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ABSTRACT

Incentives and Coordination in Vertically Related Energy Markets*

by Augusto Rupérez Micola, Albert Banal Estañol and Derek W. Bunn

We present an agent-based model of a multi-tier energy market including gas shippers, electricity generators and retailers. We show how reward interdependence between strategic business units within a vertically integrated firm can increase its profits in oligopolistic energy markets. The effects are shown to be distinct from those of the raising rivals' costs model. In our case, higher prices relate to the nature of energy markets, which facilitate the emergence of financial netback effects.

Keywords: Agent-based modeling, energy markets, reward interdependence.
JEL Classification: C63, L22, L97.

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ZUSAMMENFASSUNG

Anreize und Koordination in vertikal integrierten Energiemärkten

Es wird ein Agenten-basiertes Modell eines Energiemarktes mit mehreren Ebenen der Wertschöpfungskette vorgestellt, das Gaslieferanten, Stromerzeuger und Händler berücksichtigt. Es kann gezeigt werden, wie ein vertikal integriertes Unternehmen, das auf oligopolistischen Energiemärkten agiert, die Honorierungsbeziehungen zwischen strategischen Geschäftsbereichen nutzen kann, um seine Gewinne zu steigern. Üblicherweise versuchen Firmen, die die gesamte Wertschöpfungskette integriert haben, ihren Vorteil dadurch zu nutzen, dass sie die Kosten der Wettbewerber durch Preisdiskriminierung erhöhen und den Markt gegen sie abschotten. Das ist in Energiemärkten nicht möglich. Im vorgestellten Modell wird ein Mechanismus gewählt, der den Charakteristika von Energiemärkten angepasst ist, um über Anreize denselben Endeffekt zu erzielen. Dieser beruht aber nicht auf der Marktabschottung, sondern auf einem finanziellen Valorisierungseffekt, bei dem Unternehmensbereiche am Beginn der Wertschöpfungskette die Preisspannen für die Unternehmensteile am oberen Ende vorgeben.

1 Introduction

This paper studies the vertical relationships between gas and electricity markets. Vertical relationships are those that involve an exchange between sequential stages of the value chain. In the energy industry, gas is an important input for electricity generation, and therefore wholesale natural gas and electricity markets are vertically interrelated. The same is true for wholesale and retail electricity markets since retailers buy electricity from wholesalers (Stern, 1998).

Vertical interactions may involve separate firms or different strategic business units (SBUs) within the same firm (Gulati et al., forthcoming). Vertical integration is widespread among European energy firms. Gas producers often own gas-fired power plants and many electricity firms consist of generation and retail SBUs (Midttun and Finon, 2004). Mergers between gas and electricity firms are relatively new in the United States but they are occurring at a rapid pace (Hunger, 2003). Moreover, the pace of merger activity appears to be accelerating as competition opportunities expand, incentive regulation diffuses more widely, and regulators have become less hostile to mergers (Joskow, 2000).[1]

Several streams of literature have studied the advantages as well as the disadvantages of vertical integration. Industrial economists have long argued that vertically related firms could strategically benefit from integrating.[2] Consider an intermediate market in which upstream and downstream firms interact. An integrated firm could gain market share and profits downstream by internalising production and refusing to sell (or selling at higher prices) to non-integrated downstream firms. Indeed, the firm's upstream opponents would then exert more market power at the margin and increase prices, thereby raising the costs of non-integrated downstream firms. Higher costs would become a competitive disadvantage in the downstream market against the vertically integrated firm, resulting in lost market shares. Trading internalisation would then increase both upstream and downstream prices and lead to higher integrated firm profits.

Studies of vertical relationships in energy markets (e.g. Granitz and Klein, 1996; Bushnell et al., 2005) often explain their findings using this foreclosure argument. However, the "raising rivals' costs" or "foreclosure" logic depends crucially on the firm's ability to internalise transactions and / or price discriminate in favour of its downstream SBU. In practice, wholesale energy markets are often compulsory, so trading internalisation is not feasible. Moreover, the standard energy market mechanism is the uniform price auction, which seems to make price differentiation impossible at the outset. Thus, two of the main resting points of the raising rivals' costs logic are often not present in energy markets.

This paper shows that energy firms may benefit from vertical integration by

[1] Note that the discussion here is about separation between the buying and selling sides of the wholesale market and quite different from regulatory unbundling of transmission infrastructures which is also widespread in the energy industry.

[2] Management scholars have also identified several motives for firms to integrate vertically (Harrigan, 1984, 1986), including the reduction of transaction costs (Williamson, 1975; Mahoney, 1992) and the reduction of corporate risk (Chatterjee et al., 1992).

using an alternative mechanism to foreclosure. The new mechanism is based on the presence of vertical incentives, which are widely used within energy firms, does not require internalisation or price discrimination and can be a way of circumventing regulatory constraints. One of the main contributions of this paper is to show that, although the new mechanism yields prices that are superficially equivalent to those of foreclosure, it operates in a fundamentally different manner.

The general reward system of an organisation plays a major role in the behavioural choices of its members. Bonuses tied to overall profits create incentives for cooperative behaviour both between individuals (Zander and Wolfe, 1964; Wageman and Baker, 1997) and across departments within a firm (Petersen, 1992; Kretschmer and Puranam, 2004). For individuals, the more interdependent the task, the more interdependent the reward system should be (Wageman and Baker, 1997) because it results in a positive relationship between effectiveness of the integrative devices and organisational performance (Lawrence and Lorsch, 1967). For firms, the importance of cooperation between SBUs grows with their interdependence (Gulati and Singh, 1998) and the higher the inter-unit synergies, the more useful are the collaborative incentives (Kretschmer and Puranam, 2004). Collaborative incentives, however, not only encourage cooperation but may also enhance free riding. Indeed, rewards based on aggregate profits hinder the identification of individual performances. As a consequence, individuals have more incentives to shirk hoping that the others will compensate (Holmstrom, 1982; Petersen, 1992).[3]

Despite the importance of collaborative incentives, the existing literature provides no guidance as to how they should be given to sequential SBUs in vertically integrated energy firms. In order to fill this gap, we consider a setting consisting of three sequential, multiple-unit, compulsory, uniform-price auctions representing a wholesale gas market, a wholesale electricity market and a retail electricity market. Although quite realistic, this complex trading environment presents a manifold of non-Pareto ranked Nash equilibria (von der Fehr and Harbord, 1993). To achieve predictions, we adopt an inductive selection method based on the adaptive theory of reinforcement learning put forward by Roth and Erev (1995).

The agent-based simulations show that coordination overcomes the potential disadvantages of broad collaborative incentives due to the large interdependences between energy markets. More importantly, our results uncover a simple but powerful mechanism to exert vertical market power. Using collaborative incentives that link the reward to the performance of the different SBUs, vertically integrated firms achieve higher prices and higher profit. These observable outcomes are consistent with the foreclosure argument. Closer inspection, however, reveals that the downstream SBU behaves less competitively, increasing downstream prices instead of taking advantage of the rivals' higher costs. Moreover, the upstream SBU behaves more competitively and takes advantage of the

[3] Broad incentives could also obstruct learning since it is more difficult to identify the most successful business strategies.

higher downstream prices. Rather than foreclosure, the results are due to a financial netback effect connecting the different markets in which downstream prices set the scope for the level of upstream prices.

The remainder of the paper is organised as follows: Section 2 outlines the agent-based simulation model; Section 3 presents the results, which are extended in Section 4; and a short discussion follows in Section 5.

2 The Computational Model

2.1 General Setting

The model incorporates key features of electricity and gas markets in the short-run. Consider three sequential, oligopolistic energy markets, a wholesale gas market, a wholesale electricity market and a retail electricity market. Gas sold in the wholesale gas market is an input for the generation of the electricity traded in the wholesale electricity market that, in turn, is sold to end users in the retail market. In the gas market, there are A upstream natural gas shippers that sell gas to B electricity generators. These generators buy gas to produce electricity and sell it in the electricity market to C electricity retailers. These, in turn, re-sell the electricity in the end-user market.[4] Marginal costs are assumed to be constant throughout and normalised to 0 for simplicity. There are no transmission constraints or storage.

Firms are capacity constrained and total capacity is equal across tiers. Moreover, firms in each tier are identical. If one denotes market capacity as K^m, the individual capacity of a gas shipper is $K^g = \frac{K^m}{A}$, that of an electricity generator is $K^e = \frac{K^m}{B}$ and that of an electricity retailer is $K^r = \frac{K^m}{C}$.

2.2 Market Rules

Goods are traded repeatedly along the value chain (Figure 1). In a given round t, three uniform price auctions take place sequentially, at the retail, wholesale electricity and wholesale gas levels. In each market i, $i \in \{r, e, g\}$, trading occurs as follows. Suppliers simultaneously submit single price bids at which they are willing to sell (up to) their capacity, starting from 0 and up to $\overline{P}^i(t)$, a maximum level for each market that will be explained below. An independent auctioneer determines a uniform market price ($P^i(t)$) by intersecting the *ad hoc* supply function with the corresponding inelastic demand curve, $Q^i(t)$. The independent auctioneer assigns full capacity, $q^i_j(t) = K^i$, to the m sellers that submitted bids below the market price; the remaining capacity, $q^i_j(t) = Q^i(t) - mK^i$, to the seller that submitted a bid equal to the market price;[5] and zero sales, $q^i_j(t) = 0$, to the sellers that submitted bids above the market price. The market price and the individual quantities are then communicated independently to each supplier.

[4] Although relevant in the medium term, we do not deal with entry and exit of firms, variation in end-user demand or capacity expansion.

[5] In case of a tie, the selling firm is selected randomly.

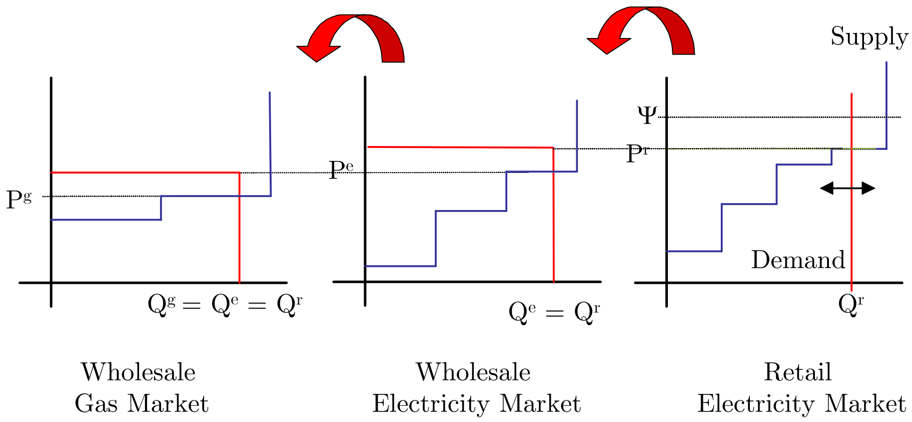

Figure 1: Sequential Clearing of the Market Simulation

At the retail level, the inelastic market demand $Q^r(t)$ is drawn, independently in each round, from a uniform distribution in $[\bar{Q}^r - \varepsilon,\, \bar{Q}^r + \varepsilon]$, where $\bar{Q}^r$ is the expected end-user demand and ε accounts for the small uncertainty typical in day-ahead electricity forecasting.[6] Possible retail prices are bounded in $(0, \Psi]$, with Ψ being the maximum reasonable end-user price and therefore $\overline{P}^r(t) = \Psi$.[7] Retail commitments are honoured with purchases in the wholesale electricity market. The retailers' aggregated demand curve in the wholesale electricity market is therefore equal to the market demand at the retail level if the price is below the retail market price, $Q^e(t) = Q^r(t)$ if $P^e(t) \leq P^r(t)$, and zero otherwise, $Q^e(t) = 0$ if $P^e(t) > P^r(t)$. Accordingly, electricity generators submit bids bounded between $(0, P^r(t)]$ and therefore $\overline{P}^e(t) = P^r(t)$. The generators' aggregated demand curve in the wholesale gas market is equal to the market demand at the retail level if the price is below the wholesale electricity market price, $Q^g(t) = Q^r(t)$ if $P^g(t) \leq P^e(t)$, and zero otherwise, $Q^g(t) = 0$ if $P^g(t) > P^e(t)$. Gas shippers submit bids bounded between $(0, P^e(t)]$ and therefore $\overline{P}^g(t) = P^e(t)$.

By construction, the end-user market demand in each round t determines the volumes traded in the wholesale markets,

$$Q^g(t) = Q^e(t) = Q^r(t).$$

Moreover, the three prices are vertically related,

$$P^g(t) \leq P^e(t) \leq P^r(t).$$

[6] Similarly to real electricity markets, the model also includes some excess capacity, i.e. $\bar{Q}^r + \varepsilon < K^m$.

[7] This upper price ceiling can be understood as a limit triggering regulatory intervention or the cost of alternative, expensive, peaking load fuels to which the system administrator could switch at short notice if gas prices exceed Ψ.

Profits for each firm type are

$$\begin{aligned}
\pi_a^g(t) &= P^g(t)\ q_a^g(t) && \text{for } a = 1...A && (1)\\
\pi_b^e(t) &= [P^e(t) - P^g(t)]\, q_b^e(t) && \text{for } b = 1...B && (2)\\
\pi_c^r(t) &= [P^r(t) - P^e(t)]\ q_c^r(t) && \text{for } c = 1...C. && (3)
\end{aligned}$$

There are apparently no other multi-tier simulations driven by netback principles in the energy modelling literature. This new method is the paper's main methodological contribution.

2.3 Vertical Integration and Reward Interdependence

In the basic model, it is assumed that a shipper (without loss of generality, $a = 1$) and a generator ($b = 1$) are vertically integrated in that they belong to the same organisational structure, i.e. the same firm. Trading is compulsory and firms are not allowed to price discriminate. However, the vertically integrated firm can influence its traders' decisions by giving them incentives that depend on the profits of their own unit but also on the other unit,

$$\begin{aligned}
\Omega_1^g(t) &= (1-\alpha)\pi_1^g(t) + \alpha\pi_1^e(t) \text{ and} && (4)\\
\Omega_1^e(t) &= (1-\alpha)\pi_1^e(t) + \alpha\pi_1^g(t), && (5)
\end{aligned}$$

where $\alpha = \{0, .01, .02, ..., .5\}$ parameterises the "reward interdependence" (Wageman and Baker, 1997) between the two vertically related SBUs. A small α represents narrow incentives, which become broader for growing α. Note that for $\alpha = 0$, $\Omega_1^g(t) = \pi_1^g(t)$ and $\Omega_1^e(t) = \pi_1^e(t)$, and SBUs trade as if they were independent. For tractability and realism, the model is restricted to the case in which SBUs are rewarded predominantly on the basis of their own performance, i.e. $\alpha \leq 0.5$.

Managers in the non-integrated firms do not have reward interdependences so their incentives are correlated to their own unit performance,

$$\Omega_j^i(t) = \pi_j^i(t) \text{ for either } i = \{g, e\} \text{ and } j \neq 1 \text{ or } i = r \text{ and any } j. \qquad (6)$$

2.4 Bidding and Behavioural Learning

The feasible price offer domain for each firm is approximated by a discrete grid consisting of a fixed number of possible actions (independent of t). In each trading period, suppliers choose among S^i possible prices, equally spaced between the minimum and the maximum reasonable price offer, $(0, \overline{P}^i(t)]$, where $\overline{P}^r(t) = \Psi$, $\overline{P}^e(t) = P^r(t)$ and $\overline{P}^g(t) = P^e(t)$. Hence, the set of possible actions, A^i at a tier i in a period t is given by

$$A^i(t) = s * \left(\frac{\overline{P}^i(t)}{S^i}\right) \; for \; s = 1, ..., S^i. \qquad (7)$$

Notice that in the wholesale markets, the sets of possible prices change over time. In all markets, actions with a lower s are more competitive or closer to the marginal costs.

Each trader plays each possible action with a given likelihood or "propensity", $r^i_{j,s}$. The probability that an agent j plays an action s is given by its propensity divided by the sum of the propensities of all possible actions,

$$p^i_{j,s}(t) = \frac{r^i_{j,s}(t)}{\sum_{s=1}^{S^i} r^i_{j,s}(t)}. \tag{8}$$

Propensities for all actions are initialised to the firms' maximum profit, i.e. $r^i_{j,s}(1) = \Psi K^i$ for all s, so that all actions have the same initial probability, $p^i_{j,s}(1) = \frac{1}{S^i}$ for all s and i.

At the end of each round, traders reinforce the selected action, k, through an increase in its propensity equivalent to the performance, $\Omega^i_j(t)$. Moreover, actions that are similar, i.e. $k-1$ and $k+1$, are also reinforced, by $\Omega^i_j(t) * (1-\delta)$ where $0 < \delta < 1$ ("persistent local experimentation" in the terminology of Roth and Erev). All propensities are discounted by γ ("gradual forgetting") and actions whose probability falls below a certain threshold are removed from the space of choice ("extinction in finite time"). Summarising, the pre-extinction propensities $r^{i\prime}_{j,s}$ are

$$r^{i\prime}_{j,s}(t) = \begin{cases} (1-\gamma) r^i_{j,s}(t-1) + \Omega^i_j(t) & \text{if } s = k \\ (1-\gamma) r^i_{j,s}(t-1) + (1-\delta)\ \Omega^i_j(t) & \text{if } s = k-1 \text{ or } s = k+1 \\ (1-\gamma) r^i_{j,s}(t-1) & \text{if } s \neq k-1,\ s \neq k \text{ and } s \neq k+1 \end{cases} \tag{9}$$

and the final propensities, corrected by the extinction feature, are

$$r^i_{j,s}(t) = r^{i\prime}_{j,s}(t) I_{\left\{\frac{r^{i\prime}_{j,s}(t)}{\sum_{s=1}^{S^i} r^{i\prime}_{j,s}(t)} > \mu\right\}} \tag{10}$$

where I is an indicator function that takes value 1 if the condition between brackets is satisfied and zero otherwise.

2.5 Simulation Parameters

In the first instance, industry structure is simplified to consist of two gas shippers, three generators and four retailers (i.e. $A = 2$; $B = 3$; $C = 4$). Gas shippers will be referred to as G_1 and G_2, generators as E_1, E_2 and E_3 and retailers as R_1, R_2, R_3 and R_4. As mentioned above, in the base case, the two vertically integrated entities are G_1 and E_1. Total capacity is set to $K^m = 300$, so that the individual capacity of a gas shipper is $K^g = 150$, of an electricity generator is $K^e = 100$ and of an electricity retailer is $K^r = 75$. Expected market demand is $\bar{Q}^r = 240$ and $\varepsilon = 5$, so that there is an expected excess capacity of 20% with about 5% uncertainty in the day-ahead forecasted demand, approximately of the magnitude observed in energy markets. The end-user reasonable price ceiling is set at $\Psi = 200$.

Fifty-one reward interdependence cases $\alpha = \{0, .01, .02, .03, ..., .50\}$ are studied and 50 simulation runs consisting of 500 periods were carried out for each of them. The data presented consists of averages for the last 200 periods, for each run and each case. These represent long term stationary values[8] to which the three markets converge, based on the R&E reinforcement parameters.[9]

3 Results

3.1 Market Prices and Profits

Figures 2, 3 and 4 report the 95% mean confidence intervals of simulated prices in the three sequential markets when G_1 and E_1 are vertically integrated. They present the relationship between reward interdependence α (on the horizontal axis) and P^g, P^e and P^r (on the vertical axis), respectively. As shown by Figure 2, shippers coordinate on higher prices as α grows. The lack of reward interdependences ($\alpha = 0$) results in an average gas price of approximately 59 monetary units, which increases to about 63 units for $\alpha = .50$. Figure 3 shows that wholesale electricity prices are also clearly influenced by α. When $\alpha = 0$, the simulation produces an average price of about 83 units, for $\alpha = .50$ it is about 93. Finally, Figure 4 presents retail price levels not varying systematically as a function of α. The structure of incentives in the vertically integrated firm does not influence P^r.

By construction, the expected absolute size of the resource rent shared by the three market tiers is constant ($= \Psi\bar{Q}^r$). What changes is the proportion accruing to each of them. Increasing P^g with constant production costs results in a higher proportion of the rent staying with the gas duopoly. Taking Figures 2, 3 and 4 together, P^e increases compensate to some extent the higher P^g, but that is not the case for P^r. Market prices seem to indicate that generators and, particularly, retailers are subject to shippers foreclosure emerging from reward interdependences between G_1 and E_1.

Moreover, α influences both the profits of the vertically integrated firm and its two SBUs (Figure 5). Broader vertical incentives increase the G_1's profit but decrease those of E_1. The resulting overall corporate profit ($\pi_1^g + \pi_1^e$) is clearly increasing from about 9,000 monetary units to over 10,000. Thus, there is a positive relationship between vertical reward interdependence across the two strategic business units, the firm's overall profit and the concentration of profit upstream.

3.2 Price-setting Behaviour

In a uniform price auction, prices are determined by the last bid on the merit order, and therefore being a marginal seller is a necessary condition to influence prices. Hence, the frequency with which each firm takes the marginal

[8] Augmented Dickey-Fuller (ADF) reject the null unit root hypotheses with $p < .01$.

[9] The R&E parameters used throughout are $\gamma = 0.01$, $\delta = 0.5$ and $\mu = 0.0005$.

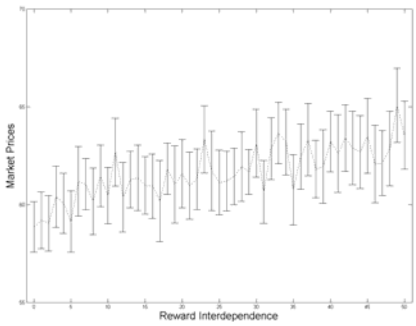

Figure 2: Natural Gas Prices

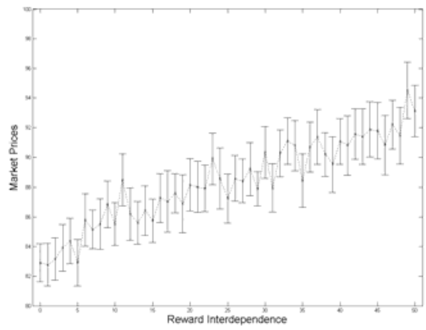

Figure 3: Wholesale Electricity Prices

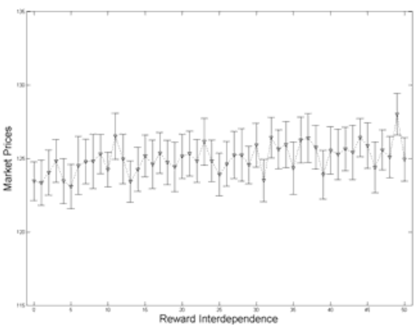

Figure 4: Retail Electricity Prices

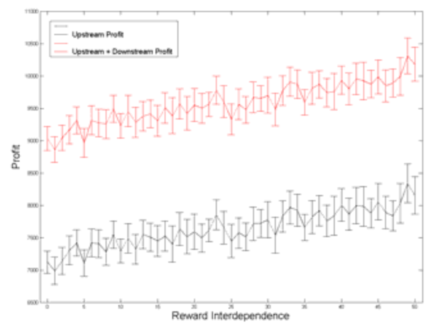

Figure 5: Profit, Vertically Integrated Firm

Figure 2: Natural Gas Prices; Figure 3: Wholesale Electricity Prices; Figure 4: Retail Electricity Prices, Figure 5: Profit, Vertically Integrated Firm.

price-setting position on the supply merit order represents one dimension of its predisposition to exert market power (at the expense of market share). The raising rivals' cost logic would require G_1 to concede market power upstream and E_1 to undercut their rivals downstream. Following that argument, G_1 and E_1 should be setting prices less often for a higher α.

The vertical axes in Figures 6 and 7, provide averages over the frequencies with which each market player sets the price in the 200 end-of-simulation periods averaged across the 50 simulation runs. An increase in the reward interdependence between G_1 and E_1 creates two simultaneous effects. On the one hand, the proportion of trading periods in which G_1 sets prices goes down from about 50% when $\alpha = 0$ to around 41%, when $\alpha = 0.5$ (Figure 6). Consistent with the foreclosure predictions, reward interdependence provides incentives for the G_1 to influence P^g less often at the benefit of G_2.

On the other hand, the proportion of trading periods in which E_1 is price-setting increases from 33% when $\alpha = 0$ to about 50% for $\alpha = 0.5$ (Figure 7). Hence there is a positive relationship between α and E_1's predisposition to exert market power, which is *at odds* with the foreclosure prediction. Since E_1 bidding behaviour results in lower profits downstream but higher overall profits, there is an alternative mechanism to foreclosure that, operating via α, links E_1's behaviour to the overall firm profit.

3.3 Latent Intensity of Competition

Figures 8 and 9 characterise the S^i end-of-simulation individual latent probability distributions from which agents choose. The concentration of probabilities is largely invariant across a large number of periods once the market reaches convergence, so the distributions at $t = 500$ are an indication of the firms' long-term mixed strategies.

On the horizontal axes, strategies are identified with numbers ranging from 1 for the more competitive to 100 for the highest possible bid. Cumulative probabilities for the three tiers are calculated on the vertical axes for each element of the strategy space. The curves summarise the cumulative bidding probabilities for $\alpha = 0$ and $\alpha = 0.5$, averaged across the 50 simulation runs. In all cases, probabilities concentrated on lower (higher) strategies result on the agents behaving more (less) competitively. That is, curve movements to the "Northwest - NW" and "Southeast - SE" are indications of more and less competition, respectively. The figures offer a number of insights linking individual probability distributions to market outcomes:

(a) The shippers' distribution are very similar under $\alpha = 0$ but become different under $\alpha = 0.5$ (Figure 8). Reward interdependence incentives in the vertically integrated firm have the effect of making G_1 bids more competitive (NW movement). Moreover, G_2's prior is slightly less competitive (movement to SE). Gas firms behave as predicted by the foreclosure argument and concentrate market power on G_2.

(b) Probability distributions on the generator side are similar for all firms under $\alpha = 0$ (Figure 9). However, when $\alpha = 0.5$, E_1 tends to exert more

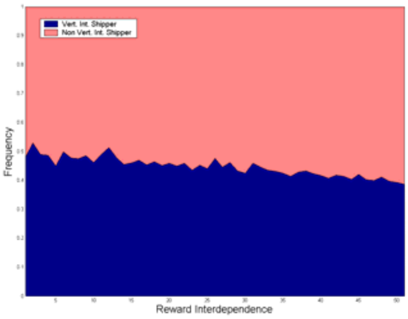

Figure 6: Shippers' Price-setting Frequencies

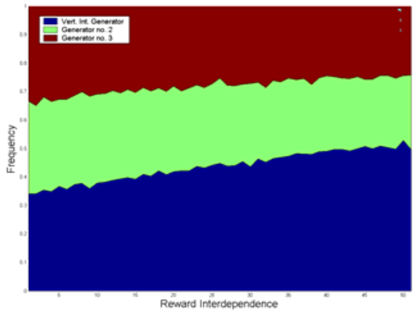

Figure 7: Generators' Price-setting Frequencies

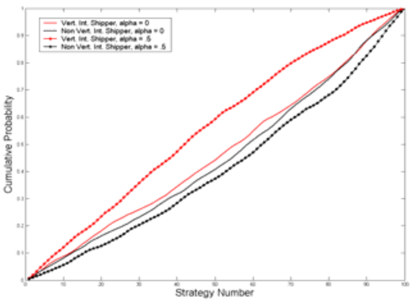

Figure 8: End of Simulation Distribution of Strategies of Shippers

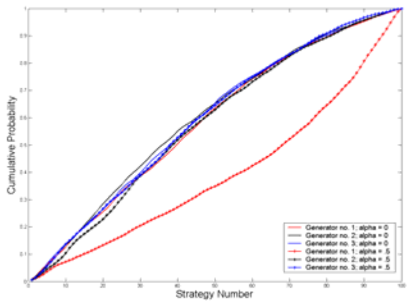

Figure 9: End of Simulation Distribution of Strategies of Generators

Figure 3: Shippers' Price-setting Frequencies, Figure 7: Generators' Price-setting Frequencies; Figure 8: End of Simulation Distribution of Strategies of Shippers; Figure 9: End of Simulation Distribution of Strategies of Generators.

market power than that of its competitors, E_2 and E_3 (movement to the SE). This does not fit into the raising rivals' costs logic and suggests that the coordination mechanism is driven by reward interdependences and the ability of the generating SBU to benefit from higher natural gas prices.

3.4 Firm Learning, Behaviour and Market Outcomes

Through their dynamic trading interaction, firms learn to prioritise those bidding strategies that achieve higher payoffs and choose them more often. Each firm's price setting frequency is related to that prioritisation of the strategies and, once marginal supply and demand patterns are established, price regularities follow. The results suggest a link between α, firm learning, trading behaviour and market outcomes.

As α increases, E_1 sets P^e more often and manages to increase it markedly. Being at the margin more often is clearly at the expense of market share, reducing π_1^e. However, due to the netback market clearing procedure, a higher P^e provides more scope for higher P^g's. G_1 then lets G_2 exert more market power and increase P^g. G_1, on the other hand, trades on the base-load more often, increasing its market share and profitability. The rise in upstream profits compensates the losses downstream and therefore $\pi_1^g + \pi_1^e$ increase.

The simulations' logic is therefore quite different from foreclosure. The vertically integrated firm learns to gain market share in the upstream market and gives up market share downstream in exchange for higher P^e. The identification of this mechanism relating the market clearing sequence to vertical coordination via broad reward interdependences is this paper's main economic policy contribution.

4 Extensions

This section checks whether the results depend on the position of the vertically integrated SBUs in the value chain and on the market concentration levels.

4.1 Alternative Positions of the Vertically Integrated Firm

New simulations analyse reward interdependences between G_1 and R_1 plus those between E_1 and R_1, keeping all other parameters constant. Table 1 and Figures 10 and 11 summarise results for $\alpha = 0$ and $\alpha = .5$ in these new simulations.

Two interesting findings emerge from the simulated consequences of a merger between a natural gas shipper and a retailer, complementing and extending the previous results. First, retail prices, P^r, increase from an average of 124 for $\alpha = 0$ to 144 when $\alpha = .5$ (+16.12%), compared to a negligible change when there is a merger between a shipper and a generator (+0.88%). Reward interdependence with G_1 induces R_1 to implement a less competitive–mixed strategy through which the firm becomes price setting more often with P^r increasing steadily.

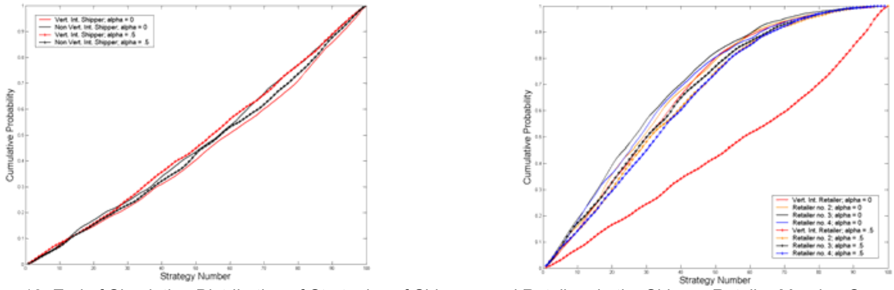

Figure 10: End of Simulation Distribution of Strategies of Shippers and Retailers in the Shipper-Retailer Merging Case

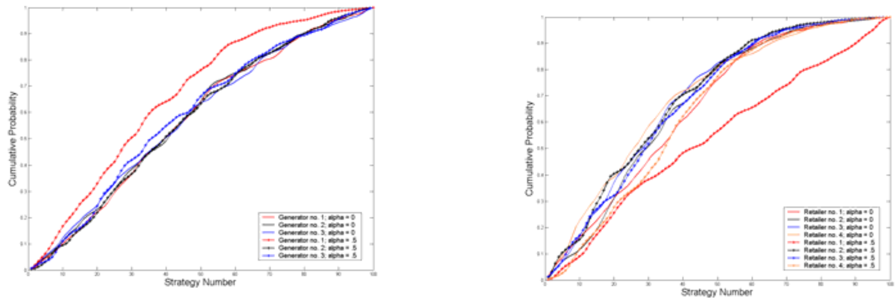

Figure 11: End of Simulation Distribution of Strategies of Generators and Retailers in the Generator-Retailer Merging case

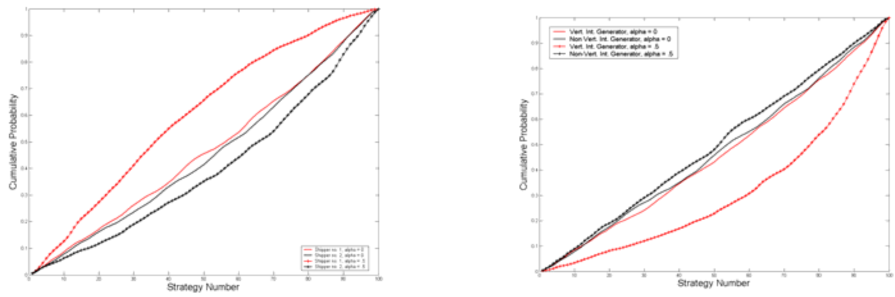

Figure 12: End of Simulation Distribution of Strategies Shippers and of Generators for a Symmetric Market Structure

Figure 4: End of Simulation Distribution of Strategies of Shippers and Retailers in the Shipper-Retailer Merging Case; Figure 11: End of Simulation Distribution of Strategies of Generators and Retailers in the Shipper-Retailer Merging Case; Figure 12: End of Simulation Distribution of Strategies of Shippers and Generators for a Symmetric Market Structure.

	$\mathbf{P}^g$	$\mathbf{P}^e$	$\mathbf{P}^r$
Separation ($\boldsymbol{\alpha} = \mathbf{0}$)	59	83	124
Shipper-Generator ($\boldsymbol{\alpha} = .\mathbf{5}$)	63 +6.77%	93 +12.04%	125 +0.88%
Shipper-Retailer ($\boldsymbol{\alpha} = .\mathbf{5}$)	67 +15%	95 +14.45%	144 +16.12%
Generator-Retailer ($\boldsymbol{\alpha} = .\mathbf{5}$)	63 +6.77%	88 +6.02%	136 +9.67%

Table 1: Average Prices, A=2; B =3; C=4

	$\mathbf{P}^g$	$\mathbf{P}^e$	$\mathbf{P}^r$
Separation ($\boldsymbol{\alpha} = \mathbf{0}$)	71	100	143
Shipper-Generator ($\boldsymbol{\alpha} = .\mathbf{5}$)	73 +2.81%	108 +8%	143 0%

Table 2: Average Prices, A=B=C=2.

The second result is that wholesale prices also increase. The P^r effect moves up in the value chain. It translates into higher P^e and P^g from about 83 to 95 (+14.45%) and 59 to 67 (+15%), respectively. Reward interdependences hurt end users in this case. Although the E_1, E_2, E_3 probability priors and trading behaviour change little, G_1 becomes more competitive and facilitates the exertion of G_2 market power (Figure 10). That effect results in a $P^e - P^g$ difference similar to the initial case. Moreover, by construction, higher P^r widens the $[0, P^r]$ range within which P^e is determined. With a constant number of bidding strategies, S^i, similar generators' probability distributions result in higher P^e as P^r increases.

The simulations assuming integration between E_1 and R_1 show increases in P^e (+6.02%) and P^r (+9.67). R_1 manages to leverage its overall revenue and implement a more collusive mixed strategy that expands the base for higher P^e. E_1, on the other hand, bids more often on the base part of the load curve – more competitively. That results in E_2 and E_3 setting (higher) P^e (Figure 11). It is interesting to note how the non-integrated G_1 and G_2 capture a large proportion of that rent through a P^g increase of 6.77%.

4.2 Symmetric Market Structure Across Tiers

In the analysis above, market structure remained invariable and progressively less concentrated ($A = 2$; $B = 3$; $C = 4$). The vertical foreclosure literature suggests that higher upstream concentration is an important element of the firms' ability to exert vertical market power. This conclusion is checked by simulating a market structure symmetric across tiers.

Table 2 summarises market prices for $A = B = C = 2$. Vertical integration between a shipper and a generator leads, as in the asymmetric case, to higher wholesale electricity and natural gas prices but not higher end user prices. Higher prices with increasing α, therefore, hinge on the market clearing sequence rather than on market structure asymmetries.

The panels in Figure 12 present the strategy cumulative probability distributions in this setting. The left hand side panel shows the probability distribution for the vertically integrated firm's upstream SBUs moving to the NW when α changes from $\alpha = 0$ to $\alpha = .5$, complemented again by the independent firm's SE movement. The right hand side panel offers evidence of the downstream firm positioning itself so as to set higher prices when $\alpha = .5$. While there is no variation in the independent firm's bidding strategies, the vertically integrated firm's cumulative probability distribution moves to the SE.

These results strengthen the chapter's main insight of higher prices emerging through market sequence coordination, rather than via the foreclosure logic. They also suggest that market structure asymmetries are not a necessary condition for the mechanism to operate.[10]

5 Discussion

The existence of interdependences between vertically related SBUs has become a bedrock in the business strategy literature, yet we know relatively little about the underlying forces that create these interdependences and their effects. A set of agent-based simulations identifies one such effect in the de-regulated energy industry. Reward interdependences between SBUs lead to trading coordination and higher prices. Under tight reward interdependence structures, vertically integrated firms give up profits downstream in order to increase the scope for upstream profits. This leads to strategic behaviour that superficially has the appearance of foreclosure but that is based on a quite different principle. This paper adds to the preceding literature in at least three ways.

On the methodological side, there are apparently no other multi-tier energy simulations driven by netback principles in the literature. Industry wisdom suggests that this type of market clearing characterises better the reciprocal relationships between electricity and gas prices than conventional supply chain models.

The second contribution relates to the literature on the sources of vertical market power in the energy industry (e.g. Bushnell et al., 2005; Granitz and Klein, 1996; Kühn and Machado, 2004). The financial dependence between electricity and natural gas markets is not captured in the foreclosure argument, where causal pricing relationships are sequential from the upstream to the downstream segment. The simulations unveil a new mechanism that suggests a solution to the puzzle of how vertical market power is observed in some energy markets where it should not really appear. Netback, i.e. "spark spread", pricing means that wholesale gas and electricity prices are determined

[10] Results under symmetrical $A = B = C = 3$ and $A = B = C = 4$ assumptions were qualitatively equivalent to those of $A = B = C = 2$.

in a down-to-upstream sequence. Hence, vertical market power can occur in compulsory, uniform price auction, without trading internalisation and price discrimination.

Thirdly, the research identifies a link between internal incentive structures, SBU behaviour and firm performance. Reward interdependence has been shown to be an instrument leading to market power, via higher vertical SBU coordination. Ways in which reward interdependences can be articulated include direct bonuses and stock options, and casual evidence indicates that these are widespread in the energy industry. It is interesting to note that such reward interdependence contracts are internal to the firm and, hence, normally fall outside the scope for regulatory intervention. Whether firms use them explicitly as a way of aligning their interests to those of their SBU employees is an interesting question for future empirical work.

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