Nash Equilibrium, then one of the players (say Pl.1) can increase his profit changing his strategy (s_{sf}, s_{ba}) given the strategy of the other. Pl.1 can change his strategy in three possible ways.

a) Pl.1 changes his strategy at St Fergus only. This can not improve his profit, since s_{sf} is the best reply at St Fergus to the strategy of the other at Bacton (proposition "a" above), for any possible combination of strategies at Bacton.

b) Pl.1 changes his strategy at Bacton only. This can not improve his profit, by proposition "b" above.

c) Pl.1 changes his strategy at Bacton and St Fergus playing $(s*_{sf}, s*_{ba})$. Given these new strategies the profits are Π_1^{sf*}, Π_2^{sf*} and Π_1^{ba*}, Π_2^{ba*}.
Given Π_1^{sf*}, Π_2^{sf*} the only equilibrium at Bacton is (s_{ba}, v_{ba}). Thus, pl.1 can not improve his profit playing $s*_{ba}$. The same applies for the other terminal and for the other player.

and

d) there are no other Nash equilibria in the Flexibility Market Subgame[6].

It follows that, given assumption on the parameters, there is a single equilibrium outcome in the Flexibility Market Subgame. Moreover we know that there are no Nash equilibria of the Flexibility Market Subgame in which some terminal is not in one of the equilibria described in the previous paragraph. Now we can give a taxonomy of the possible equilibria in the Flexibility Market Subgame.

1) If $X_{sf} > C_1^{sf} + C_2^{sf}$ and $X_{ba} < C_1^{ba} + C_2^{ba}$ then equilibrium on the Flexibility Market implies Competitive Equilibrium at St Fergus and Competitive Equilibrium at Bacton.

Equilibrium strategies: $\begin{array}{l}\left\{p_1^{sf} = c, q_1^{sf} \geq q, p_1^{ba} = c, q_1^{ba} \geq q\right\} \\ \left\{p_2^{sf} = c, q_2^{sf} \geq q, p_2^{ba} = c, q_2^{ba} \geq q\right\}\end{array}$

Profit at the terminals: $\begin{array}{l}\Pi_1^{sf} = \Pi_2^{sf} = 0 \\ \Pi_1^{ba} = \Pi_2^{ba} = 0\end{array}$

2) If $X_{sf} = C_1^{sf} + C_2^{sf}$ and $X_{ba} = C_1^{ba} + C_2^{ba}$ in the Flexibility Market equilibrium we have Low Price Equilibrium at St Fergus and High Price Equilibrium at Bacton

Equilibrium strategies: $\begin{array}{l}\left\{p_1^{sf} = Min, q_1^{sf} = SF_1 - C_1^{sf}, p_1^{ba} = Max, q_1^{ba} = C_1^{ba} - BA_1\right\} \\ \left\{p_2^{sf} = Min, q_2^{sf} = SF_2 - C_2^{sf}, p_2^{ba} = Max, q_2^{ba} = C_2^{ba} - BA_2\right\}\end{array}$

If players can not change their strategy increasing their profit given the strategy of the other, then $(s_{sf}, s_{ba}, v_{sf}, v_{ba})$ must be a Nash Equilibrium of the Flexibility Market Subgame.

[6] Take a Nash Equilibrium of the Flexibility Market Subgame, then the equilibrium strategies must be equal to the strategies in proposition "a" and "b" above (i.e. the strategies such that each terminal is in equilibrium given profits at the other terminal)

Proof:
take a Nash equilibrium of the Flexibility Market with strategies $(s_{sf}, s_{ba}, v_{sf}, v_{ba})$. By proposition "a" we know that at St Fergus there is only one equilibrium outcome (for any Π_1^{ba}, Π_2^{ba}) characterised by the strategies $(\tilde{s}_{sf}, \tilde{v}_{sf})$. Assume that $s_{sf} \neq \tilde{s}_{sf}$ and $v_{sf} \neq \tilde{v}_{sf}$. Then one of the players can increase his overall profit changing his strategy at St Fergus only, since players are not in equilibrium at St Fergus given Π_1^{ba}, Π_2^{ba}. But this is not possible, since $(s_{sf}, s_{ba}, v_{sf}, v_{ba})$ is a Nash Equilibrium. Thus we have to conclude that $s_{sf} = \tilde{s}_{sf}$ and $v_{sf} = \tilde{v}_{sf}$.

Profit at the terminals: $\begin{matrix} \Pi_1^{sf} = (c - Min)(SF_1 - C_1^{sf}) \\ \Pi_2^{sf} = (c - Min)(SF_2 - C_2^{sf}) \end{matrix}$; $\begin{matrix} \Pi_1^{ba} = (Max - c)(C_1^{ba} - BA_1) \\ \Pi_2^{ba} = (Max - c)(C_2^{ba} - BA_2) \end{matrix}$

3) If $X_{sf} = C_1^{sf} + C_2^{sf}$ and $X_{ba} < C_1^{ba} + C_2^{ba}$ in equilibrium on the Flexibility Market we have Low Price Equilibrium at St Fergus and Competitive Equilibrium at Bacton

Equilibrium strategies:

$$\left\{ p_1^{sf} = Min, q_1^{sf} = SF_1 - C_1^{sf}, p_1^{ba} = c + \frac{(c - Min)q}{X_{sf} + BA_1 + BA_2}, q_1^{ba} \geq q \right\}$$

$$\left\{ p_2^{sf} = Min, q_2^{sf} = SF_2 - C_2^{sf}, p_2^{ba} = c + \frac{(c - Min)q}{X_{sf} + BA_1 + BA_2}, q_2^{ba} \geq q \right\}$$

Profit at the terminals: $\begin{matrix} \Pi_1^{sf} = (c - Min)(SF_1 - C_1^{sf}) \\ \Pi_2^{sf} = (c - Min)(SF_2 - C_2^{sf}) \end{matrix}$; $\Pi_2^{ba} = \Pi_1^{ba} = \frac{1}{2} \frac{(c - Min)q^2}{X_{sf} + BA_1 + BA_2}$

4) If $X_{sf} > C_1^{sf} + C_2^{sf}$ and $X_{ba} = C_1^{ba} + C_2^{ba}$ the in equilibrium on the Flexibility Market we have Competitive Equilibrium at St Fergus and High Price Equilibrium at Bacton

Equilibrium strategies: $\begin{matrix} \left\{ p_1^{sf} = c, q_1^{sf} \geq q, p_1^{ba} = Max, q_1^{ba} = C_1^{ba} - BA_1 \right\} \\ \left\{ p_2^{sf} = c, q_2^{sf} \geq q, p_2^{ba} = Max, q_2^{ba} = C_2^{ba} - BA_2 \right\} \end{matrix}$

Profit at the terminals: $\Pi_1^{sf} = \Pi_2^{sf} = 0$; $\begin{matrix} \Pi_1^{ba} = (Max - c)(C_1^{ba} - BA_1) \\ \Pi_2^{ba} = (Max - c)(C_2^{ba} - BA_2) \end{matrix}$

4. The nomination stage and the equilibria of the terminal game

In the first stage of the game players choose nominations at each terminal. Given the available capacity at each terminal, the constrained quantity is then determined. We examined the possible equilibria of the Flexibility Market Subgame and now we focus on the strategic behaviour of the two players in the first stage of the game. In the following paragraph the four possible cases are examined again, and for each case we find what the best reply is for each player in the nomination stage.

4.1. Competitive equilibrium at St Fergus and Competitive Equilibrium at Bacton

The equilibrium profit in this case is zero, since at each terminal no player can make any profit and the neutrality charge is consequently zero. Thus any possible nomination gives the same payoff, independently on what the other player does.

In this case there is no clear incentive to use strategically the nomination process and eventually break the Shippers' License. In a more complex environment nominations could be probably determined by the cost structure of the shippers, by the geographical distribution of the demand or by the existing contracts with customers and producers. The intuition is that the constrained quantity is relatively small with respect to what shippers can trade on the Flexibility Market. The competition is then fierce and both players engage in price competition which leads to zero profits.

4.2. Low Price Equilibrium at St Fergus and High Price Equilibrium at Bacton

Although in this situation players have positive profits at each terminal, the total profit of each player (including the neutrality charge) may be positive or negative. The total profit function in this case is linear in the nomination. The best reply of each player (profit functions are symmetric) to any nomination of the other is then to nominate the largest possible quantity at St Fergus[7] ($SF_i = D_i$) and the smallest possible quantity[8] at Bacton ($BA_i = 0$). Substituting the equilibrium nominations into the profit function of Pl.1 we obtain

$$P_1^* = (c - Min)\left(D_1 - C_1^{sf}\right) + (Max - c)C_1^{ba} - X_{ba}\frac{C_1^{sf} + C_1^{ba}}{X_{sf} + X_{ba}}$$

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[7] Take the profit function for Pl.1

$$P_1 = (c - Min)\left(SF_1 - C_1^{sf}\right) + (Max - c)\left(C_1^{ba} - BA_1\right) - [(c - Min)q + (Max - c)q]\frac{C_1^{sf} + C_1^{ba}}{X_{sf} + X_{ba}}$$

which is a linear function of BA_1. Substituting for SF_1 and q and differentiating with respect to the nomination at Bacton

$$\frac{\partial P_1}{\partial BA_1} = (Max - Min)\frac{-X_{sf} - X_{ba} + C_1^{sf} + C_1^{ba}}{X_{sf} + X_{ba}} = (Max - Min)\frac{-\left(C_2^{sf} + C_2^{ba}\right)}{X_{sf} + X_{ba}} < 0$$

The above derivative is negative since all the parameters are positive by definition.
The best reply of Pl.1 to any nomination of Pl.2 is nominating the largest possible quantity at St Fergus ($SF_1 = D_1$) and the smallest possible quantity at Bacton ($BA_1 = 0$).

[8] Note that $SF_1 = D_1 - BA_1$ by Assumption 4.

The equilibrium profit for Pl.1 is the sum of the equilibrium profits at St Fergus and Bacton less the neutrality charge. P_1^* is a function of the parameters and can be positive or negative, thus shippers may loose or gain depending on the situation.

If we are willing to impose that the same upper and lower bound apply to both players, $\left(C_1^{sf} = C_2^{sf}, C_1^{ba} = C_2^{ba}\right)$ then we will obtain[9] a more intuitive result

$P_1^* = \left(Max - c\right)\tfrac{1}{2}\left(D_1 - D_2\right)$

Under this extra assumption the shipper with the largest demand has positive profits in equilibrium. As intuition might suggest, given the symmetry of the game, the other player will have a loss of the same amount, since the system manager is cash neutral. If players have the same demand ($D_1 = D_2$) they will exactly compensate terminal profits with neutrality charges. This will result in both players having zero profits.

In this second kind of equilibrium nominations are completely determined by "strategic" reasons. At each terminal the constrained quantity is the largest possible and competition on the Flexibility Market is weak: players can freely charge the highest possible sell price and the lowest buy price trading the maximum possible quantities. In the nomination stage players can influence the amount of the constraint, the quantities that they can trade on the Flexibility Market ($SF_1 - C_1^{sf}; SF_2 - C_2^{sf}$) and thus their total profit. The equilibrium strategies are such that the constrained quantities and the traded quantities are maximised.

4.3. Low Price Equilibrium at St Fergus and Competitive Equilibrium at Bacton

Substituting for the equilibrium prices and quantities on the Flexibility Market and maximising the profit function with respect to BA_1, we have the same equilibrium nominations[10] $\left(BA_i^* = 0, SF_i^* = D_i\right)$.

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[9] Substituting in the profit function we have

$P_1 = (Max - c)\left(D_1 - C^{sf} - C^{ba}\right)$

then using $C_1^{sf} + C_2^{sf} + C_1^{ba} + C_2^{ba} = D_1 + D_2 \Rightarrow 2C^{sf} + 2C^{ba} = D_1 + D_2$

we get $P_1 = (Max - c)\,\tfrac{1}{2}\left(D_1 - D_2\right)$

[10] The overall profit of Pl.1 (and symmetrically for Pl.2) is

$$P_1 = (c - Min)\left(SF_1 - C_1^{sf}\right) + \frac{1}{2}\frac{(c - Min)q^2}{X_{sf} + BA_1 + BA_2} - \left[(c - Min)q + \frac{(c - Min)q^2}{X_{sf} + BA_1 + BA_2}\right]\frac{C_1^{sf} + BA_1 + \frac{1}{2}q}{X_{sf} + X_{ba}}$$

Substituting now the equilibrium strategies in the profit function for Pl. 1, we obtain

$$P_1 = (c - Min)\left[D_1 - C_1^{sf} - \frac{X_{ba}}{X_{sf}} C_1^{sf}\right]$$

The above equation can be positive or negative, depending on the parameters. As in the previous case, if we are willing to impose an "extra" condition $\left(C_1^{sf} = C_2^{sf}, C_1^{ba} = C_2^{ba}\right)$ then the equilibrium profit of Pl.1 will be

$$P_1 = (c - Min)\tfrac{1}{2}\left(D_1 - D_2\right)$$

This is the same equilibrium profit obtained with Low Price Equilibrium at St Fergus and High Price Equilibrium at Bacton. There is a transfer from the "small" player to the "big" player. In this kind of equilibrium a "small" capacity at one of the terminals (St Fergus) may be enough to trigger an extreme change in the nominations at both terminals.

4.4. Competitive equilibrium at St Fergus and High price Equilibrium at Bacton

The overall profit of Pl.1 in this case is

$$P_1 = (Max - c)\left(C_1^{ba} - BA_1\right) - (Max - c)q\frac{SF_1 - \tfrac{1}{2}q + C_1^{ba}}{X_{sf} + X_{ba}}$$

substituting for SF_1 and q in the profit function and maximising[11] we have

$$BA_1 = C_1^{ba} - D_2$$
$$SF_1 = D_1 + D_2 - C_1^{ba}$$

and similarly for Pl.2.

The optimal nominations do not depend on the nominations of the other player. The equilibrium profit depends on the structure of the parameters and may be positive or negative depending on the situation. The equilibrium profit has the usual specification:

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differentiating with respect to BA_1

$$\frac{\partial P_1}{\partial BA_1} = (c - Min)\left[\left(X_{sf} + X_{ba}\right)\left(\frac{-C_2^{sf} - BA_2}{\left(X_{sf} + BA_1 + BA_2\right)^2}\right)\right] < 0$$

Thus we have a corner solution with the nomination at Bacton equal to zero, independently on what the other player does.

[11] Under the constraints $BA_1 \geq 0$ and $SF_1 \geq 0$. These are always satisfied in equilibrium if parameters are well behaved ($C_i^{ba} \geq D_j$) and considering that the maximum quantity that shippers can input can not be realistically larger than the total demand for gas in the market ($C_i^{ba} \leq D_j + D_i$) .

$$P_1 = (Max - c)\frac{1}{2}(D_2 - D_1)$$

In this case there is a transfer from the large to the small shipper. Both shippers have zero profits at St Fergus but the small shipper may nominate less than the other player at Bacton, thus selling a larger quantity on the Flexibility Market. Consequently he can exploit more profitably the opportunities given by the locational constraint at Bacton.

4.5. Equilibria in the terminal game

Four possible kinds of equilibria, then, can be obtained in the terminal game (Table 1).

Table 1

		Bacton	
		"normal" capacity $X_{ba} < C_1^{ba} + C_2^{ba}$	*"high" capacity* $X_{ba} = C_1^{ba} + C_2^{ba}$
St Fergus	*"normal" capacity* $X_{sf} > C_1^{sf} + C_2^{sf}$	*(1)* Competitive Eq. at St Fergus Competitive Eq. at Bacton Any nomination	*(4)* Competitive Eq. At St Fergus High Price Eq. at Bacton $BA_1 = C_1^{ba} - D_2$ $SF_1 = D_1 + D_2 - C_1^{ba}$
	"low" capacity $X_{sf} = C_1^{sf} + C_2^{sf}$	*(3)* Low Price Eq at St Fergus Competitive Eq. at Bacton $SF_i = D_i$ $BA_i = 0$	*(2)* Low Price Eq at St Fergus High Price Eq. at Bacton $SF_i = D_i$ $BA_i = 0$
	Equilibrium (1) is described in paragraph 4.1, similarly for the others.		

A general conclusion is that if in equilibrium players make profits on the Flexibility Market, without considering the neutrality charge, then they have incentive to nominate strategically. In three out of four cases, players nominations are influenced by the possibility of forcing a constraint at the terminals. Only if both capacities are "normal" the equilibrium nominations will not be affected by this possibility.

Fortunately "normal" capacities are likely to occur most of the time and nominations are likely to be not affected by the strategic behaviour of the players in many circumstances.

In normal situations the "terminal game" can not explain the level of nominations. Nominations are likely to be determined by other factors which are deliberately kept out of the model or they will simply follow the gas demand, without giving any "false impression" to the transporter about the quantity that shippers want to input[12].

In particular situations, when at St Fergus the available capacity is thought to be extremely small and/or at Bacton the necessary quantity is thought to be extremely large, the outcome of the game is very different. On the Flexibility Market prices will fall at St Fergus and raise at Bacton and shippers will force significant constraints at both terminals.

As we mentioned before this is a zero sum game. Only one player can have positive profits. In "normal" situations, when the Flexibility market is in its Competitive Equilibrium at both terminals, both players will have zero (extra) profits and there will not be any cost to be shared via the neutrality charge. Out of "normal" situations one of the players may have positive profits. Clearly, who the winner is depends on the characteristics of the players.

At this point it may be of interest to describe what the game seems to suggest as a possible explanation of the events at St Fergus and Bacton. The maintenance and reinforcement projects undertaken in Summer 1998 reduced the available capacity at St Fergus and precluded Transco from buying gas at any other terminal than Bacton, increasing the required gas at Bacton. On the other hand a new associated gas field started input and increased the (minimum) quantity of gas that shippers wanted to input at St Fergus. These events, together with seasonal effects, may have induced shippers to think that, at least at one of the terminals, competition on the Flexibility Mechanism was weak enough to obtain positive profits. The next step may have been simply to increase as much as possible these profits using nominations to force a large constraint. Thus, the singular events at St Fergus and Bacton could be interpreted as the effects of the change from a Competitive Equilibrium to a High/Low Price Equilibrium at the terminals.

[12] After all this is what the Shippers' Licence requires!

5. St Fergus and Bacton Investigation

In September 1998, Ofgas initiated a formal investigation which was finally published in December 1999. A shift from a competitive to a "non competitive" equilibrium in Autumn 1998 seems to be supported by the observed shipper strategies.

Ofgas collected specific data on terminal nominations and carried out different tests[13]. The aim of the Authority was to find out if shippers were in breach of condition 2(2) and 2(3) of the Gas Shippers License. Ofgas incidentally showed that shippers strategies suddenly changed in Summer 1998 and were broadly in line with the predictions of our model.

The main result of our analysis is that shippers have a strong incentive to manipulate gas flows when capacities are not "normal". Ofgas showed that shippers indeed "ignored their obligation" and/or "deliberately chose to protect their interests by breaching regulatory obligations" and/or "exploited weakness in Transco Network Code to profit at the expenses of other shippers who have had to bear the costs of the events at St Fergus and Bacton"(Ofgas 1999b, p. 90).

Moreover Ofgas pointed out that "Transco's failure to complete the St Fergus re-enforcement on time contributed towards the events under investigation", as we suggest, and that "shipper actions were undertaken either to take advantage of the unique set of circumstances present in Summer and Autumn 1998 or in response to commercial pressures resulting from the actions of other shippers and Transco's failure". Consistently with our analysis of the shipper incentives "the investigation has not revealed any grounds for concluding that, in similar circumstances, those shippers will not behave the same way".

6. Conclusions

The topic of this paper has been the incentives of shippers during the singular events occurred at Bacton and St Fergus. We have given a description of the situation at the terminals -in Summer and Autumn 1998 and then we have defined a "terminal game". We characterised the Nash equilibria in pure strategies of the game.

[13] The idea is simply to compare differences between AT Link nominations, offshore nominations, capacity bookings, shippers' contractual nomination rights for different years before and after Autumn 1998.

Different equilibria may result from different combinations of the parameters of the model and we noted that the capacity at each terminal, in particular, plays a central role in defining the equilibrium outcome of the game. If the capacity at each terminal is not too high or too low the Flexibility Market will be in its Competitive Equilibrium and nominations will not be used strategically. On the other hand, if capacity at one of the terminals is very low or very high then the equilibrium outcome of the game will be different and *nominations will be used to force significant constraints*. This result is extremely important for the regulator.

We presented an intuitive interpretation of the events at St Fergus and Bacton and we concluded that the unusually low capacity at St Fergus and the rigidities in the supply of gas at the same terminal may have caused a sudden change in the equilibrium at both terminals. The equilibria of the terminal game seem to explain clearly why nominations where so peculiar in Summer and Autumn 1998. The anomalies in the buy and sell prices on the Flexibility Mechanism can also be explained by the outcomes of the terminal game. The Ofgas investigation, finally, gives evidence in favour of our explanation.

The events occurred in 1998 in the gas market showed that, given the "rules" of the market, there may be the opportunity for players to manipulate prices and "game" the trading arrangements to the detriment of other players, with the effect of frustrating the efforts of the authorities to regulate the market.

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