Do Firms Sell Forward for Strategic Reasons? An Application to the Wholesale Market for Natural Gas[*]

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Abstract

We develop an empirical strategy to test whether oligopolistic firms use forward contracts for strategic motives, for risk-hedging, or for both. The test builds on a model of the interaction of risk-averse firms that compete in futures and spot markets. We show that the effects of an increase in the number of players on equilibrium inverse hedge ratios crucially depend on the firms' ability to infer rivals' positions from forward prices. This result provides the analyst with a way to identify whether strategic considerations are important at motivating firms to sell futures. Using data from the Dutch wholesale market for natural gas where we observe the number of players, spot and forward sales, and churn rates, we find evidence that strategic reasons play an important role at explaining the observed firms' (inverse) hedge ratios. In addition, the data lend support to the existence of a learning effect by wholesalers.

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1 Introduction

Electricity and gas industries used to consist of vertically integrated monopolies, state-owned or not, operating under regulatory constraints. Each country, or region, used to have a single monopolistic importer, which typically owned the transmission network and either sold directly to consumers or to downstream distribution monopolies. One-to-one negotiations was the standard of trade throughout the value chain and the different parties were typically subject to long-lasting contractual relationships.

Short- and long-run efficiency considerations have led energy policy makers worldwide to gradually restructure energy markets. A key feature has been the vertical separation of production and transportation activities. This separation has enabled the creation of spot commodity markets. The *Pool* in the U.K., ISO in California, the real-time PJM market in Pennsylvania, New Jersey and Maryland, ERCOT in Texas, EPEXSPOT in Austria, France, Germany and Switzerland are examples in electricity; NBP in the U.K., The Henry Hub in the U.S., Zeebrugge in Belgium and TTF in The Netherlands are examples in natural gas.[1]

The 2000-2001 electricity crisis in California has revealed that the combined prevalence of price risks and market power in energy markets may have fatal consequences when risk-hedging mechanisms are absent (Bushnell, 2004). As a consequence, in nowadays restructuring, it is widely held that spot markets must necessarily be complemented with forward markets (Ausubel and Cramton, 2009). In an attempt to aid firms to contract forward, platforms have been created where property rights can easily be transferred among the participants. In addition, in some markets we have witnessed the creation of futures exchanges. Examples of markets for electricity futures are CALPX in California and EEX Power Derivatives in Austria, France, Germany and Switzerland; ENDEX runs a market for natural gas futures in The Netherlands, as well as markets for U.K. and Dutch electricity futures.

Facilitating forward transactions has the potential to deliver social benefits on two accounts. First, forward markets address the need of a firm *to hedge risks*. Forward contracts typically specify fixed delivery prices so risk-averse market participants can mitigate their exposure to price shocks in the spot market by acquiring a portfolio of futures. Central results in the literature relate to the decisions of a competitive risk-averse firm facing price uncertainty (see e.g Baron, 1970; Holthausen, 1979; and Sandmo, 1971). In the absence of a futures market, this type of firm turns out to restrict its output relative to what the firm would produce under certainty. The opening of a forward market restores the level of output that would prevail if uncertainty were removed.

Forward markets can deliver further social benefits in situations where firms wish to sell forward for *strategic* reasons. In their influential paper, Allaz and Vila (1993) show that forward contracts confer competitive advantages to Cournot firms so, even when there is no uncertainty at all about future market conditions, firms have incentives to engage in forward trading. By selling futures contracts at a pre-specified price, a firm ends up attaching a

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[1]These gas hubs also allow for forward trading.

lower value to a high spot market price. As a result, a firm that sells forward is indirectly committing to an aggressive behavior in the spot market so competitors respond by adopting a compliant spot market strategy. This raises firm profitability. Selling forward exhibits however the characteristics of a prisoner's dilemma. Because every seller has incentives to sell (part of) its output forward, the resulting equilibrium aggregate production is higher (and the price lower) than in the absence of a futures market.[2]

To the best of our knowledge, whether the forward market institution *by itself* is successful on these two fronts at a time is not well understood yet. One obvious reason for this lack of knowledge is that a great deal of the contracts we have observed in gas and electricity markets has not been dictated by market forces but imposed by the regulators in the form of gas release programs or vesting electricity contracts (Wolfram, 1999). A second reason is that disentangling the two rationales motivating firms to sell forward –strategic commitment and risk-hedging– from the field data is, at least, methodologically challenging; in addition, it requires a wealth of data on forward transactions. In this paper we propose an empirical strategy to separate the various incentives behind the contract cover of a firm and we apply it to the Dutch natural gas market.

That forward contracting serves to expand output beyond what risk hedging in isolation does has been subject to criticism from various angles. One objection, which serves as a basis to build our empirical strategy, is that the result in Allaz and Vila (1993) obtains under the assumption that sellers are able to perfectly observe each other's forward (net) positions (Kao and Hughes, 1997). It is not clear at all this assumption is verified in real-world energy markets. First of all, where they exist, markets for natural gas and electricity futures are designed to be anonymous and this anonymity puts impediments for the positions of rival firms to be observed with good precision. Strictly speaking, of course, it would be sufficient to just observe the forward price to correctly infer rivals' aggregate forward position. However, the process of price discovery is far from simple. First of all, some (or all) of the transactions in these markets are made over the counter (OTC) because organized exchanges are often bypassed by the traders or totally lacking. OTC markets are relatively non-transparent and price indices for these markets, typically provided by broker associations of by specialized agencies, are based on a limited pool of recent transactions. By construction, these price indices are complex statistics so it is unclear how much a participant in the market can learn about rivals' deviations from equilibrium play. The centralized futures markets are more transparent; however, seen that arbitrage opportunities across the exchanges and the OTC markets are not fully exhausted, the existence of conflicting price signals (the law of one price fails) further troubles the quality of the inferences market participants can make (see e.g. Anderson, Hu, Winchester, 2007; Bushnell, 2007).[3]

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[2]The model of Allaz and Vila has been adapted to suit the particular organization of power markets in the U.K. by von der Fehr and Harbord (1992), Powell (1993), Newbery (1998) and Green (1999).

[3]An additional issue adding to the debate has to do with the number of periods the contract market opens. Ferreira (2003) studies a market where firms are able to sell in a futures market at infinitely many moments prior to the spot market and concludes, differently from Allaz and Vila, that the availability of futures markets may have an anti-competitive effect in oligopolistic markets. Finally, there is a number

Our structural methodology to test whether firms use forward contracts for strategic reasons and/or for risk hedging motives builds on the idea that commitment has value only if it is observable. We develop a model of the interaction of risk-averse firms that compete in a forward market before they set quantities in a spot market. The key aspect of the modelling is that it introduces the extent to which forward positions are observable (or correctly inferred from the forward price) as a structural parameter that can be estimated. The new model gains in flexibility to fit the data and nests the extreme cases of full transparency (perfect observability) and complete opacity of the forward market (no observability at all).

We show how to estimate the model using data on total sales, forward sales, churn ratios and numbers of wholesalers. Identification of the key parameter requires variation in the number of active wholesale firms. In our data this variation comes from entry of new players in the market but in other studies the analyst could exploit variation in the number of wholesalers across regional/separated markets. The empirical test exploits the effect that changes in the number of players has on the so-called *inverse hedge ratio* –defined as the total-to-forward-sales ratio.[4] Interestingly, for the linear model this ratio is independent of demand intercept and marginal cost so firms with similar aversion to risk hedge in the same way no matter their marginal costs of production and the state of the demand.

In a nutshell, the identification arguments are as follows. The incentives of a firm to trade forward are shaped by three forces. The first two, the risk-hedging effect and the strategic effect, are pro-contracts. The third is a *price* effect that arises because offering forward contracts lowers the spot price and, by arbitrage, the forward price too. This price effect actually puts a downward pressure on firm's (expected) profits and therefore makes forward contracting less attractive.[5]

When the forward market is relatively opaque so that players have a difficult time to infer deviations from equilibrium play, the strategic effect is hardly present and the contract cover of a firm is the outcome of trading off the risk-hedging effect against the price effect. In that situation, as the number of competitors rises, the residual demand of an individual firm becomes less susceptible to demand shocks. Therefore, the incentive to hedge becomes weaker if more suppliers enter the market. The price effect, by contrast, stays constant if the number of suppliers in the market increases. As a result, by virtue of these two forces, the inverse hedge ratio increases in the number of competitors.

If however the forward market is relatively transparent so that price and/or the forward positions of the rival firms are regularly and precisely observed, in addition to the risk-hedging and the price effects, a significant role is played by the strategic effect. This strategic effect turns out to be stronger as more players are around. This is because the (marginal)

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of papers pointing out that the market mechanism may be important for the result. Mahenc and Salanié (2006) show that if firms compete in prices instead of quantities in a market with product differentiation, the presence of a futures market leads to a less competitive outcome. See also Newbery (1998) and Green (1999), who study models where firms compete in the spot market using supply schedules.

[4]To be precise, inverse hedge ratio = (spot sales + forward sales) / forward sales .

[5]Indeed, a risk-neutral monopolist would never engage in forward contracting (see Tirole, 2006).

gains from affecting the rivals' spot market strategy rise with the number of competitors. We show that the strategic effect may have a dominating influence in which case inverse hedge ratios turn out to be decreasing in the number of firms. This different impact of the number of firms on inverse hedge ratios in case forward positions can correctly be forecasted by the market participants constitutes the source of identification of the strategic effect.

We estimate the model using data from the Dutch wholesale market for natural gas. In contrast to restructured markets elsewhere, the Dutch natural gas market is one where futures contracts have not been forced upon the wholesalers by the regulator. This is important because otherwise it is difficult to learn whether the market by itself provides the players with hedging and commitment opportunities. Our data set consists of a fairly large fraction of all (forward, spot and speculative) trades conducted at the Dutch gas hub Title Transfer Facility (TTF), from April 2003 until June 2008.[6] We use information on churn rates (i.e. information on the fraction of speculative trades) to construct the inverse hedge ratios concerning the actual deliveries of natural gas. The model imposes a restriction on the inverse hedge ratios which, using variation on number of wholesalers, can be estimated. The main empirical finding is that strategic considerations cannot be discarded as an explanation for the observed (inverse) hedge ratios. Seen under the light that most of the forward transactions occur OTC and therefore the forward market we study can initially be regarded as relatively non-transparent, we think this is an important result. Moreover, we document a learning effect, which we relate to the increase in the share of forward transactions conducted in the centralized market place (the ENDEX gas exchange), as opposed to trades over-the-counter. By contrast, we do not find significant evidence that risk-hedging is important in this market. We discuss the possible explanations for this latter result.

Our paper contributes to the literature that studies forward contracting of non-storable goods. Longstaff and Wang (2004) document significant risk-premia in electricity forward prices. Bessembinder and Lemmon (2006) derive the equilibrium forward risk premium in a competitive model of the interaction of wholesalers and retailers in the absence of speculators. Our paper differs from theirs in that our wholesalers have market power. This allows us to address the issue of whether wholesalers sell futures contracts to hedge or to gain market power in the spot market.[7]

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[6]The TTF is a virtual market place that offers market participants the possibility to buy and sell gas that is already injected into the Dutch gas transmission grid, or for which transportation capacity is already booked. Gas hubs can be virtual (like the TTF) or physical (like the Zeebrugge hub). Virtual hubs are more liquid.

[7]An alternative, and complementary, approach to address this issue is to use controlled experiments. In a recent paper, Brandts, Pezanis-Christou and Schram (2008) set up laboratory experiments to study the efficiency effects brought about by the possibility of forward contracting. Working with deterministic demand and cost parameters, risk hedging can be, if not fully eliminated, at least significantly reduced. Brandts et al. observe that significant price decreases and efficiency gains are obtained compared to the case in which only spot market trading is possible. Additional experimental evidence on the pro-competitive effects of futures contracts is provided by Coq and Orzen (2006). Ferreira, Kujal and Rassenti (2009) challenge this view and present experimental evidence to suggest that forward contracts make collusion more likely. Their results are in line with Liski and Montero (2006).

Our paper also adds to a growing empirical literature on the effects of forward contracting on spot market strategies and market outcomes (Green, 1999; Wolak, 2000; Fabra and Toro, 2005; Puller and Hortacsu, 2008; Bushnell, Mansur and Saravia, 2008). These papers have focused on electricity markets where forward contracts have often been imposed by regulators and can therefore be considered exogenous to the equilibrium process. By contrast, we deal with a market where forward contracts are endogenous. Our results lend support to the idea that the market may by itself provide the necessary incentives to the firms to engage in a healthy amount of forward contracting.

The rest of the paper is organized as follows. The next section presents a two-period model of competition. In the first period, the forward market opens and firms sell futures contracts. In the second period, the spot market opens, firms sell quantities and delivery of all contracted and spot quantities takes places. This Section presents the main empirical prediction of our model. We take it to the data in Section 4. Before that, Section 3 discusses in some detail the institutions of the Dutch wholesale gas market. The paper closes with a discussion of the main results, some extensions of the basic model and some concluding remarks.

2   A model of forward and spot contracting

Consider an oligopolistic market with n asymmetric risk-averse firms selling a homogeneous good. Firms are asymmetric on two accounts, risk-aversion and marginal costs of production. Firms can sell output in the spot market; in addition, they can also sell (or buy) the good in a forward market. Let s_i and x_i be, respectively, firm i's total spot and forward market sales; the total output firm i supplies on the market will be denoted $q_i(= s_i + x_i)$. The marginal cost of production of a firm i is denoted c_i.[8]

We assume that market demand is random and given by the linear-normal specification

$$p = a - bQ + \epsilon, \ \epsilon \sim N(0, \sigma^2), \tag{1}$$

where $Q = \sum_{i=1}^{n} q_i$ denotes the aggregate output delivered to consumers and ϵ is a zero-mean random shock normally distributed with standard deviation σ. We assume that the realization of ϵ is observed when the spot market opens so, at that stage, a firm i chooses its spot sales s_i to maximize its deterministic spot market profits.

At the forward market stage, by contrast, firms are uncertain about the price that will prevail in the market. As a result, at that stage, a firm views its monetary flow of profits as a random variable. We assume firms are risk averse and have constant absolute risk aversion (CARA) utility functions. Let π_i be the realized (forward and spot) monetary profits of a firm i. The utility function of a firm i is $u(\pi_i) = -e^{-\rho_i \pi_i}$, where $\rho_i > 0$ denotes firm i's

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[8]In the natural gas industry, wholesalers typically have take-or-pay contracts with producers. These contracts used to be indexed to the oil price. The constant marginal cost assumption is probably a good approximation. Nevertheless, in section 4.2 we address the potential endogeneity problem that would arise if marginal cost were not constant.

degree of risk aversion.[9] Denote by $F(\pi_i)$ the distribution of the monetary profits π_i of a firm i. (Note that this distribution is endogenous and will be determined later.) Then a firm i will choose its forward sales x_i to maximize its expected utility:

$$E[u(\pi_i)] = \int -e^{-\rho_i \pi_i} dF(\pi_i), \tag{2}$$

For simplicity, future spot market profits are not discounted.[10]

Next, and central to our paper, we assume that whether firms observe each other's forward positions is uncertain. To model this idea, we introduce a Bernoulli random variable, denoted I, with parameter γ. If $I = 1$ forward positions become observable to the players and then we get the standard Allaz and Vila (1993) setting. By contrast, if $I = 0$ we obtain the case of unobservable forward trading, as discussed by Kao and Hughes (1997).[11] The parameter γ can then be interpreted as the degree of transparency of the forward market. As mentioned in the Introduction, another, and perhaps more compelling, interpretation of this parameter is that it reflects the ability of firms to infer deviations from the equilibrium path from forward price changes.[12] One objective of the paper is to estimate the Bernoulli parameter γ.

We further assume there is a fringe of outside speculators. These traders, which are assumed to be risk-neutral, do not have transmission capacity rights so they cannot physically deliver the commodity to the final customers. For the moment, we shall assume that pure financial traders are better informed and observe wholesalers' deviations from the equilibrium path. This assumption ensures that a strong version of arbitrage (off and on the equilibrium path) between forward and spot markets holds.[13] In Section 4.3 we relax this assumption by introducing imperfectly informed financial traders. We now solve the game by backward induction.

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[9]The case of risk-neutrality obtains when $\rho_i \to 0$ for all i.

[10]We also worked with mean-variance utility functions and the results obtained were similar. As it will become clear later, monetary profits are not normally distributed so maximizing (2) is not equivalent to maximizing the corresponding mean-variance specification.

[11]We model imperfect observability by assuming that firms either observe the (correct) forward price or they miss it altogether. An alternative way to model imperfect observability is by assuming that firms may observe forward prices that are wrong. In that case Bagwell (1995) shows that the value of commitment is fully destroyed; van Damme and Hurkens (1997) show that Bagwell's striking result relies on an unnecessary restriction to pure strategies.

[12]Forward markets are to some extent opaque. Many transactions occur over the counter and therefore invisible to market participants. Forward price indices are publicized by brokers and specialized information agencies. Firms may be able to infer rivals' forward positions upon observation of those indices but the question is how well. We can think of γ as the fraction of times the firms are able to forecast how deviations from the equilibrium forward sales will affect the spot market price. In this sense, firms can be seen as been ignorant $1 - \gamma$ of the times.

[13]Ferreira (2006) studies the role of the observability assumption at length. He argues that it is hard to reconcile the assumption that firms are not informed of the rivals' forward positions with the assumption that speculators observe deviations at the forward stage. As mentioned earlier, in the real-world forecasting quantities sold upon observing forward price indices is far from trivial, specially if firms are heterogeneous.

2.1 Spot market stage

At the time the spot market opens, demand is certain and firm i chooses its spot sales s_i to maximize its spot market profits:

$$\pi_i^s = (p - c_i)s_i \tag{3}$$

where p is the realized spot market price given in (1). For this, a firm i takes the forward positions of the rival firms as well as their spot market strategies as given. The spot market equilibrium turns out to be in linear strategies. Putting the linearity of the strategies up front, we write the spot market strategy of a firm i as:

$$s_i = A_i + B_i \epsilon, \ \ i = 1, ..., n. \tag{4}$$

When $I = 1$, which occurs with probability γ, firms observe each other forward positions. In that case, the realization of the spot market price can be written as:

$$p = a + \left(1 - b \sum_{j \neq i}^n B_j\right) \epsilon - bx_i - b\sum_{j \neq 1}^n x_j - bs_i - b\sum_{j \neq i}^n A_j \tag{5}$$

where $\sum_{j \neq 1}^n x_j$ is the sum of the *actual* forward positions of firm i's competitors. Profit maximization at the spot market stage gives

$$s_i = \frac{1}{2b}\left(a + \left(1 - b\sum_{j \neq i}^n B_j\right)\epsilon - c_i - bx_i - b\sum_{j \neq i}^n x_j - b\sum_{j \neq i}^n A_j\right) \tag{6}$$

We know that each firm's spot strategy has the form in (4); then, we can solve for A_i and B_i:

$$A_i = \frac{a + \sum_{j \neq i}^n c_j - nc_i - bx_i - b\sum_{j \neq i}^n x_j}{b(n+1)}$$

$$B_i = \frac{1}{b(n+1)} \tag{7}$$

We thus obtain that, conditional on the forward positions being observable, the equilibrium spot market output of firm i equals:

$$s_i^{I=1} = \frac{a + \epsilon + \sum_{j \neq i}^n c_j - nc_i - bx_i - b\sum_{j \neq i}^n x_j}{b(n+1)} \tag{8}$$

and the equilibrium spot market price equals:

$$p^{I=1} = \frac{a + \epsilon + \sum_i^n c_i - bx_i - b\sum_{j \neq i}^n x_j}{n+1}. \tag{9}$$

The conditional profits are given by:

$$\pi_i^{I=1} = b(s_i^{I=1})^2 + (f - c_i)x_i \tag{10}$$

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where f denotes the forward price.

When $I = 0$, which occurs with probability $1 - \gamma$, firms do not observe each other actions in the forward market. This implies that deviations of a firm i from the equilibrium path go undetected by the rival wholesalers. In that case, the price in the spot market is given by:

$$p = a + \left(1 - b\sum_{j \neq i}^{n} B_j\right)\epsilon - bx_i - b\sum_{j \neq 1}^{n}\hat{x}_j - bs_i - b\sum_{j \neq i}^{n} A_j \tag{11}$$

where $\sum_{j \neq i}^{n}\hat{x}_j$ is firm i's *conjecture* about the rivals' aggregate forward position. The first order condition (FOC) for the spot market stage is given by:

$$s_i = \frac{1}{2b}\left(a + \left(1 - b\sum_{j \neq i}^{n} B_j\right)\epsilon - c_i - bx_i - b\sum_{j \neq i}^{n}\hat{x}_j - b\sum_{j \neq i}^{n} A_j\right) \tag{12}$$

Note that because firm i does not observe deviations from the conjectured (equilibrium) forward sales of the rival firms, its spot market strategy only depends on its own level of forward sales. We can solve for $\sum_{j \neq i}^{n} A_j$ and $\sum_{j \neq i}^{n} B_j$:

$$\sum_{j \neq i}^{n} A_j = \frac{(n-1)(a + c_i - b\hat{x}_i - b\sum_{j \neq i}^{n}\hat{x}_j) - 2\sum_{j \neq i}^{n} c_j}{b(n+1)}$$

$$\sum_{j \neq i}^{n} B_j = \frac{n-1}{b(n+1)} \tag{13}$$

As a result, conditional on the forward positions not being observable, the spot market sales for firm i are:

$$s_i^{I=0} = \frac{a + \epsilon + \sum_{j \neq i}^{n} c_j + b(n-1)\hat{x}_i/2 - nc_i - b(n+1)x_i/2 - b\sum_{j \neq i}^{n}\hat{x}_j}{b(n+1)} \tag{14}$$

and the realized market price:

$$p^{I=0} = \frac{a + \epsilon + c_i + \sum_{j \neq i}^{n} c_j + b(n-1)/2\hat{x}_i - b(n+1)x_i/2 - b\sum_{j \neq i}^{n}\hat{x}_j}{n+1} \tag{15}$$

The conditional profit of firm i's equals:

$$\pi_i^{I=0} = b(s_i^{I=0})^2 + (f - c_i)x_i. \tag{16}$$

2.2 Forward market stage

At the forward market stage, firms sell (or buy) part of their total output in the futures market to maximize their expected utility.[14] Note that $u(\pi_i) = Iu(\pi_i^{I=1}) + (1 - I)u(\pi_i^{I=0})$.

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[14]We do not a priori restrict firms' level of forward trading to be positive. However, in equilibrium each firm will sell a non-negative amount in the forward market.

Using the expressions for the conditional profits derived above, the expected utility of firm i is thus given by:

$$E[u(\pi_i)] = -\gamma \int e^{-\rho_i \pi_i^{I=1}} f(\epsilon) d\epsilon - (1-\gamma) \int e^{-\rho_i \pi_i^{I=0}} f(\epsilon) d\epsilon \qquad (17)$$

where $f(\epsilon)$ is the density function of the normal distribution with zero mean and variance given by σ^2.

A firm i picks its amount of forward sales x_i to maximize its expected utility. It is instructive to write the FOC as follows:

$$\gamma \int \rho_i e^{-\rho_i \pi_i^{I=1}} \left(\frac{\partial \pi_i^{I=1}}{\partial x_i} + \sum_{j=1}^{n} \frac{\partial \pi_i^{I=1}}{\partial s_j} \frac{\partial s_j}{\partial x_i} \right) f(\epsilon) d\epsilon +$$

$$(1-\gamma) \int \rho_i e^{-\rho_i \pi_i^{I=0}} \left(\frac{\partial \pi_i^{I=0}}{\partial x_i} + \frac{\partial \pi_i^{I=0}}{\partial s_i} \frac{\partial s_i}{\partial x_i} \right) f(\epsilon) d\epsilon = 0 \qquad (18)$$

In equilibrium $\hat{x}_i = x_i$ for all i, and therefore $\pi_i^{I=1} = \pi_i^{I=0} = \pi_i$, so this FOC can more compactly be written as follows:

$$\int \rho_i e^{-\rho_i \pi_i} \left(\frac{\partial \pi_i}{\partial x_i} + (1-\gamma) \frac{\partial \pi_i}{\partial s_i} \frac{\partial s_i}{\partial x_i} + \gamma \sum_{j=1}^{n} \frac{\partial \pi_i}{\partial s_j} \frac{\partial s_j}{\partial x_i} \right) f(\epsilon) d\epsilon = 0 \qquad (19)$$

The first term of this equation (after the integral sign) represents marginal utility from (monetary) profit, while the second term between parentheses is the marginal monetary profit from selling futures contracts. A firm i chooses its amount of futures x_i to make the expected value of the product of marginal utility and marginal monetary profit equal to zero.

The incentives of a firm i to sell forward are shaped by three forces. There is a risk-hedging effect, a strategic effect and a price effect. The first two forces are pro-contracts; the third one dampens the incentives to sell futures. These three forces can actually be seen after taking a closer look at equation (19). To see them more clearly, it is useful to consider the two extreme cases of complete opacity ($\gamma = 0$) and complete transparency ($\gamma = 1$) of the forward market.

When forward positions cannot be observed by the rivals the strategic effect is absent and equation (19) simplifies to

$$\int \rho_i e^{-\rho_i \pi_i} \left(\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i}{\partial s_i} \frac{\partial s_i}{\partial x_i} \right) f(\epsilon) d\epsilon = \int \rho_i e^{-\rho_i \pi_i} \left(-\frac{bx_i}{2} - \frac{\epsilon}{n+1} \right) f(\epsilon) d\epsilon = 0 \qquad (20)$$

In parenthesis we see the direct effect of selling forward on a firm's monetary profits, along with a second effect that goes via its own spot market strategy, s_i. This effect is clearly negative and has a deterministic component and a random component. The deterministic component, $-bx_i/2$, constitutes a negative *price effect* that is independent of the number of firms. A firm that puts one unit more in the forward market cuts its spot sales by less

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than one unit so its total aggregate sales increase. This results in a fall in the spot market price, which is anticipated by the speculators and therefore the forward price falls too.[15] This own price effect dampens the incentives to put futures in the market, which explains why a risk-neutral monopolist would choose not to engage in forward contracting at all (see Tirole, 2006). Since this effect is always negative no matter the number of firms, it is also true that a risk-neutral oligopolist would opt out of the contract market (Hughes and Kao, 1997).

The random component explains the *risk-hedging* motive. This incentive arises because the covariance between marginal utility and marginal profit is strictly positive. A firm that increases its contract cover away from zero lowers its exposure to price shocks by $\epsilon/(n+1)$ and since the marginal utility of monetary profit co-vary negatively with the price, the firm experiences an increase in its expected utility. This risk-hedging motive pushes a firm to sell contracts. When contracts cannot be observed by the market participants, the optimal contract cover of a firm i is the outcome of trading off the (positive) risk-hedging motive against the (negative) price effect.

When forward positions are easily observable by the firms, or can easily be inferred from the forward price, $\gamma = 1$ and equation (19) simplifies to

$$\int \rho_i e^{-\rho_i \pi_i} \left(\frac{\partial \pi_i}{\partial x_i} + \sum_{j=1}^{n} \frac{\partial \pi_i}{\partial s_j} \frac{\partial s_j}{\partial x_i} \right) f(\epsilon) d\epsilon =$$

$$\int \rho_i e^{-\rho_i \pi_i} \left(-\frac{bx_i}{2} - \frac{\epsilon}{(n+1)} + \frac{b(n-1)}{2(n+1)}(x_i + s_0) + \frac{(n-1)\epsilon}{(n+1)^2} \right) f(\epsilon) d\epsilon = 0 \qquad (21)$$

where

$$s_0 = \frac{a + \sum_{j \neq i} c_j - nc_i - bx_i + b\sum_{j \neq i} x_j}{b(n+1)}$$

In this case there is a third, *strategic*, effect of selling futures. This effect also has a deterministic component and a random component. Suppose the firms are risk-neutral. By the strategic effect, a firm that puts units in the forward market positively affects its profit via the spot market strategies of the rival firms. This gives firm i an incentive to sell forward, since by doing so it benefits from rival firms' cuts in their spot sales (Allaz and Vila, 1993). The random component has a positive sign and this implies that works counter to the risk hedging effect discussed above. This is because, since the rival firms cut their spot sales, the effect of putting one unit forward is less effective at lowering exposure to price shocks.

Obviously, the importance of the strategic motive depends on the likelihood forward positions are learnt by the players. Moreover, because the risk-hedging effects and the strategic effects

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[15]The fall in the forward price originates from the assumption that speculators observe the forward quantities (Ferreira, 2006). Since they anticipate a higher total quantity to be delivered when the spot market closes, they correspondingly lower the prices they bid for the quantities on sale in the futures market. In Section 4.3 we introduce imperfectly informed financial traders. In that case, forward and spot prices need not coincide off-the-equilibrium.

on a firm's expected utility are intertwined, it is now clear why it is difficult to disentangle them. In the remainder of the paper, our main focus will be on the equilibrium inverse hedge ratio of an individual firm i, defined as total-to-forward-sales (or q_i/x_i) ratio, because of its useful properties that we will exploit in the empirical application. The following proposition discusses the equilibrium inverse hedge ratio and its properties in the general model.

Proposition 1 *In equilibrium, the average inverse hedge ratio of a firm i, defined as total-to-forward-sales ratio, is given by*

$$\Gamma_i \equiv \frac{b(n+1)^2(1+n+(n-1)\gamma) + 2(3+\gamma+(3-\gamma)n)\rho_i\sigma^2}{2(n+1)(b(n^2-1)\gamma + 2\rho_i\sigma^2)}. \tag{22}$$

The inverse hedge ratio Γ_i satisfies the following properties:
(i) It is independent of the demand intercept parameter a and of the firm marginal cost c_i, but increases in the demand slope parameter b
(ii) It decreases as the risk-aversion parameter of the firm ρ_i goes up
(iii) It decreases as the probability that forward positions are observed γ increases
(iv) There exists a critical parameter $\tilde{\gamma}$ such that: For all $\gamma \le (\ge)\tilde{\gamma}$, Γ_i increases (decreases) in the number of firms n.

The proof is in the Appendix A.

The main properties of the inverse hedge ratio as stated in Proposition 1 need some further explanation. First, the inverse hedge ratio does not depend on the demand parameter a and the cost parameter c_i. This means that firms with similar risk aversion hedge in the same way on average, no matter how much they differ in their marginal cost of production. In addition, it is interesting to see that inverse hedge ratios in periods of demand expansion are similar to those in periods of demand contraction. This result, of course, rests on the linearity assumptions of the demand and cost functions. However, it should be seen as a reasonable approximation that is useful because it allows us to estimate the model without cost and demand data.

Inverse hedge ratios go down when firms becomes more risk averse, when demand uncertainty increases, or when the transparency of the forward market goes up. The former two results are driven by the risk-hedging rationale: the higher the degree of risk aversion (or the greater the uncertainty), the more a firm wants to hedge in the forward market instead of selling spot. The latter is explained by the strategic motive, since a high level of contract cover is worth more to a firm the more convincing the commitment is.

The most interesting feature of inverse hedge ratios, at least for our purposes, is that whether firm entry/exit has an upward or downward effect on them depends on the extent to which the forward market is transparent. If the futures market is relatively opaque and rivals' futures contracts go often unobserved, the strategic effect is hardly present and the contract cover of a firm trades off the the risk-hedging effect against the price effect. In that situation

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the incentive to hedge against demand shocks becomes weaker (see 20) if more suppliers enter the market, which pushes up the inverse hedge ratio of an individual firm. This is because at the contracting stage, the rivals' strategies are random so the residual demand of a particular firm is less susceptible to demand shocks the higher the number of competitors. By contrast, the price effect appears not to depend on the number of competitors (see 20). Therefore, it is clear that when the forward market is relatively obscure, inverse hedge ratios decrease in the number of suppliers.

If the futures market is more transparent and the contract positions of the rivals are regularly observed, in addition to the risk-hedging effect and the price effect, the strategic effect plays a significant role. This strategic effect turns out to be stronger as more players are around (see 21). This is because the (marginal) gains from affecting the rivals' spot market behavior are higher the more competitors are around. While the risk-hedging and the price effect (weakly) decrease as the number of competitors increases, we show that the strategic effect may have a dominating influence.

It is illustrative to briefly consider the extreme cases of full transparency (perfect observability), $\gamma = 1$, and complete obscurity (no observability at all), $\gamma = 0$, of the futures market. In the first case, the inverse hedge ratio can be written as:

$$\Gamma_i(\gamma = 1) = 1 + \frac{1}{n+1} + \frac{2b}{b(n^2 - 1) + 2\rho_i\sigma^2},\tag{23}$$

which clearly decreases as n goes up.

In the alternative extreme case of no observability at all, the hedge ratio becomes:

$$\Gamma_i(\gamma = 0) = \frac{6\rho_i\sigma^2 + b(n+1)^2}{4\rho_i\sigma^2}\tag{24}$$

This ratio is clearly decreasing in the number of firms n. As shown in Proposition 1, for intermediate cases, the relationship between the number of firms and the inverse hedge ratio depends on how likely it is that forward positions will be observed. This is illustrated in Figure 1.

3   Empirical application

We seek to answer the question whether firms sell futures for strategic reasons, for risk hedging considerations, or for both. If firms' forward positions were totally opaque to the agents in the market, strategic reasons would not play any role and therefore the observed inverse hedge ratios in the data would only be explained by risk-hedging considerations. Answering this inquiry thus amounts to finding out the extent to which firms can observe each other's forward sales. Or, in different words, figuring out the ability of the players to forecast correctly the aggregate position of the rivals' upon observing the forward price/index.
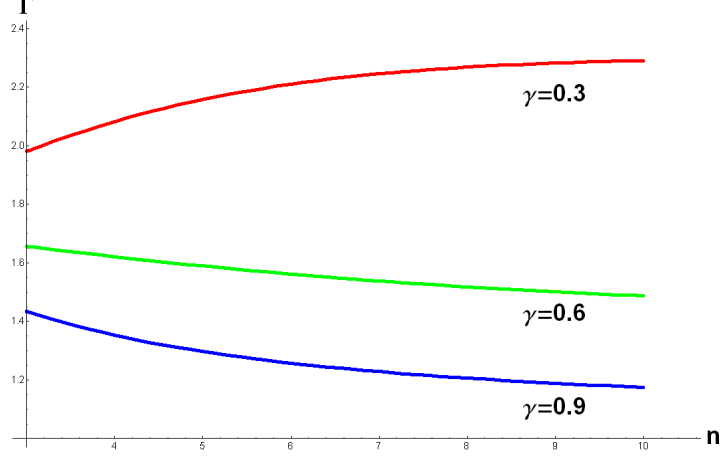
Figure 1: The inverse hedge ratio and the number of firms ($\rho_i = 4$, $\sigma^2 = 1$, $b = 1$)

If one were provided with firms' forward and spot sales data corresponding to various levels of observability and risk, one could estimate the effects of these two factors on the hedge ratio. The problem with this approach is that these variables are hard to measure. One could for example gather data from different regional markets. Within market price dispersion could be used as a measure of price risk. However, it is not clear how to measure the extent to which firms are capable of deducing deviations from changes in the forward price. The analyst would have to make a priori assumptions about the observability parameter γ. Instead, we propose to estimate the model in Section 2 structurally. We do this for the Dutch wholesale market for natural gas. For this market, we have obtained the minimal set of data: forward and spot sales, churn ratios and number of wholesalers. Before presenting the market under study and the data we have obtained, we discuss the empirical approach. Our results can be found in Section 3.3.

3.1 Empirical strategy

The variable of interest is the inverse hedge ratio of an individual firm i. As shown above in the Proof of Proposition 1, the inverse hedge ratio of an individual firm i has a random generating process given by:

$$\frac{q_i^*}{x_i^*} = \frac{b(n+1)^2(1+n+(n-1)\gamma) + 2(3+\gamma+(3-\gamma)n)\rho_i\sigma^2}{2(n+1)(b(n^2-1)\gamma+2\rho_i\sigma^2)} + \frac{1}{b(n+1)x_i^*}\epsilon \qquad (25)$$

Inverse hedge ratios are normally distributed. We can rewrite equation (25) as:

$$(n+1)q_i^* = \frac{(n+1)^2(1+n+(n-1)\gamma) + 2(3+\gamma+(3-\gamma)n)\frac{\rho_i\sigma^2}{b}}{2((n^2-1)\gamma+2\frac{\rho_i\sigma^2}{b})}x_i^* + \frac{1}{b}\epsilon \qquad (26)$$

Using individual firm level data on total quantities brought to the market, forward sales and number of wholesalers, the system of equations in (26) can be fitted to the data. Since these equations are non-linear in the parameters of interest, we suggest applying non-linear least squares (NLS).

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Notice that the parameters ρ_i, σ and b cannot be separately identified. Even if we use data to proxy for demand volatility, we cannot estimate both ρ_i and b. However, with the appropriate data, one could estimate relative risk-aversion parameters across firms, i.e. ρ_i/ρ_j. The identification of these parameters would stem from variation in the hedge ratios of the different firms. If some firms were systematically seen to hedge more than others, this would provide information on the extent to which the former firms have greater risk-aversion than the latter.

The identification of the observability parameter γ stems from variation in the number of wholesalers n. As shown above, when forward positions are relatively transparent to the firms, the model predicts that an individual firm responds to entry by *decreasing* its inverse hedge ratio. By contrast, if firms' forward sales are relatively opaque and rivals' rarely observe them, then an individual firm *increases* its inverse hedge ratio as a response to entry. It is precisely this differential effect of entry that enables the identification of the observability parameter γ using data containing variation in the number of players.

Unfortunately, due to confidentiality reasons, individual firm level data are not publicly available in the market we study and we have only been able to obtain aggregate forward and spot sales. To work with this type of data, we proceed by aggregating at the market level. For this we need to assume that all firms have similar risk aversion parameters, i.e., $\rho_i = \rho$ for all $i = 1, 2, ..., n$. Summing up for all firms in (26), we get

$$\frac{n+1}{n} \sum_{i=1}^{n} q_i = \frac{b(n+1)^2(1+n+(n-1)\gamma) + 2(3+\gamma+(3-\gamma)n)\frac{\rho\sigma^2}{b}}{2n((n^2-1)\gamma + 2\frac{\rho\sigma^2}{b})} \sum_{i=1}^{n} x_i + \frac{1}{b}\epsilon \quad (27)$$

Note that $\sum_{i=1}^{n} q_i = \sum_{i=1}^{n} s_i + \sum_{i=1}^{n} x_i$, so that equation (27) can be rewritten as:

$$\frac{n+1}{n} \sum_{i=1}^{n} s_i = \frac{n+1}{n} (\Gamma(\cdot) - 1) \sum_{i=1}^{n} x_i + \frac{\epsilon}{b} \quad (28)$$

where $\Gamma(\cdot)$ is the hedge ratio as defined in Proposition 1 for symmetric firms. We fit this equation to the data by applying NLS. The regression results, shown in Section 3.3, tell us whether firms use forward contracts for risk-hedging purposes, for strategic reasons, or for both. We now give some details on the market we study and the data set.

3.2   The data

We use data from the Dutch wholesale market for natural gas. For the purpose of this paper, these data are very useful because forward contracts have not been imposed by the regulator so they can be considered endogenous to the market process.

As in many other countries, traditionally, gas supply in the Dutch wholesale market was controlled by a single integrated network company –the *NV Nederlandse Gasunie*.[16] Gasunie

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[16]Gasunie was a joint venture between De Staatsmijnen (DSM), Shell, Esso and the Dutch State.

did not only own the transmission network, but also had control over the national distribution pipelines and the gas supplies. Gas originated from the Dutch gas fields or was imported from foreign producers.[17] Gasunie sold the gas to industrial customers and distribution companies.

Market deregulation in the Netherlands started back in the late 1990s with the *Price Transparency Directive*, but gained full momentum with the *First Gas Directive* of the European Parliament in 1998. This ruling abolished import monopolies, forced the opening of markets and imposed the accounting unbundling of vertically integrated network companies. The *Second Gas Directive* of the European Parliament in 2003 furthered the liberalisation process by requiring full market opening, regulated third party network access, regulated or negotiated access to storage and legal unbundling of integrated network companies. As a consequence of this directive, Gasunie was split up into two independent companies: *Gas Transportation Services (GTS)*, which controls the national transmission network, and *Gasterra*, which is engaged in gas wholesaling. The second directive also required the creation of national energy regulators.

To attain a well-functioning wholesale gas market in The Netherlands, the *Title Transfer Facility (TTF)* was created in 2003. The TTF is a virtual trading hub that offers market parties/shippers the possibility to buy and sell gas that is already injected into the national gas transmission grid, or for which transportation capacity has already been booked. Thanks to the TTF gas can easily change hands before it is extracted at a specific local or export exit point. This triggered the entry of new players into the Dutch market.[18] The TTF made the emergence of gas exchanges possible. APX Gas NL B.V. runs an exchange for spot contracts. At APX, market parties can trade gas one day ahead and within the day of delivery. Volumes are standardized. ENDEX N.V. runs an exchange for gas futures contracts. At ENDEX firms sell and buy a variety of futures contracts.[19]

Our data set consists of a substantial fraction of all (forward and spot) contracts traded at the Dutch TTF for the period from April 2003 until June 2008. These data were provided by the company ICIS Heren.[20] In addition, we obtained data from the transport operator GTS

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[17]In 2008 there were 35 production fields and 17 import entry points (GTS, 2008). The bulk of Dutch gas production takes place in the Groningen gas field. After the discovery of this field in 1959, the Nederlandse Aardolie Maatschappij (NAM), a joint venture between Shell and Esso, obtained a governmental concession to explore and exploit this gas field. The NAM was however obliged to sell all the gas extracted from the Groningen field (and other small fields in the Netherlands) to Gasunie.

[18]New players include new wholesale companies such as Gaz de France, BP, EON, Gazprom, RWE, Statoil, Total, etc., as well as new financial players such as JP Morgan, The Royal Bank of Scotland, BNP Paribas, Morgan Stanley, Citygroup, Barclays Bank, etc. There were various distribution companies at the retail level in the Netherlands. There has also been some entry of new retailers, but an important change has been that existing distribution companies have become active outside their traditional territories.

[19]The minimum length of a contract is one month and the maximum length is one (calendar) year. Contracts can range from a month ahead to three years ahead of delivery. In Appendix B we provide more details on the types of contracts traded at the TTF.

[20]ICIS Heren (http://www.icis.com/heren/) is a leading specialized information provider for energy markets. The company publishes price assessments, indices, news and analysis for various energy markets. ICIS

on the number of wholesalers active every month, on the daily churn rates and on the total daily volumes.[21] Unfortunately, we do not have information on the identity of the trading partners so we are unable to perform the analysis at the firm level. As explained earlier, if firms do not differ much in their aversion to risk, they will hedge in a similar fashion, even if there exist significant cost differences across them.

Transactions can be either facilitated by brokers, or exchange-based, or the outcome of bilateral negotiations. All these three types of transactions are included in our data set, but we cannot distinguish between them in the sense that we cannot tell whether a transaction is over-the-counter or has occurred at the centralized exchange ENDEX. As said before, there are several types of contracts traded at TTF. For a given trading day, we are interested, on the one hand, in the total volume of gas delivered and, on the other hand, in the amount that has been sold forward. To compute all the gas delivered in a given date, we sum all the quantities specified in different contracts that call for delivery on such a day. To compute how much of this volume is contracted forward, we need to make an assumption about the nature of uncertainty in this market. We make the assumption that only day-ahead and within-day contracts form the spot market so the rest of the contracts are considered futures contracts.[22]

To be clear, suppose that in year 2003, three products have been traded: (i) a forward contract traded on November 6 that calls for delivery of 720 MegaWatt hour (MWh) each day in December 2003, (ii) a day-ahead contract traded on December 6, 2003 for delivery of 4,320 MWh the next day, and (iii) a spot contract traded on December 20, 2003 for delivery of 1,440 MWh the same day. Then, except for two days, December 7 and 20, for each day in December 2003 the delivery volume is 720 MWh. On December 7, the total delivery volume equals (720+4,320=)5,040 MWh while on December 20, the delivery volume is (720+1,440=) 2,160 MWh. As a result, the hedge ratio is 1 for all days of December 2003 except for December 7, with an inverse hedge ratio of 8, and December 20, with an inverse hedge ratio of 3.

One difficulty of the data at hand is that a substantial part of the transactions we observe concerns contracts that are traded with or between speculators. Since financial traders must have zero net positions before delivery, many of the contracts we see are re-trades and do not involve volumes that are finally brought to the market. Fortunately, we can deal with this issue using data on churn rates (net-to-gross-volume ratios). Churn rates are

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Heren gathers daily price and quantity information from brokers and directly from the participants in the industry via telephone calls.

[21]The participants in the industry must make *nominations* to the transport operator once the gas changes hands. In this way, the transport operator receives the necessary information to compute total traded volumes and the churn rates. Using the data on total volumes delivered at the TTF, we estimate that our data contains well above 50 percent of the total market.

[22]We have discussed the validity of this assumption with participants in this industry. At the margin, the main driver of demand is temperature. Therefore, if any, the main source of uncertainty here is due to temperature fluctuations. According to the participants, the weather predictions one day ahead are quite accurate.

reported by GTS. These rates do not distinguish between forward trades and spot market trades. Obviously, actual churn rates for spot market transactions are much lower than those corresponding to forward trades, since the length of time to resell contracts is rather short in the spot market. In what follows, we assume forward transactions have a churn rate equal to the churn rate reported by the GTS; for spot market trades, we assume the churn rate equals one.[23] Table 1 provides some descriptive statistics of our data and Figure 2 displays the forward sales adjusted for the churn rate, as well as the spot market sales.

The descriptive statistics reveal four interesting aspects of the data. One, volumes traded at the TTF have gone up a great deal.[24] Two, a significant part of the total volume traded at the TTF is hedged (between 60 and 90 %). Three, the hedge ratio has increased over time but, by no means, it has changed by the order of magnitude the volumes have changed. And fourth, the standard deviation of the inverse hedge ratio sems to have gone down over the sample period. The latter two observations appear to be in line with our model of firm behavior (inverse hedge ratios have mean independent of the strength of the demand parameter and standard deviation negatively correlated with it, see Proposition 1).
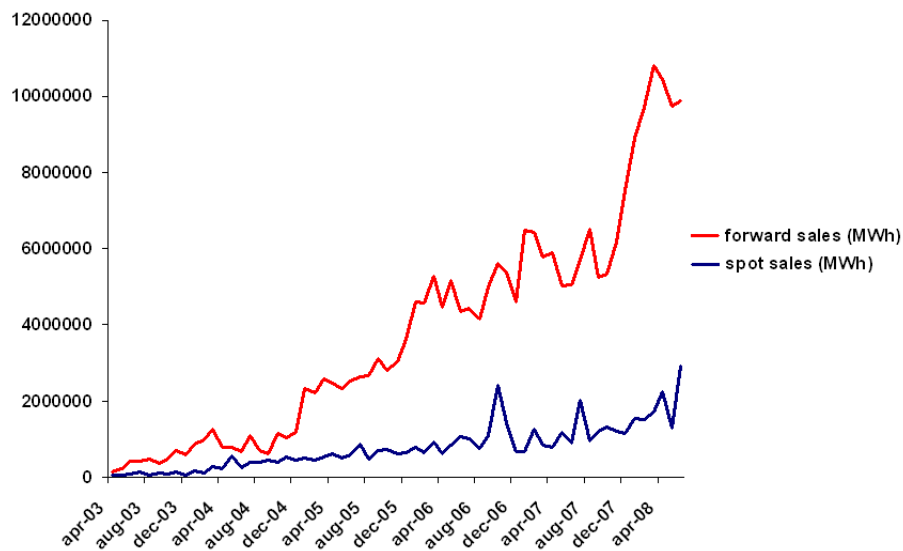

Figure 2: Forward market and spot market sales

As discussed earlier, identification of the key parameters of the model requires variation in the number of wholesalers operating in the market. The TTF is a market where in fact there has been a steady increase in the number of participants. However, from our data on

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[23]In different words, we are assuming speculators do not take positions during the time the spot market is open. If we had information on the identity of the traders, we could check the validity of this assumption.

[24]Currently net volumes in the TTF are approximately equal to the total supplies of natural gas to large industrial users in The Netherlands, including the electricity generating companies. This is about 10% of the total amount of gas that enters the Dutch pipeline system (about 50% of the gas that enters the Netherlands is 'transit' gas, i.e., exports to other countries).

Year	Variable	Min	Max	Mean	Std. Dev.
2003	Wholesalers	9	11	10.11	0.93
	Wholesalers 80%	4	6	5.22	0.67
	Spot (MWh)	63,960	145,536	93,251	34,046
	Forward (MWh)	193,920	1,646,640	856,907	491,320
	Churn rate	1.42	2.67	1.92	0.41
	Net forward (MWh)	136,709	712,280	419,614	172,415
	Inv. hedge ratio	1.11	1.49	1.26	0.12
2004	Wholesalers	11	15	13	1.48
	Wholesalers 80%	5	8	6.5	0.90
	Spot (MWh)	133,440	561,840	353,818	137,081
	Forward (MWh)	1,512,000	3,494,016	2,455,108	638,825
	Churn rate	2.04	3.15	2.65	0.37
	Net forward (MWh)	624,382	1,281,437	932,053	220,232
	Inv. hedge ratio	1.14	1.73	1.4	0.19
2005	Wholesalers	14	20	17.17	1.90
	Wholesalers 80%	7	10	8.58	0.9
	Spot (MWh)	433,920	866,880	599,638	126,261
	Forward (MWh)	6,479,280	10,911,600	8,322,368	1,183,816
	Churn rate	2.69	3.34	3.09	0.18
	Net forward (MWh)	2,220,239	3,622,442	2,699,183	397,344
	Inv. hedge ratio	1.18	1.33	1.22	0.04
2006	Wholesalers	21	24	22.42	1.24
	Wholesalers 80%	10	11	10.25	0.45
	Spot (MWh)	621,600	2,397,683	1,022,418	487,182
	Forward (MWh)	13,030,152	19,472,208	15,788,766	2,150,126
	Churn rate	2.83	4.23	3.29	0.41
	Net forward (MWh)	4,166,793	5,615,750	4,805,133	471,609
	Inv. hedge ratio	1.14	1.43	1.21	0.08
2007	Wholesalers	25	28	25.67	0.98
	Wholesalers 80%	11	14	12.75	1.06
	Spot (MWh)	684,336	2,027,784	1,130,286	353,964
	Forward (MWh)	18,279,168	26,240,352	22,141,362	2,734,632
	Churn rate	2.84	4.66	3.77	0.56
	Net forward (MWh)	5,033,525	7,520,365	5,934,651	732,208
	Inv. hedge ratio	1.11	1.35	1.19	0.07
2008	Wholesalers	28	29	28.67	0.52
	Wholesalers 80%	12	12	12	0
	Spot (MWh)	1,310,184	2,910,576	1,875,076	603,480
	Forward (MWh)	28,625,400	35,767,021	33,389,210	2,531,015
	Churn rate	3.22	3.57	3.37	0.12
	Net forward (MWh)	8,900,285	10,797,620	9,911,698	659,240
	Inv. hedge ratio	1.13	1.29	1.19	0.06

Notes: Year 2003 averaged over 9 months. Year 2008 over 6 months.

Table 1: Descriptive Statistics (monthly averages)

transactions we cannot extract the number of wholesalers since we do not have information on the identity of the traders engaged in a transaction. We obtained data on the number of active wholesalers in a given month from the GTS.[25] Since some wholesalers are probably

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[25]We thank Mark Hobbelink and Sybren de Jong from GTS for providing us with this information. To conduct transactions at the TTF, traders must first subscribe with the TTF. The subscription can be made for a single gas month or for a full calendar year. Subscribing involves the payment of some fixed fees and, in addition, traders have to pay some variable fees for the volumes traded.

very small and have no market power whatsoever, we also asked for the number of active wholesalers making up for 60 and 80 percent of total delivery. Figure 3 shows the evolution of the total number of active wholesalers, as well as the development of the number of suppliers that account for more than 60 and 80 percent of the gas delivered in the TTF. Note that not only more gas wholesalers have entered the TTF in the period under analysis, but also that, as time has elapsed, the 60 and 80 percent market share has become distributed over more firms. This suggests that the supply of gas has become less concentrated in the Netherlands.
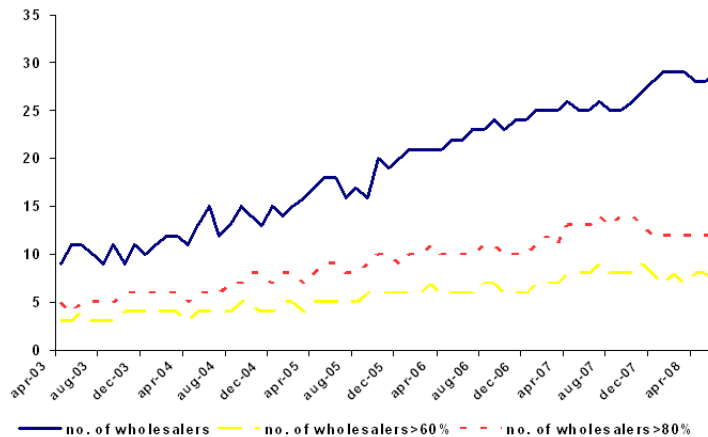

Figure 3: Number of wholesalers active at TTF

Given the monthly nature of our data on the number of active wholesalers, we compute aggregate monthly delivery forward and spot volumes and conduct the analysis using 63 monthly observations. To get a first impression of whether gas wholesalers trade forward contracts for strategic reasons, we pool together the months in which the number of active suppliers that serve 80% of the market is the same and compute the average hedge ratio for those months. We then regress the hedge ratio on a constant and on the number of wholesalers. Figure 4 displays the relation between the number of wholesalers trading at the TTF and the average ratio of interest. The dots in the figure represent the average ratio for a given number of wholesale firms, while the dashed line shows the estimated relation between the number of wholesalers and the inverse hedge ratio. The results of the regression suggest that this relation is negative, which, according to the theoretical model, indicates that forward contracts are used as strategic instruments.[26] Since this regression does not allow us to learn the extent to which the players' positions are observed, we proceed by estimating the model structurally.

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[26]More precisely, we estimate by OLS the model $\hat{\Gamma}_n = \alpha + \beta n + u_n$, where $\hat{\Gamma}_n$ is the average inverse hedge ratio for a given number of wholesale firms, n the number of wholesalers and u_n the usual error term. The estimates become $\hat{\alpha} = 1.36$ and $\hat{\beta} = -0.01$, with t-statistics being equal to 21.97 and -1.66, respectively.
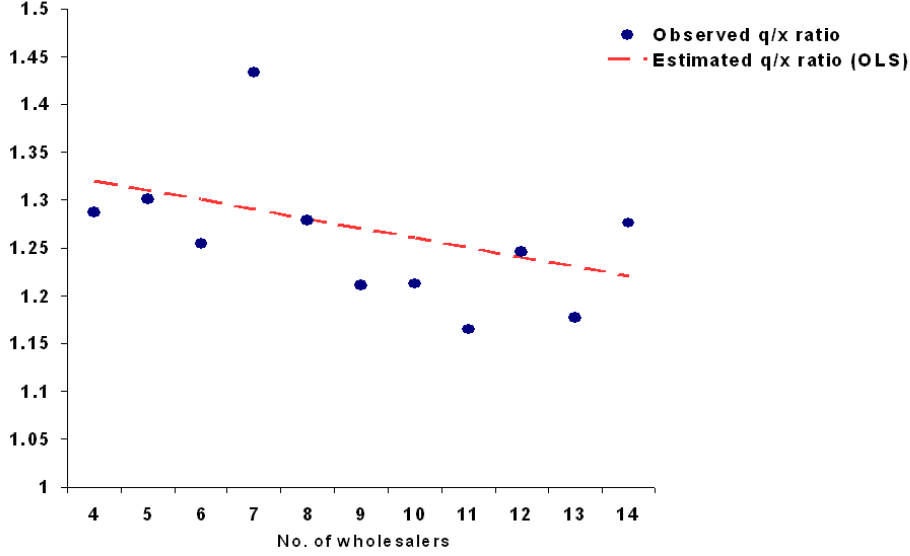
Figure 4: Inverse hedge ratio and the number of wholesalers

3.3 Results

The relation to be estimated is given by equation (28). This relation can be rewritten as:

$$y_t = g\left(n_t, \sum_{i=1}^{n} x_{it}, \gamma, \lambda\right) + \frac{\epsilon_t}{b}, \quad \epsilon_t \sim N(0, \sigma^2) \tag{29}$$

where t indexes the time period (month) and

$$\lambda \equiv \frac{\rho\sigma^2}{b} \tag{30}$$

$$y_t \equiv \frac{n_t + 1}{n_t} \sum_{i=1}^{n} s_{it} \tag{31}$$

$$g\left(n_t, \sum_{i=1}^{n} x_{it}, \gamma, \lambda\right) \equiv \frac{n_t + 1}{n_t} \left(\Gamma(n_t, \gamma, \lambda) - 1\right) \sum_{i=1}^{n} x_{it}. \tag{32}$$

The NLS regression results are summarized in Table 2.

As can be seen from table 2, the estimate for the observability parameter, $\hat{\gamma}$, is equal to 0.83 and is highly significant. We interpret this result as providing strong evidence that strategic considerations play an important role in explaining the hedge ratios observed in the data. As said above, this can be interpreted as if firms attached approximately 80 percent probability to the event that their forward positions are correctly forecasted by the rival firms upon observing the forward price. Seen from the perspective that most transactions at the TTF occur OTC, we find the result that the forward market is quite transparent interesting. It

Parameter	Estimate	t-statistic
λ	11.98	0.45
γ	0.83*	25.96
$R^2 = 0.70$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent level

Table 2: NLS regression results

actually means that the market by itself is able to activate the role of forward sales as a commitment device.

The estimate for the risk aversion parameter, $\hat{\lambda}$, turns out not to be significant. This suggests that there is not clear evidence that risk-hedging is a key factor explaining observed hedge ratios in the Dutch natural gas market. [27]

The previous regression assumes demand volatility is constant over time. To explore further this latter result on the lack of risk-hedging incentives, we construct a measure of demand volatility using spot market prices and use it to increase the variation in the data. Using equation (56), and rearranging, we can write the equilibrium spot price as follows:

$$p_t = a_t - b_t \sum_i \Gamma_{it} x_{it} + \frac{1}{(n_t + 1)} \epsilon_t \tag{33}$$

From this expression we can compute a measure of demand volatility:

$$\sigma_t^2 = (n_t + 1)^2 \sigma_{p_t}^2. \tag{34}$$

To determine the monthly volatility of demand shocks, we thus need some measure for price variability. For this, we first proxy daily spot prices by computing a weighted price index for day-ahead contracts. Then, monthly demand volatility, σ_t^2, is obtained by calculating the variance of the spot prices within a particular month and multiplying this measure by $(n_t + 1)^2$. The new estimates of equation (28) are in Table 3. The estimate of the transparency parameter γ is somewhat lower and continues to be highly significant. Again we do not obtain significant evidence that risk is an important issue in this market.

We have searched for explanations for the result that risk-hedging does not seem to be an important factor in our data. One possible explanation is that being the strategic effect present and relatively strong, the incentives to hedge are minimal. In fact, when γ is close to one, the risk-hedging effect decreases in a quadratic way in the number of firms (see equation 21). For the firm numbers in our data (from 4 to 14 players), this effect is very small. Another observation is that for this range of parameters the hedge ratio is pretty insensitive to changes in λ. This makes it difficult to estimate precisely the parameter with

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[27]We have also estimated equation (28) for the case where n equals the number of all active wholesalers. We obtain similar results. The estimate for γ is equal to 0.76 and is significant at the 1 percent level, while λ, in this case becoming nearly zero, is again non-significant.

Parameter	Estimate	t-statistic
ρ/b	9189.1	0.00
γ	0.70*	30.83
$R^2 = 0.70$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent level

Table 3: NLS regression with demand volatility measure

a limited amount of data. Finally, we note that most TTF-trade is on high-calorific gas, for which demand is mainly industrial and therefore less subject to unpredictable weather shocks. The other type of gas sold at the TTF is low-calorific gas. Demand for this type of gas is weather-driven to a larger extent because this type of gas is meant for household usage; however, due to limited conversion capacity, a lot of the low-calorific gas delivered in the Netherlands does not pass the TTF.

4 Discussion and further results

4.1 Learning

It is conceivable that forward market transparency has increased over time. First, one can imagine that market participants' ability to interpret price signals has improved as time has elapsed. Second, it is also reasonable to believe that the quality and the quantity of the price indices available in the market has increased over time. Price information is now provided by information agencies such as ICIS Heren and Argus Media Ltd.,[28] brokers' associations such as LEBA[29] as well as the centralized marketplace ENDEX. Finally, the share of trades conducted (or cleared) at the gas exchange (vis-à-vis OTC) has increased over time and, since the exchange may be considered a more transparent marketplace than the OTC market, this adds to the supposition that the forward market as a whole has become more transparent. If this conjecture is borne by the data, we should observe an increase in the observability parameter γ over time.

To test this learning hipothesis, we introduce year dummies into the empirical model in (29). The new estimates are given in Table 4.

The results suggest that wholesalers' ability to infer deviations from equilibrium play has indeed increased over time.

4.2 Endogeneity of the number of wholesalers

In our model we have assumed demand is linear and this has implied that the hedge ratios are independent of the demand intercept parameter and the marginal cost of the firms. As

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[28]www.argusmedia.com

[29]London Energy Brokers' Association (www.leba.org.uk)

Parameter	Estimate	t-statistic
ρ/b	9967.8	0.00
γ_{2003}	0.81	1.19
γ_{2004}	0.30	0.99
γ_{2005}	0.67^*	7.42
γ_{2006}	0.66^*	13.20
γ_{2007}	0.71^*	18.12
γ_{2008}	0.71^*	20.76
$R^2 = 0.72$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent level

Table 4: NLS regression with demand volatility measure and year dummies.

a result, data on demand and costs are not essential to estimate equation (29). A related implication is that the estimates reported in Tables 2, 3 and 4 assume that the number of wholesalers is exogenous.

If, instead, we had used other demand specifications, the demand and cost parameters would probably have entered the equilibrium condition we want to estimate. Omitting these variables, together with the fact that market profitability –and therefore the number of active wholesalers– at the TTF depends on market characteristics such as demand strength, the cost of supplying gas and the cost of entering the hub, raises the issue that the number of active wholesalers is not exogenous from an econometrics point of view. To address this potential endogeneity issue, we propose to use a free-entry condition that we estimate together with equation (29).

We assume that gas wholesalers enter the TTF till the last firm that enters makes zero profit in expectation.[30] By substituting the equilibrium forward sales, given by equation (54), into the expression for profits we obtain the following zero-profit condition:

$$(a-c)^2 \Omega(b, \gamma, \rho, \sigma^2, \mu, n)/b - F + \nu = 0, \quad \nu \sim N(0, \sigma_\nu^2) \tag{35}$$

where F denotes a firm's cost of entry, $\Omega = \omega_1 \omega_2$, with

$$\omega_1 = \frac{(n+1-\gamma(n-1))((n+1)^2 + 2\lambda)}{(n+1)^2}$$

$$\omega_2 = \frac{(n+1)^2(n+1+\gamma(n-1)) + 2(3(n+1) - \gamma(n-1))\lambda}{((n+1)^2(n+1-\gamma(n-1)) + 2\gamma n(n^2-1) + 2(n(3-\gamma)+1+\gamma)\lambda)^2}$$

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[30]While in our theoretical framework firms maximize expected utility once they have entered the market, we assume that firms base their entry decision on expected profits. A practical reason for doing this is that in case we let firm entry incentives be based on (expected) utility, the entry condition, which we are going to exploit in the estimation, becomes very cumbersome to deal with. One theoretical validation for the dissimilarity between firms' pre-entry and post-entry objectives could be that market entry is decided upon by firm owners, who are typically assumed to be risk neutral, while daily control is delegated to firm managers, who are often considered as being risk-averse.

and the term ν is a random shock normally distributed with mean equal to zero and standard deviation given by σ_ν.

To add the information provided by the free entry condition (35) we need additional data. As a proxy for the demand intercept parameter a, we take monthly average prices of electricity spot contracts traded at the Dutch spot electricity exchange APX. In particular, we assume $a_t = a_0 + a_1 e_t$ where a_0, a_1 are free parameters and e_t is the spot price of electricity in period t.[31] On the cost side, we consider the oil price as being informative for the marginal production cost of a gas wholesaler. The rationale behind this is that prices in long-term contracts between gas producers and wholesalers are often indexed by the oil price. We therefore proxy the monthly marginal cost by $c_t = c_0 + c_1 o_t$, where c_0, c_1 are free cost parameters and o_t is the monthly world oil price.

It is difficult to obtain information on entry costs. Wholesalers operating in the TTF have to pay a fixed fee of 1,263 Euros to register at the TTF for a single gas month. In addition, if these wholesale firms also want to participate in the centralized exchanges, they have to pay an extra fixed fee of 2083 Euros per month.[32]

We thus estimate the following system of equations:

$$\begin{pmatrix} y_t \\ 0 \end{pmatrix} = \begin{pmatrix} g(n_t, \sum_{i=1}^n x_{it}, \gamma, \lambda) \\ \xi r(a_t, c_t, F, n_t, \gamma, \lambda) \end{pmatrix} + \begin{pmatrix} \epsilon_t \\ \xi \nu_t \end{pmatrix}, \quad \begin{pmatrix} \epsilon_t \\ \xi \nu_t \end{pmatrix} \sim \left(0, \begin{pmatrix} \sigma_\epsilon^2 & 0 \\ 0 & \sigma_\nu^2 \end{pmatrix} \right) \qquad (36)$$

where $r(a_t, c_t, F_t, n_t, \gamma, \lambda) \equiv (d + a_1 e_t - \beta_1 c_t)^2 \Omega(\gamma, \lambda, n_t) - F_t$, $d = a_0 - c_0$ and ξ is a weighting parameter that is attached to the restrictions. Since the degree of informativeness of the zero-profit conditions depends on the variability of these restrictions, we set ξ equal to the ratio of the standard deviations of the two error terms in (36), $\xi = \sigma_\epsilon / \sigma_\nu$.[33] The new regression results are summarized in Table 5.

Parameter	Estimate	t-statistic
λ	26.83	0.64
γ	0.81*	21.83
$R^2 = 0.83$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent significance level

Table 5: NLS regression results with endogenous n

As can be seen from the table, the estimates of the key parameters do not change much if we include the stochastic zero-profit conditions in the regressions. The strategic effect is again

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[31]As mentioned above, a great deal of the gas traded in the TTF is high-calorific gas whose main use is in industrial applications such as the production of ammoniac as well as in the production of electricity.

[32]Next to the fixed fee, participants pay a variable tariff for each MWh traded in the TTF. These variable fees are picked up by the constant c_0 in our estimation.

[33]We conduct a feasible weighted NLS regression (see Greene, 1993). The estimate of the weight ξ is given by $\hat{\xi} = \sqrt{\dfrac{\hat{\epsilon}'\hat{\epsilon}}{\hat{\nu}'\hat{\nu}}}$, which is the square root of the ratio of the sums of squared residuals.

highly significant, while the risk-hedging motive is still non-significant. The explanatory power of the regression increases.

4.3 Imperfect observability by financial traders

In the analysis so far we have assumed that financial traders are informed about the wholesalers' forward positions at all times. The implication of this assumption is that a strong version of arbitrage (off and on the equilibrium path) between forward and spot markets holds. In this Section we explore the importance of this assumption. If, instead, speculators do not observe the wholesalers' forward positions at all, they do not react to out of equilibrium deviations. As a result, the forward price is rigid and does not change off the equilibrium path. Of course in equilibrium traders' beliefs are correct, so that $f = E(p)$ still holds true.

To explore the role of this assumption, we propose to consider the case in which financial traders observe wholesalers' forward positions imperfectly. We model this idea by introducing a new Bernoulli random variable, denoted I_s, with parameter μ. If $I_s = 1$ deviations in the forward market become observed by the financial traders; this occurs with probability μ. If $I_s = 0$, forward positions remain opaque and the forward and the spot price need not coincide off the equilibrium path. The parameter μ can then be interpreted as the extent to which the forward transactions are observed by the financial traders/speculators.

In this case, the average hedge ratio is

$$\Gamma_i = \frac{b(n+1)^2((n-1)(2-\mu)\gamma + (1+n)\mu) - 2(2 + \mu(1+\gamma) + (2 + \mu(1-\gamma))n)\rho_i\sigma^2}{2(n+1)(b(n^2-1)\gamma + 2\rho_i\sigma^2)}. \quad (37)$$

Note that

$$\frac{\partial \Gamma_i}{\partial \mu} = \frac{(1 + \gamma + n(1-\gamma))(b(n+1)^2 + 2\rho_i\sigma^2)}{2(n+1)(b(n^2-1)\gamma) + 2\rho_i\sigma^2} > 0. \quad (38)$$

Therefore, as the probability that traders observe deviations goes up, a smaller fraction of a firm i's output is hedged. The intuition or this result is simple: everything else equal, the negative price effect brought about by a firm's forward sales (referred to above) strengthens as the forward market becomes less opaque for the speculators (spot and forward price falls only if this deviation is anticipated by the traders).

We now estimate this extension where the traders observe forward positions with probability μ. This amounts to fitting equation (29) modified by the fact that the average hedge ratio is now given by (37). We obtain an estimate of speculators' observability parameter μ. The new estimates are in Table 6.
The new results show a somewhat weaker strategic effect, though, in line with the previous results, it is still highly significant. We continue not obtaining conclusive evidence that the

Parameter	Estimate	t-statistic
λ	0.00	0.00
γ	0.63 *	8.27
μ	0.47	0.01
$R^2 = 0.71$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent significance level

Table 6: NLS regression results with imperfect financial traders

risk-hedging effect is relevant in our market. Finally, the observability parameter of the financial traders equals 0.47, though it is not estimated with much precision.[34]

Lastly, we estimate the model with imperfect trader observability by including year dummies for γ. The results are displayed in Table 7. We again observe an increase in the year dummies, which suggests that the strategic motive has gained more importance over the years. However, since none of the estimates is significant we do not want to draw any strong conclusion from these results.

Parameter	Estimate	t-statistic
λ	26.83	0.64
μ	0.38	0.43
γ_{2003}	0.32	0.29
γ_{2004}	0.00	0.00
γ_{2005}	0.37	0.72
γ_{2006}	0.40	0.89
γ_{2007}	0.48	1.03
γ_{2008}	0.48	1.03
$R^2 = 0.73$		

Notes: n equal to wholesalers 80% of market

Table 7: NLS regression results with imperfect trader observability and year dummies

5   Concluding remarks

This paper has proposed a methodology to investigate whether oligopolistic firms sell futures for strategic reasons, for risk-hedging motives, or for both. Our empirical test builds on a theoretical model of the interaction of risk-averse firms that compete in futures and spot markets. We find that the effects of an increase in the number of players on the equilibrium hedge ratio depend on the strategic role played by forward contracts. If forward sales play

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[34]When instead of using 80% of the wholesalers we use all of them, we obtain an estimate of γ equal to 0.76, with a t-statistic 16.45, an estimate of λ equal to 0.10, with a t-statistic 0.00, and an estimate of μ equal to 1.00, with a t-statistic 0.00.

no strategic role whatsoever, the hedge ratio decreases as more firms enter the market; otherwise, the hedge ratio increases. Firms hedge less if demand is very elastic and, as expected, more risk averse firms have a greater propensity to hedge. These results serve to structure our empirical research.

Using data from the Dutch wholesale market for natural gas where we observe the number of wholesalers, forward and spot sales, and churn rates, we find evidence that strategic reasons play an important role at explaining the observed firms' hedge ratios. By contrast, the data do not support the idea that risk-hedging motives are an important aspect behind the observed firms' hedge ratios. Seen under the perspective that most of the forward transactions in the Dutch natural gas market occur OTC we think this is an important result. We also document a learning effect, which is probably related to the development of the market and the increase in the share of trades conducted, or cleared at, the centralized gas futures exchange.

Setting up futures markets involves social costs. The costs of operating a futures market are non-negligible even in a time where virtual market places have displaced the more traditional physical hubs. In fact, personnel and ICT costs, along with the insurance and financial costs of dealing with default and other risks involved may render a marketplace unprofitable. For example, the Dutch futures exchange ENDEX has been making losses for 5 out of its 6 or 7 years of existence. At the end of 2009, ENDEX was taken over by the APX Group, which owns various platforms for spot trading of natural gas and electricity in the NL, Belgium and the U.K.

Whether the OTC market provides sufficient incentives to sell forward for strategic reasons and not only to hedge risks is therefore central to the cost-benefit analysis of the futures market institution. Since the gas exchange seems to have increased transparency in the system and therefore increased overall output in the industry, our findings add to the case in favor of sustaining a market for natural gas futures. A complete cost-benefit analysis is outside the scope of this paper.[35]

Futures markets exist for a number of commodities, including electricity, natural gas, emission trading permits, copper, iron ore, aluminium, steel etc. Though we have applied our model to the natural gas market in the Netherlands, we believe the general message of this paper is broader. Our insights, and in particular our methodology to address the question whether firms trade futures for strategic motives, should be applicable to other markets where firms have significant market power.

6   Appendix A: Proofs

Proof of Proposition 1.

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[35] For a recent cost-benefit analysis of ERCOT see the 2008 *Report on the Cost and Benefits of Transition to ERCOT Nodal Market*, available from the Public Utility Commission of Texas. This report states that system-wide costs of ERCOT for the period 2009-2020 will likely offset the social benefits by 43%.

After some algebra, equation (17) can be written as:

$$E[u(\pi_i)] = -\gamma \int \frac{1}{\sigma\sqrt{2\pi}} e^{-(\rho_i\pi_i^{I=1}+\epsilon^2/2\sigma^2)} d\epsilon - (1-\gamma) \int \frac{1}{\sigma\sqrt{2\pi}} e^{-(\rho_i\pi_i^{I=0}+\epsilon^2/2\sigma^2)} d\epsilon \tag{39}$$

or

$$\begin{aligned}
E[u(\pi_i)] &= -\gamma e^{-\frac{\alpha\beta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}} \int e^{-\frac{2\alpha\sigma^2+1}{2\sigma^2}\left(\epsilon+\frac{2\alpha\beta(x_i)\sigma^2}{2\alpha\sigma^2+1}\right)^2} d\epsilon \\
&\quad - (1-\gamma) e^{-\frac{\alpha\delta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}} \int e^{-\frac{2\alpha\sigma^2+1}{2\sigma^2}\left(\epsilon+\frac{2\alpha\delta(x_i)\sigma^2}{2\alpha\sigma^2+1}\right)^2} d\epsilon
\end{aligned} \tag{40}$$

Integrating yields

$$E[u(\pi_i)] = -\frac{\gamma}{\sqrt{2\pi\tau^2}} e^{-\frac{\alpha\beta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}} - \frac{1-\gamma}{\sqrt{2\pi\tau^2}} e^{-\frac{\alpha\delta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}} \tag{41}$$

where

$$\alpha = \frac{\rho_i}{b(n+1)^2} \tag{42}$$

$$\beta(x_i) = a + \sum_{j\neq i}^{n} c_j - nc_i - bx_i - b\sum_{j\neq i}^{n} x_j \tag{43}$$

$$\varphi(x_i) = (f - c_i)x_i \tag{44}$$

$$\delta(x_i) = a + \sum_{j\neq i}^{n} c_j + b/2(n-1)\hat{x}_i - nc_i - b/2(n+1)x_i - b\sum_{j\neq i}^{n} \hat{x}_j \tag{45}$$

$$\tau^2 = \frac{\sigma^2}{2\alpha\sigma^2+1}. \tag{46}$$

Taking the derivative of (41) with respect to x_i gives:

$$\begin{aligned}
&\frac{\gamma}{\sqrt{2\pi\tau^2}} e^{-\frac{\alpha\beta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}} \frac{d}{dx_i}\left(\frac{\alpha\beta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}\right) \\
&+\frac{1-\gamma}{\sqrt{2\pi\tau^2}} e^{-\frac{\alpha\delta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}} \frac{d}{dx_i}\left(\frac{\alpha\delta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}\right) = 0
\end{aligned} \tag{47}$$

Imposing the rational expectations requirement that firms' conjectures must be correct in equilibrium, i.e., $\hat{x}_i = x_i$ and $\hat{x}_j = x_j$, we obtain:

$$\gamma\frac{d}{dx_i}\left(\frac{\alpha\beta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}\right) + (1-\gamma)\frac{d}{dx_i}\left(\frac{\alpha\delta(x_i)^2+(2\alpha\sigma^2+1)\rho_i\varphi(x_i)}{2\alpha\sigma^2+1}\right) = 0 \tag{48}$$

or

$$\gamma\frac{d}{dx_i}\left(\frac{\alpha\beta(x_i)^2}{2\alpha\sigma^2+1}\right) + (1-\gamma)\frac{d}{dx_i}\left(\frac{\alpha\delta(x_i)^2}{2\alpha\sigma^2+1}\right) + \rho_i\frac{d\varphi(x_i)}{dx_i} = 0 \tag{49}$$

We now notice that

$$\frac{d}{dx_i}\left(\frac{\alpha\beta(x_i)^2}{2\alpha\sigma^2+1}\right) = -\frac{2b\rho_i\left(a+\sum_{j\neq i}^n c_j - nc_i - bx_i - b\sum_{j\neq i}^n x_j\right)}{2\rho_i\sigma^2+b(n+1)^2} \tag{50}$$

$$\frac{d}{dx_i}\left(\frac{\alpha\delta(x_i)^2}{2\alpha\sigma^2+1}\right) = -\frac{(n+1)b\rho_i\left(a+\sum_{j\neq i}^n c_j + b/2(n-1)\hat{x}_i - nc_i - b/2(n+1)x_i - b\sum_{j\neq i}^n \hat{x}_j\right)}{2\rho_i\sigma^2+b(n+1)^2} \tag{51}$$

and

$$\begin{aligned}
\frac{d\varphi(x_i)}{dx_i} = f - c_i + \frac{df}{dx_i}x_i &= \gamma\frac{a+\epsilon+\sum_i^n c_i - bx_i - b\sum_{j\neq i}^n x_j}{n+1}\\
&+ (1-\gamma)\frac{a+\epsilon+c_i+\sum_{j\neq i}^n c_j + b/2(n-1)\hat{x}_i - b/2(n+1)x_i - b\sum_{j\neq i}^n \hat{x}_j}{n+1}\\
&- c - \left(\frac{b\gamma}{n+1} + \frac{b(1-\gamma)}{2}\right)x_i
\end{aligned} \tag{52}$$

since $f = E(p) = \gamma p^{I=1} + (1-\gamma)p^{I=0}$. Plugging these expressions in (49) and using again the equilibrium conditions $\hat{x}_i = x_i$ and $\hat{x}_j = x_j$, we can simplify the FOC to:

$$-\frac{2b\gamma+b(n+1)(1-\gamma)}{2\rho_i\sigma^2+b(n+1)^2}\beta(x_i) + \frac{\beta(x_i)}{n+1} - \left(\frac{2b\gamma+b(n+1)(1-\gamma)}{2(n+1)}\right)x_i = 0 \tag{53}$$

Solving for x_i gives:

$$x_i = \frac{2(b(n^2-1)\gamma+2\rho_i\sigma^2)(a+\sum_{j\neq i}^n c_j - nc_i - b\sum_{j\neq i}^n x_j)}{b(b(n+1)^3 - b(n-1)^2(n+1)\gamma + 2(3+\gamma+n(1-\gamma))\rho_i\sigma^2)} \tag{54}$$

Using equation (8), we can write firm i's total output $q_i = s_i + x_i$ as:

$$q_i = \frac{n}{n+1}x_i + \frac{a+\sum_{j\neq i}^n c_j - nc_i - b\sum_{j\neq i}^n x_j}{b(n+1)} + \frac{\epsilon}{b(n+1)} \tag{55}$$

One way to measure the relationship between forward and spot sales is to consider the inverse hedge ratio –the ratio total-to-forward-sales:

$$\frac{q_i}{x_i} = \frac{b(n+1)^2(n+1+(n-1)\gamma) + 2(3+\gamma+(3-\gamma)n)\rho_i\sigma^2}{2(n+1)(b(n^2-1)\gamma+2\rho_i\sigma^2)} + \frac{1}{b(n+1)x_i}\epsilon \tag{56}$$

The average inverse hedge ratio of a firm i, Γ_i, follows from taking expectations in (56). It is clear that Γ_i depends neither on c_i nor on a. Given that

$$\frac{\partial\Gamma_i}{\partial b} = \frac{(n+1-\gamma(n-1))^2\rho_i\sigma^2}{(b\gamma(n^2-1)+2\rho_i\sigma^2)^2} > 0 \tag{57}$$

the inverse hedge ratio goes up with the slope parameter b. Since

$$\frac{\partial\Gamma_i}{\partial\rho_i} = -\frac{(n+1-\gamma(n-1))^2 b\sigma^2}{(b\gamma(n^2-1)+2\rho_i\sigma^2)^2} < 0 \tag{58}$$

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the inverse hedge ratio decreases as the firm is more risk averse. Since

$$\frac{\partial \Gamma_i}{\partial \gamma} = -\frac{(n-1)(b(n+1)^2 + 2\rho_i\sigma^2)^2}{2(n+1)(b\gamma(n^2-1) + 2\rho_i\sigma^2)^2} < 0 \tag{59}$$

the inverse hedge ratio decreases in the probability forward positions are observed.

Finally, we note that

$$\frac{\partial \Gamma_i}{\partial n} = \frac{2b(n+1)((n+1)^2 + (n-1)^2\gamma^2 - 2\gamma n(n+1))\rho_i\sigma^2 - b^2\gamma(n+1)^4 - (2\rho_i\sigma^2)^2}{(n+1)^2(b\gamma(n^2-1) + 2\rho_i\sigma^2)^3}$$

Note that $\partial \Gamma_i/\partial n$ is differentiable w.r.t. γ, which implies that $\partial \Gamma_i/\partial n$ is continuous in γ.

Next, we observe that

$$\left.\frac{\partial \Gamma_i}{\partial n}\right|_{\gamma=0} = \frac{b(n+1)}{2\rho_i\sigma^2} > 0$$

and

$$\left.\frac{\partial \Gamma_i}{\partial n}\right|_{\gamma=1} = -\frac{1}{(n+1)^2} - \frac{4b^2 n}{(b(n^2-1) + 2\rho_i\sigma^2)^2} < 0$$

for all $n \geq 2$, $b > 0$, $\rho_i > 0$ and $\sigma^2 > 0$. Given that $\partial \Gamma_i/\partial n$ is continuous in γ, this implies that $\partial \Gamma/\partial n = 0$ for at least one $\gamma \in (0,1)$.

Further, $\partial \Gamma/\partial n = 0$ has two solutions for γ, denoted by $\tilde{\gamma}$ and $\tilde{\gamma}_2$:

$$\tilde{\gamma} \equiv \frac{b^2(n+1)^4 + 4bn(n+1)^2\rho_i\sigma^2 + 4\rho_i^2\sigma^4 - (b(n+1)^2 + 2\rho_i\sigma^2)\sqrt{Z}}{4b(n-1)^2(n+1)\rho_i\sigma^2} \tag{60}$$

and

$$\tilde{\gamma}_2 \equiv \frac{b^2(n+1)^4 + 4bn(n+1)^2\rho_i\sigma^2 + 4\rho_i^2\sigma^4 + (b(n+1)^2 + 2\rho_i\sigma^2)\sqrt{Z}}{4b(n-1)^2(n+1)\rho_i\sigma^2} \tag{61}$$

where $Z = b^2(n+1)^4 + 4b(n+1)^2(2n-1)\rho_i\sigma^2 + 4\rho_i^2\sigma^4$. Now for all $n \geq 2$, $b > 0$, $\rho_i > 0$ and $\sigma^2 > 0$, we have:

$$\tilde{\gamma}_2 > \frac{2(b(n+1)^2 + 2\rho_i\sigma^2)^2 + 4b(n-1)(n+1)^2\rho_i\sigma^2}{4b(n-1)^2(n+1)\rho_i\sigma^2}$$

$$> \frac{2(b(n+1)^2 + 2\rho_i\sigma^2)^2 + 4b(n-1)(n+1)^2\rho_i\sigma^2}{4bn(n-1)(n+1)\rho_i\sigma^2}$$

$$= \frac{n+1}{n} + \frac{(b(n+1)^2 + 2\rho_i\sigma^2)^2}{2bn(n-1)(n+1)\rho_i\sigma^2}$$

$$> 1$$

Since $\tilde{\gamma}_2 > 1$ and $\partial \Gamma_i/\partial n = 0$ for at least one $\gamma \in (0,1)$, it must be true that $\tilde{\gamma} \in (0,1)$. Now, because $\left.\frac{\partial \Gamma_i}{\partial n}\right|_{\gamma=0} > 0$ and $\left.\frac{\partial \Gamma_i}{\partial n}\right|_{\gamma=1} < 0$ and by continuity in γ, we have $\frac{\partial \Gamma_i}{\partial n} < 0$ if $\gamma < \tilde{\gamma}$ and $\frac{\partial \Gamma_i}{\partial n} > 0$ if $\gamma > \tilde{\gamma}$.

Derivation of equilibrium inverse hedge ratios under imperfect observability of speculators.

In this case, equation (52) above is modified to

$$\frac{d\varphi(x_i)}{dx_i} = f - c + \mu\frac{df}{dx_i}x_i \tag{62}$$

and the FOC for wholesaler i given by equation (49) is modified by plugging:

$$
\begin{aligned}
\frac{d\varphi(x_i)}{dx_i} &= \gamma\frac{a + \epsilon + \sum_i^n c_i - bx_i - b\sum_{j\neq i}^n x_j}{n+1} \\
&+ (1-\gamma)\frac{a + \epsilon + c_i + \sum_{j\neq i}^n c_j + b/2(n-1)\hat{x}_i - b/2(n+1)x_i - b\sum_{j\neq i}^n \hat{x}_j}{n+1} \\
&- c - \mu\left(\frac{b\gamma}{n+1} + \frac{b(1-\gamma)}{2}\right)x_i
\end{aligned}
\tag{63}
$$

The optimal level of forward selling becomes

$$x_i = \frac{2(b(n^2-1)\gamma + 2\rho_i\sigma^2)(a + \sum_{j\neq i}^n c_j - nc_i - b\sum_{j\neq i}^n x_j)}{b\left(b\mu(n+1)^3 - b(n^2-1)(\mu(n+1)-2)\gamma + 2(2+(1+\gamma+n(1-\gamma))\mu)\rho_i\sigma^2\right)} \tag{64}$$

and the corresponding equilibrium inverse hedge ratio:

$$
\begin{aligned}
\frac{q_i}{x_i} &= \frac{b(n+1)^2((n-1)(2-\mu)\gamma + (1+n)\mu) + 2(2+\mu(1+\gamma) + (2+\mu(1-\gamma))n)\rho_i\sigma^2}{2(n+1)(b(n^2-1)\gamma + 2\rho_i\sigma^2)} \\
&+ \frac{1}{b(n+1)x_i}\epsilon.
\end{aligned}
$$

7 Appendix B: TTF contracts

All contracts traded in the TTF call for physical delivery of natural gas at the GTS transmission grid. Concerning forward transactions, the most prominent types of contracts are the ones that are also eligible at Endex:[36]

- Single-month contracts; these contracts can be traded from three months ahead till the expiration date, which is, with the exception of holidays, the penultimate working day of the month that precedes the month of delivery. The monthly contract then moves into delivery at the GTS transmission grid.

- Single-quarter contracts (quarters being defined as January-March, April-June, July-September and October-December); trade in these contracts starts four quarters ahead and continues till the moment the contract expires. For this product, the day of expiration is the last but two working days of the last quarter before physical supply takes place. After expiration, the quarterly contract converts into three monthly contracts.

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[36]There exist also some contracts that can be traded OTC but not in the centralized exchange Endex. Among them are the *Balance-of-Month* (BOM) and *Working-Days-Next-Week* (WDNW) contracts. These kind of forward products constitute only a tiny share of the total number of the transactions in the TTF.

- Single-season contracts (seasons being defined as April-September and October-March); these contracts can change hands from four seasons ahead till the day of expiration, which is the last but two working days of the season preceding the delivery period. When the seasonal contract expires, it falls into three monthly contracts and one quarterly contract.

- Single-calendar-year contracts (calendar year being defined as January-December); these contracts can be traded from three calendar years ahead till the moment of expiration, which is the last but two working days of the last year before the gas is delivered. After the contract expires, it cascades into three monthly contracts and three quarterly contracts.

The minimum volume that can be specified in quarterly, seasonal and calendar contracts is 10 MWh/h; for monthly contracts, this minimum volume equals 30 MWh/h.

Next to forward contracts, participants also trade spot contracts at TTF. Two types of spot market contracts can be distinguished:

- Day-ahead contracts; the trading market for these contracts opens two working days before physical supply takes place and closes two hours prior to the start of delivery.

- Within-day contracts; these contracts can be traded from 26 hours prior to delivery till two hours before the gas is physically supplied.

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