Stockholm Institute of Transition Economics

WORKING PAPER

April 2019

No. 47

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April 23, 2019

Abstract

We study the use of financial contracts as bid-coordinating device in multi-unit uniform price auctions. Coordination is required whenever firms face a volunteer's dilemma in pricing strategies: one firm (the "volunteer") is needed to increase the market clearing price. Volunteering, however, is costly, as inframarginal suppliers sell their entire capacity whereas the volunteer only sells residual demand. We identify conditions under which signing financial contracts solves this dilemma. We test our framework exploiting data on contract positions by large producers in the New York power market. Using a Monte Carlo simulation, we show that the contracting strategy is payoff dominant and provide estimates of the benefits of such strategy.

Keywords: Auctions, Coordination, Volunteer's dilemma, Forward markets.
JEL-Classification: D21, D44, L41.

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1 Introduction

A variety of goods and services are traded in multi-unit auctions. Classic examples include auctions for government bonds (Hortaçsu et al. (2018)), spectrum rights (Cramton and Ockenfels (2017)), electricity (Fabra et al. (2006)), carbon emissions allowances (Lopomo et al. (2011)), or gas pipeline capacity (Newbery (2002)). The majority of multi-unit auctions clear at a uniform price, which facilitates market entry (Ausubel et al. (2014)). Depending on the market architecture, bidders may also take financial positions on forward markets before participating in the auction.

The theoretical literature on strategic forward trading shows that forward contracts affect spot market prices, either by enhancing or softening spot market competition (e.g., Allaz and Vila (1993), Mahenc and Salanié (2004)). An example that seems to contradict the extant findings, however, was observed in the New York power market, which operates as a multi-unit uniform price auction. Whereas two major producers signed forward contracts in 2006, the market price stayed equal to the regulatory price cap before and after the contract start date. Both the US Federal Energy Regulatory Commission (FERC) and the Department of Justice (DOJ) investigated whether the contractual agreements constituted market manipulation. Their findings differed significantly. FERC (2008) argued against market manipulation and concluded that the contracts were instruments to hedge price risk. DOJ (2010), following Cramton (2007), found that the contracts helped firms to avoid competitive bidding strategies.

Using this case, we present a new theoretical framework to examine how forward contracts allow firms to coordinate on one of multiple equilibria in the spot market. Rather than explaining forward contracts as a means to impact equilibrium spot prices, we offer a new rationale for signing forward contracts, which is to avoid miscoordination in pricing. We apply our model using rarely observed data on firms' financial positions from the case investigated by FERC and DOJ. Simulating market outcomes with and without contracts, we show that forward positions rule out competing (off-)equilibrium outcomes and allow firms to coordinate on their pricing strategies.

For our theoretical analysis, we model a standard multi-unit uniform price auction (e.g., Fabra et al. (2006)) with two large firms and a competitive fringe. Prior to auction clearing, the two large firms can sign forward contracts with a financial intermediary.[1] As it is assumed

[1] We assume that contract positions are common knowledge. This is in line with our empirical case, where the financial intermediary publicly searched for counterparties for the contract and later was accused of coordinating financial flows, having to pay 4.8 USD million in disgorgement (DOJ (2012)).

that either firm's capacity must be deployed to satisfy full demand, all pricing equilibria are characterized by one pivotal firm that clears the auction. This price-setting firm can charge a supra-competitive price due to its market power vis-à-vis residual demand, yet it compromises on selling parts of its capacity.

As Le Coq et al. (2017) point out, firms in such a game face a coordination problem akin to the volunteer's dilemma (e.g., Diekmann (1985), Goeree et al. (2017)): one firm (the "volunteer") is needed to increase the market clearing price.[2] Volunteering, however, is costly, as inframarginal suppliers sell their entire capacity whereas the volunteer only sells residual demand. Our model illustrates conditions under which signing financial contracts solves this dilemma. More precisely, we show that signing opposite forward contracts increases both firms' profits when firms face the volunteer's dilemma. The contracts work as follows. The volunteering firm holds a long position, while the non-volunteering firm holds a corresponding short position. By holding a long position, the volunteer obtains the high clearing price not only for its spot sales, but also for its financially contracted quantity. The other ("free-riding") firm, while losing money via the contract, benefits as it sells full capacity with certainty, knowing that its rival volunteers.

We test our theoretical predictions by analyzing pricing strategies and contract choices in the New York power market. Focusing on this market offers several advantages. First, the fundamentals of this market, e.g., on marginal costs, are in line with the characteristics of our model. Furthermore, the market was highly concentrated during our period of observation which corresponds to our model with dominant and fringe firms. Moreover, our setting allows for exploiting detailed data on demand curves and firm capacities. Finally, given that the contracts at stake were publicly investigated, we can make use of detailed information on underlying contract positions.

For our empirical analysis, we conduct a Monte Carlo simulation of market outcomes with and without observed contracts. We first show that, without contracts, the two largest firms would face a volunteer's dilemma. Second, in line with our predictions, we find that the contract positions ruled out one of the two competing equilibria of the volunteering game. Third, we show that firms' contracting strategies were weakly payoff dominant, even at constant clearing prices before and after the contract start date. Our empirical investigation further illustrates that swapped profits via the forward market were just sufficient to achieve commitment and to reward the price-setting firm for its volunteering role.

Our paper is closely related to the literature on strategic interaction in forward and

[2] Alternatively, the volunteer's dilemma can be interpreted as an N-person battle of the sexes.

spot markets as pioneered by Allaz and Vila (1993). Starting from an oligopoly equilibrium on the spot market, they prove a competition-enhancing effect of forward markets. However, whether contracting triggers aggressive pricing behavior depends crucially on the institutional and structural market features, e.g., on whether market participants interact repeatedly (Liski and Montero (2006)), on the distribution of contracts among firms (de Frutos and Fabra (2012)), as well as on arbitrage opportunities (Ito and Reguant (2016)).

Within this literature, the paper closest to ours is Mahenc and Salanié (2004), who show that when products are differentiated and prices are strategic complements, producers can buy their production forward to soften spot market competition. We study a setup where firms sell a homogeneous product in multi-unit uniform price auctions. In this context, "buying forward strategies" pay off even when firms do not alter market prices. In our analysis, financial contracts establish coordination on bidding strategies amid multiple equilibria on the spot market and effectively re-distribute rents. This mechanism is similar to the one outlined in the industrial organization literature on side payments to enforce collusion (e.g., Harrington and Skrzypacz (2007)). In our case, financial contracts make side payments credible by conditioning payments on the market outcome.

Our paper is also related to the empirical literature on strategic firms signing forward contracts (e.g., Wolak (2003), Hortacsu and Puller (2008), Eijkel et al. (2016)) or investing in new capacities (Grimm and Zoettl (2013)), before competing on the spot market. Moreover, Schwenen (2015) studies spot market bidding behavior in the New York power market from 2003 to 2008. He empirically investigates the optimality of bidding strategies for all participating firms. We add to this paper by looking at a subset of his observation period and study how contracting changes the incentives to (not) volunteer for the two largest firms.

Finally, this paper also relates to the game theory literature on coordination games, as in our case firms need to coordinate on a volunteer, and miscoordination is costly. Analyzing this setting in the laboratory, Goeree et al. (2017) show that miscoordination (e.g., the no-volunteer outcome) increases with the number of players. Our model shows how contract payments contingent on the outcome of the game solve the volunteer's dilemma.[3]

The next section characterizes the auction model and the resulting volunteer's dilemma. Section 3 characterizes conditions under which forward contracts solve this dilemma. Section 4 tests our theoretical predictions using a Monte Carlo simulation. Section 5 discusses some model extensions to a broader set of market environments. Section 6 concludes.

[3]Note also that Boom et al. (2008) use equilibrium selection arguments to rule out multiple equilibria in multi-unit auctions. Risk-dominance arguments show that larger firms set the clearing price. In a supply function setting, Hortaçsu et al. (2017) reduce the number of equilibria using a Cognitive Hierarchy model.

2 The market environment

We consider a standard multi-unit uniform price procurement auction framework (e.g., Fabra et al. (2006)) and derive necessary conditions for a volunteer's dilemma in bidding strategies.

Two large and strategic firms $i, j = 1, 2$ with $i \neq j$, and a competitive fringe participate in a multi-unit uniform price auction. Prior to bidding, the auctioneer publicly announces a demand function. In line with our empirical application we assume linear demand of

$$D(p) = a - dp, \tag{1}$$

with market price p and constant parameters a and d.

All firms have zero marginal costs. Each large firm i offers a price-quantity pair (b_i, k_i), where k_i is the maximum quantity that firm i is willing to sell[4] at or above an equilibrium auction price of b_i.[5] The fringe acts as price-taker and therefore always submits its full capacity k_f at marginal costs, i.e., at prices of zero.

The clearing price p^* equates demand and supply. The auction clears with uniform pricing so that all bids below the clearing price win and receive the latter. To limit procurement costs, the auctioneer imposes a price cap $\bar{p}$. Bids are perfectly divisible. We further assume that both dominant firms are pivotal in clearing the auction at any positive price equal to or below the price cap:

Assumption 1 *[Pivotal firms and no rationing] For each large firm $i = 1, 2$ with $i \neq j$, $D(\bar{p}) - k_f - k_j > 0$ and $D(b_i \mid b_i = p^*) \leq k_f + k_i + k_j$ holds, where $b_i = p^* \in [0, \bar{p}]$ is the optimal bid of the price-setting firm i.*

Firm i's profits can be written as

$$\pi_i = q_i(b_i, b_j, k_f)p^*, \tag{2}$$

where firm i's quantity sold in the auction, $q_i(b_i, b_j, k_f)$, is defined as

$$q_i(b_i, b_j, k_f) = \begin{cases} k_i & \text{if } b_i < b_j = p^* \\ \frac{k_i}{k_i + k_j}\left(D(p^*) - k_f\right) & \text{if } b_i = b_j = p^* \\ D(p^*) - k_f - k_j & \text{if } b_i = p^* > b_j. \end{cases} \tag{3}$$

[4] The choice of submitted capacity, potentially smaller than k_i, is not relevant for our main results. We therefore assume that firms always submit their maximum capacity of k_i.

[5] The one-step bid function assumption simplifies the exposition without changing the results. As shown by Fabra et al. (2006), the equilibrium clearing price is independent of the number of bid steps.

In case of bid ties the auctioneer rations supply at the margin pro rata.[6]

2.1 Volunteer's dilemma

Given Assumption 1 and the allocation rule in (3), all firms but the price-setting one sell their entire submitted capacity. The price-setting bidder, in contrast, satisfies residual demand. Each firm hence prefers a market outcome in which its rival firm acts as price-setter. Conversely, accepting the role of price-setter is a best response if rivals choose against playing this role.

Bidders consequently face a volunteer's dilemma (Diekmann (1985)), where one price-setting bidder (the volunteer) is needed for all rivals to sell their submitted capacity at a favorably high price. However, volunteering is costly as bidders who price high and increase the clearing price on behalf of the market sell less as compared to undercutting their rival.

Next, we characterize the volunteer's dilemma more formally. When firm i volunteers to submit the clearing bid, so $b_i > b_j$, it optimizes against its residual demand and finds the optimal clearing bid

$$b_i^V = \min\{\arg\max_{b_i} q_i(b_i, b_j, k_f) b_i, \bar{p}\}, \tag{4}$$

where the superscript V denotes the optimal bid of a firm that volunteers to clear the market. Firm i volunteers if offering b_i^V is a more profitable strategy than undercutting its rival bid b_j. Formally, this holds if $\pi_i(b_i^V) = b_i^V q_i(b_i^V, \cdot) > \pi_i(b_i < b_j) = b_j k_i$. This inequality is fulfilled if firm j, in turn, chooses a bid b_j sufficiently low such that it is never optimal for firm i to undercut. This is the case if the free-riding firm j submits any bid

$$b_j^F \in [0, \bar{b}_j) \text{ with } \bar{b}_j = \frac{b_i^V q_i(b_i^V, \cdot)}{k_i}, \tag{5}$$

where the superscript F denotes bids by any firm $i, j = 1, 2$ with $i \neq j$ that intends to free-ride, becoming the inframarginal bidder and selling at full capacity.

Depending on whether or not the price cap is binding, the volunteering firms' equilibrium profits become

$$\pi_i(b_i^V) = \begin{cases} \frac{(a-k_f-k_j)^2}{4d} & \text{if } b_i^V < \bar{p}, \\ \bar{p}(D(\bar{p}) - k_f - k_j) & \text{if } b_i^V = \bar{p}. \end{cases} \tag{6}$$

The first part of the equation, when the price cap is not binding, corresponds to the profits associated with bid $b_i^V = \frac{a-k_f-k_j}{2d} < \bar{p}$ as defined in equation (4). The second part of

[6] Holmberg (2017) shows how alternative rationing rules impact auction outcomes.

the equation, when the price cap is binding, corresponds to the profits from selling residual demand of $q_i(b_i^V, \cdot)$ as defined in equation (3) at a price equal to the cap.

Due to the uniform price auction, the free-riding firm i sells all of its submitted quantity at the high price set by its rival and receives profits

$$\pi_i\left(b_i^F\right) = \begin{cases} \frac{a-k_f-k_i}{2d}k_i & \text{if } b_j^V < \bar{p}, \\ \bar{p}k_i & \text{if } b_j^V = \bar{p}. \end{cases} \tag{7}$$

Given that volunteering is the best response to a free-riding rival, there are multiple equilibria that differ in the identity of the volunteering firm as well as the low bid offered by the free-riding firm. The volunteer's dilemma arises because coordinating on one equilibrium is difficult as each firm always prefers that the other one volunteers.

Indeed, the volunteer's dilemma applies to a subset of existing equilibria described by Fabra et al. (2006) and de Frutos and Fabra (2012). In particular, for the dilemma to be relevant, the dominant firms must be sufficiently symmetric in capacities, as specified in Lemma 1.

Lemma 1 *[Sufficient symmetry] A volunteer's dilemma exists if the two pivotal firms are sufficiently symmetric such that* $k_i \leq k_j < \hat{k}_j(k_i)$ *where* $\hat{k}_j(k_i)$ *satisfies* $\pi_j(b_j < b_i^V(\hat{k}_j)) > \pi_j(b_j^V(k_i) > b_i)$ *with* $i = 1, 2$ *and* $i \neq j$.

Intuitively, Lemma 1 states that the relative capacities must be such that each firm prefers to be the inframarginal supplier. Hence $\hat{k}_j(k_i)$ characterizes the maximum capacity of the largest firm j for which the volunteer's dilemma still exists.

The functional form of $\hat{k}_j(k_i)$ follows from comparing firm j's profits from being inframarginal of $\pi_j(b_j < b_i^V(k_j))$ with profits from volunteering of $\pi_j(b_j^V(k_i) > b_i)$. When the price cap is non-binding, the condition in Lemma 1 becomes $\frac{a-k_f-k_j}{2d}k_j > \frac{(a-k_f-k_i)^2}{4d}$. Equating and solving for k_j yields the sufficient symmetry condition in Lemma 1. When the largest firm's capacity is above this threshold, the remaining demand and hence the clearing price set by its rival are so small that the larger firm prefers to clear the auction itself. As a result, the volunteer's dilemma vanishes. We derive $\hat{k}_j(k_i)$ in detail in Appendix A.1.

Note that $\hat{k}_j(k_i)$ includes the case of binding price caps for both dominant firms. In this case, firm j yields profits $\bar{p}k_j$ when free-riding and $\bar{p}(D(\bar{p}) - k_f - k_i)$ when volunteering. The only case where free-riding profits would not be larger is the case where $k_j < D(\bar{p}) - k_f - k_i$, which is ruled out by Assumption 1.

Corollary 1 *For equilibria* $(b_i^V = \bar{p}, b_j^F < \bar{b}_j)$ $\forall$ $i = 1, 2$ *and* $i \neq j$, *the volunteer's dilemma always exists.*

Hence if the price cap is the optimal bid if either of the dominant firms clears the market, the volunteer's dilemma must exist. Corollary 1 follows directly from Assumption 1, which rules out rationing. Rationing constitutes the only case where both firms could submit a bid equal to the cap without compromising on sales and hence without facing the volunteer's dilemma.

3 Financial contracts as coordination device

In this section we study how the volunteer's dilemma changes with firms' financial positions. Specifically, we show that by signing forward contracts, firms are able to coordinate on the identity of the volunteering firm and avoid miscoordination at the auction stage. Contracts are financial, hence they specify payments and no physical delivery.

3.1 Optimal bidding with contracts

We study a standard forward contract with a forward price $p^s \in [0, \bar{p}]$ and firm-specific contract quantity s_i. Net contract payments are given by $(p^* - p^s)s_i$. We assume that before interacting on the spot market, each large firm learns about its rival's position. With contracting, firm i's profits can be written as

$$\pi_i = q_i(b_i, b_j, k_f)p^* + (p^* - p^s)s_i. \tag{8}$$

Following conventional notation, the quantity contracted forward, s_i, is positive (negative) if firm i is a net buyer (seller) on the contract market. That is, for positive s_i, firm i receives payments whenever the clearing price is above the strike price. Payments instead reverse if the clearing price is below the strike price. If s_i is negative, payments flow in the opposite direction. Note that the case with negative s_i where firms are selling ahead is also studied in Allaz and Vila (1993), Wolak (2003), Hortacsu and Puller (2008), and Green and Le Coq (2010), while Mahenc and Salanié (2004) analyze the case where firms buy forward in equilibrium.

Given its contract position, the optimal clearing bid for a volunteering firm i is given by:

$$b_i^V = \min\{\arg\max_{b_i} q_i(b_i, b_j, k_f)b_i + (b_i - p^s)s_i, \bar{p}\}. \tag{9}$$

When the price cap is non-binding, equation (9) yields an optimal clearing bid of $\frac{a-k_f-k_j+s_i}{2d}$, so the clearing bid b_i^V increases in s_i. Given the uniform pricing format, free-riding firms' profits also increase in s_i. With a binding price cap however, positive forward positions of the price-setting firm do not increase market prices or producer rent.

In the following section, we focus on the case that we study in our empirical analysis, i.e., the case where the price cap is binding. Specifically, we show that by signing two offsetting forward contracts, firms can swap profits to establish coordination at the auction stage. The case of non-binding price caps is discussed in Section 5.

3.2 Coordination with contracts

To establish coordination, contracts must rule out one of the two pure-strategy equilibria (b_i^V, b_j^F) with $i = 1, 2$ and $i \neq j$. Without loss of generality, we consider the case where firm j volunteers given its contract position s_j. The contract thus needs to rule out the equilibrium (b_i^V, b_j^F). To put it differently, the contract must ensure that firm i's optimal response to firm j bidding low is to also bid low itself and thereby render free-riding bids of firm j unprofitable. For tractability, we assume $b_i^F = b_j^F = 0$ and hence zero profits in case of miscoordination. We show in Appendix A.2 that our main result does not rely on this simplification. Formally,

$$\bar{p}(D(\bar{p}) - k_f - k_j) + (\bar{p} - p^s)s_i < -p^s s_i. \tag{10}$$

The left-hand side of this inequality includes firm i's profits for $b_i^V = \bar{p}$ plus contract payments. The right-hand side represents firm i's profits for $b_i^F = b_j^F = 0$ plus contract payments. Note that, alternatively, free-riding firms could submit positive bids according to equation (5). Rearranging the inequality yields

$$s_i < -D(\bar{p}) + k_f + k_j. \tag{11}$$

Since by assumption dominant firms are pivotal, we have $-D(\bar{p}) + k_f + k_j < 0$. We therefore conclude that firm i, by taking a negative (short) contract position as in (11), can commit to free-ride. Hence the equilibrium where firm i volunteers vanishes. We summarize this finding by the following lemma.

Lemma 2 *[Sufficient contract quantity] Firm i commits to free-ride by holding a short position of $s_i^* < -D(\bar{p}) + k_f + k_j < 0$.*

Note that Lemma 2 is independent of the forward price. This is because the contract payments $-p^s s_i$ are sunk and occur in any case (i.e., on both sides of equation 11). However, the contract impacts profits at the auction stage via the spot price that determines additional payments for the contracted quantity. Moreover, because the volunteering firm j optimizes against the same demand and rival capacities with and without firm i's contract, the equilibrium clearing price set by firm j still is $\bar{p}$ and hence above p^s. In turn, this implies $(\bar{p} - p^s) > 0$, so the free-riding firm gives away producer rent in equilibrium. Because it hence is costly to commit to free-ride, we conjecture that the optimal contract satisfies the inequality in Lemma 2 only by some small ϵ close to zero.

For completeness, note that the volunteering firm j can sign an exactly off-setting contract $s_j = -s_i > D(\bar{p}) - k_f - k_j$. In this case, since $s_j > 0$, firm j still optimizes by bidding the cap, which follows immediately from equation (9) as $\frac{\partial b_j^V}{\partial s_j} > 0$. Hence, when firm j signs an off-setting contract, the contract re-distributes rents of $(\bar{p} - p^s)s_j$ from the free-riding firm i to the price-setting firm j.

Whether two off-setting contracts are beneficial to both dominant firms depends on counterfactual profits without the contract. In the empirical section, we use mixed-strategy profits as a counterfactual and illustrate that the contract in Lemma 2 not only implements a credible commitment but also increases payoffs for both contract parties.

4 Application

In this section, we employ a Monte Carlo simulation to test our model. We exploit data from the New York City power market as well as data from financial contracts signed by two dominant firms participating in this market. In particular, the data stems from the NYC procurement auctions for power-generating capacity.

4.1 Market institutions and data

For each calendar month, the New York independent electricity system operator (NYISO) procures the generating capacity needed to cover maximum electricity demand. The regulatory rationale for doing so is to secure sufficient generation capacity at all times to avoid black-outs and rationing. To this end, the NYISO conducts a procurement auction and publicly announces a demand curve for available capacity. The demand curves are announced seasonally. That is, the NYISO announces one winter demand curve that applies in six monthly auctions during a predefined "winter period" between November and April and one summer demand curve for six monthly auctions in the "summer period" from May to October. Winning bidders receive a monthly payment for holding capacity available during the respective month. As generating units commit to be available one month ahead, opportunity costs for generation are limited, and marginal costs are near zero (Cramton and Stoft (2005)). We therefore disregard costs in our simulation.

Capacity can be sold in sequential markets. The NYISO conducts forward procurement auctions and deducts all previously sold capacity from demand in each consecutive auction. As we lack sufficient data on the allocation of firm-specific capacity among the sequential markets, we abstract from sequentiality in our simulation and map the total firm capacities against total demand during the summer and winter periods.

Contract payments started with procurement auctions for the summer 2006 season and were to last until 2009. The contract specified payments for 1800 megawatts (MW). Based on this quantity, payments were determined by calculating the difference between the auction clearing price and a predefined strike price. Astoria, the inframarginal firm, thus took a short position and corresponds to the low-bidding firm i in our theoretical framework. KeySpan took the offsetting long position and corresponds to the volunteering firm j. The strike price differed marginally for either firm to guarantee a margin for the financial intermediary that acted as a counterparty for the two dominant firms.[7]

In addition to information on the contract, the data comprise demand curve parameters and firm-level capacities for the six major firms operating in the NYC power market. Capacities are scraped from the annual NYISO reports that list all installed generation capacity for the state of New York. Capacities are reported in terms of available capacity ("capability").[8] Available capacity determines the amount of capacity that firms are allowed to offer to the procurement auction. Due to seasonal outages or maintenance patterns, available capacity is, like the demand curves, determined by season.

We use data from 2005, the year prior to the contract start, for calibrating our simulation, and data from the first contracting year in 2006 to test the model. Table 1 presents the data on demand and capacities for the six firms operating in the NYC capacity market, prior to and for the first year of the contract period. The four fringe firms' capacities are aggregated. Fringe capacity and KeySpan's capacity remain somewhat constant within seasons and across years. Astoria invested around 600 MW in 2006, as shown by the differences from summer and winter 2005 to 2006, respectively. The last column of Table 1 depicts demand at the

[7] FERC (2008) and DOJ (2010) provide detailed information on the contract parties and parameters.

[8] Available capacity is an estimate using NYISO's algorithm based on historical plant availability.

Table 1: Firm capacities and auction demand curve one year prior to and during first year of contract.

Season	Capacities			Demand
	Astoria $[k_i]$	KeySpan $[k_j]$	Fringe $[k_f]$	$[D(\bar{p})]$
Summer 2005	2121	2382	5022	8859
Winter 2005	2400	2536	5525	9440
Summer 2006	2679	2305	5034	9093
Winter 2006	3073	2463	5486	9824

price cap, as announced by the NYISO.

Whereas procurement auctions clear monthly vis-à-vis seasonally defined demand curves, the granularity of our simulation is bound to information on the half-yearly capacities in Table 1. This also forces us to apply a Monte Carlo simulation rather than pursuing regression methods. Further, as can be seen, there is limited variation in capacities and demand.

In contrast to the model with one common price cap, the NYISO capacity market features firm-specific bid caps that differ marginally across firms. For Astoria, the bid caps are at \$12.34 and \$5.67 for summer and winter 2006, respectively. For KeySpan, the bid caps are at \$12.71 and \$5.84 for summer and winter 2006, respectively.

For our simulations we then set the predefined forward price, as in the contract, at \$7.57 for KeySpan and \$7.07 for Astoria. The difference is the margin for the financial intermediary. Figure B.1 in Appendix B displays observed monthly market prices (equal to KeySpan's bid cap) and the forward prices for three seasons before and after the contract start date. Note that the price cap is below the forward price during winter months. This implies that payments in winter must flow opposite to the model. We therefore analyze swapped payments over the course of one full year, over both summer and winter markets combined. We thus capture the net effect of payments from the low-bidding to the volunteering firm across seasons.

The above data, in combination with information on the contract, allow us to simulate the model. We simulate the contract for one stylized contract year, where we focus on the first contract year and simulate the contract and counterfactual outcomes in the year 2006.

4.2 Empirical strategy

Our simulation strategy proceeds in three steps. First, we test whether there exists a volunteer's dilemma in the absence of the contract. To do so, we test whether firms are pivotal and whether the price cap is binding for both firms (in line with Corollary 1). Second, we test whether the contract provides credible commitment. We hence test whether the observed contract quantity of 1800 MW is at least equal to the contract quantity that allows for successful coordination (in line with Lemma 2). Third, we test whether each firm has an incentive to sign the contract, i.e., we investigate whether contracting and thus avoiding coordination failure yields higher profits as compared to hypothesized counterfactual profit for both firms.

To capture these counterfactual profits (without forward positions), we derive expected profits against which firms decide on their contracting strategy. As in Goeree et al. (2017), we consider a mixed-strategy equilibrium in which each firm i volunteers with probability ρ_i. Firm j's mixed strategy is characterized by firm i being indifferent between volunteering and free-riding, as summarized by the following equation:

$$\rho_j \pi_i(b_i^V, b_j^V) + (1 - \rho_j)\pi_i(b_i^V, b_j^F) = \rho_j \pi_i(b_i^F, b_j^V), \tag{12}$$

where ρ_j is the likelihood that firm j volunteers. The left-hand side represents expected profits when firm i is volunteering, whereas the right hand side shows expected profits when firm i is free-riding. Note that the estimation of mixed-strategy profits is done using Astoria's cap[9] given that the calculation of mixed strategies requires the same support. Results hold when running the same simulation with KeySpan's price cap instead.

Expected profits then immediately follow from applying the mixed strategies. In particular, under the volunteer's dilemma, firm i's expected profits are given by mixed-strategy profits

$$\rho_j \pi_i(b_i^F, b_j^V), \tag{13}$$

where ρ_j is the probability that the rival firm j volunteers. We derive mixed strategies and expected profits in detail in Appendix A.3.

In what follows, we use mixed-strategy profit as the minimum profit that firms can receive when not contracting. Firms thus can sign contracts to increase and lock in profit as compared to mixed-strategy profit that includes the probability of miscoordination.

In addition, for our Monte Carlo approach we assume that at the time of signing the

[9] Table 1 reports demand at Astoria's price cap.

contract KeySpan and Astoria do not have full information on fringe capacity. We implement this assumption by making fringe capacity a random variable. In contrast, we assume perfect information on their own and rival capacities k_i and k_j, as well as on demand $D(\bar{p})$, which is announced by the regulator.

We further assume that the two contracting firms use the most recent information they have available when evaluating fringe capacities. That is, the dominant firms rely on the fringe firms' capacities from 2005, the last year before the contract started. The fringe capacity of 2005 hence constitutes the mean of the distribution of fringe capacity throughout the contract period. We then place a normal distribution around this fringe capacity with a standard deviation of about one typically sized large power plant in the sample (500 MW). This standard deviation accounts for additional investment or market exit from one year to the next. We then draw 2000 times from this distribution of fringe capacity and simulate a stylized contract year using data from 2006 as in Table 1.

Given our theoretical analysis and assumptions about the counterfactual profit, we investigate the following predictions:

Prediction 1: *Astoria and KeySpan face a volunteer's dilemma in the absence of the contract. More specifically,*

$$b_j^* = \min\{\arg\max_{b_j} q_j(b_j, b_i, \tilde{k}_f)b_j, \bar{p}\} = \bar{p} \quad \forall j = 1,2 \text{ and } i \neq j,$$

where $\tilde{k}_f$ denotes the simulated random normal of aggregate fringe firm capacity. The mean of this distribution k_f takes either the 2005 summer value of 5022 MW or, when we simulate winter auctions, 5525 MW. Due to our assumptions on perfect information and demand and rival capacities, data on k_i, k_j, and demand are for the year 2006.

Prediction 2: *The contract quantity agreed on by Astoria and KeySpan corresponds to the critical contract quantity defined in Lemma 2, that is,*

$$-s_i \approx D(\bar{p}) - k_j - \tilde{k}_f \approx 1800.$$

The right-hand side represents the observed contract quantity of 1800 MW. We apply the same 2000 draws of fringe capacity as before.

PREDICTION 3: *Both firms have an incentive to sign the contract, so it must hold that*

$$\pi_i(b_i^F, b_j^V) - (\bar{p} - 7.07)1800 \geq \rho_j \pi_i(b_i^F, b_j^V)$$

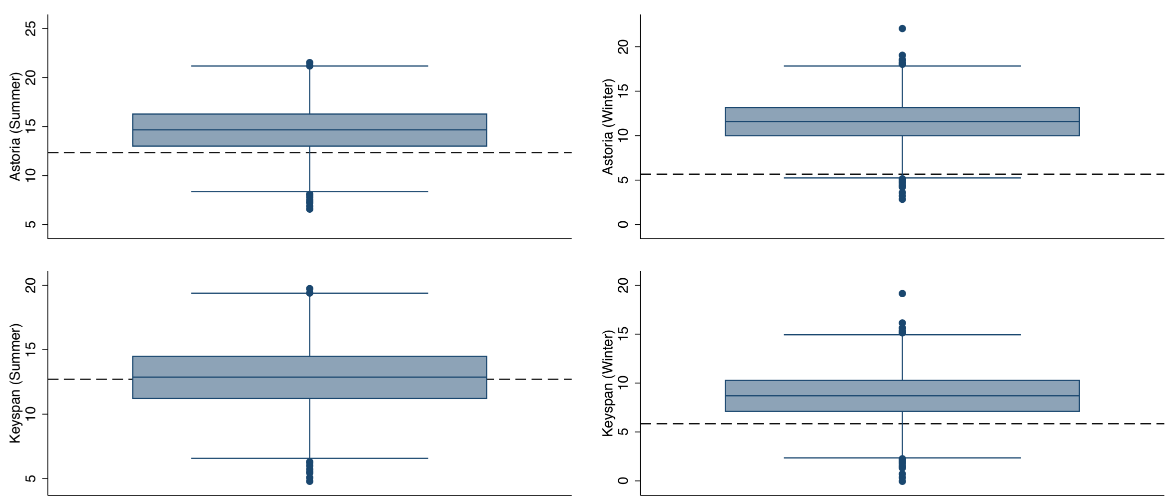
$$\pi_j(b_j^V, b_i^F) + (\bar{p} - 7.57)1800 \geq \rho_i \pi_j(b_j^F, b_i^V).$$

Note that profits of the inframarginal firm i with the contract are independent of $\tilde{k}_f$ and known with certainty, because firm i just sells its own capacity at a known price $\bar{p}$. In contrast, mixed-strategy profits for both firms and profits for firm j with the contract depend on the draw from $\tilde{k}_f$.

4.3 Results

Existence of a volunteer's dilemma. We simulate the optimal bidding function in equation (4) for both firms. In line with the model, conditional on volunteering, both firms' optimal strategy was to offer the price cap. In line with Prediction 1 (and Corollary 1), the price cap is binding for both firms. Figure 1 illustrates that the simulated optimal bids are clearly above the price cap (p-values of < 0.01). Given these results, we can conclude that the two large firms would face a volunteer's dilemma in the absence of a contract.

Figure 1: Optimal unconstrained clearing bids (box plot) and price cap (dashed line). The two upper box plots display the optimal clearing prices of Astoria against 2000 draws from the fringe capacity using capacity and demand parameters from Summer 2006 (left) and Winter 2006 (right). The two box plots below refer to the corresponding optimal clearing bids of KeySpan.



Sufficient contracting. Second, we investigate whether the contract signed is a credible commitment for Astoria to always free-ride as in equation (5). This is the case if the contract rules out coordination failure on the off-equilibrium outcome where both firms free-ride. We have shown that this equilibrium is ruled out if the contract quantity agreed on by the firms is at least equivalent to the optimal contract quantity defined in Lemma 2.

Running our simulation, we reject that the critical contract quantity is statistically different from the quantity specified in the contract of 1800 MW (p-value of 0.35). This is also illustrated in the left panel of Figure 2 showing the distribution of $D(\bar{p}) - k_j - \tilde{k}_f$, which clearly centers around the observed quantity of 1800 MW. The mean of our simulation provides a critical contract quantity needed for commitment of 1807 MW, which nearly matches the observed contract quantity of 1800 MW. These findings support Prediction 2.

Profitability. The contracts must be beneficial for each firm. Therefore, we test whether simulated profits with contracting are larger than simulated (mixed-strategy) profits without contracting. We find that both firms have an incentive to sign the contract. While the contract is payoff dominant for Astoria (p-value of 0.00), the contract is weakly payoff dominant for KeySpan. Specifically, we reject that contract and counterfactual profits are different (p-value of 0.18). The right panel of Figure 2 plots the distributions of contract profits and mixed-strategy profit and confirms Prediction 3.[10]

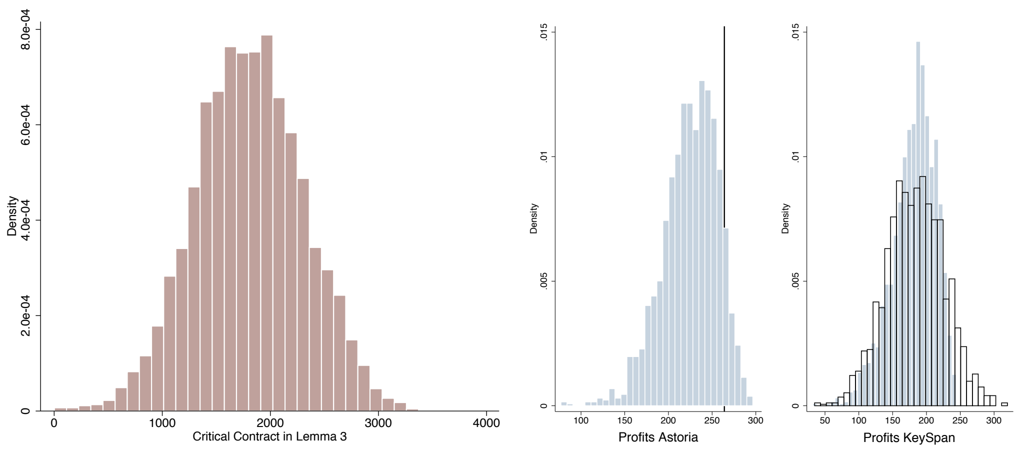
As shown in Appendix A.4, our mixed-strategy profits constitute an upper bound as we set profits in case of miscoordination on (π_i^{FF}, π_j^{FF}) equal to zero. This is because mixed-strategy profits are lower when we allow for positive miscoordination profits. It is therefore likely that assuming higher miscoordination profit would imply for our simulation that the contracts signed by Astoria and KeySpan are strictly pay-off dominant for both firms.

5 Discussion

Last, we discuss three potential extensions to our contracting framework. First, we consider the case of a unilateral contract where only one firm signs the contract derived in Lemma 2. In our theoretical framework, there is no volunteer's dilemma if both firms sign offsetting contracts of sufficient volumes. However, it is easy to show that the volunteer's dilemma also vanishes if only firm i signs a contract with the financial intermediary. As long as Lemma 2

[10] FERC (2008) reports realized profits for KeySpan in 2006 of 170 million USD. Our simulated average profit for KeySpan in 2006 is about 180 million USD. Thus the overall profit levels from our simulation compare relatively well.

Figure 2: The left panel shows the pdf of simulated optimal contract volumes as in Lemma 2 from 2000 draws for the fringe capacity. The mean is equal to 1807 MW, while the observed contract volume is 1800 MW. The right panel shows simulated profits for Astoria and Keyspan. The solid distribution represents mixed-strategy profit. The transparent distribution represents profits with the contract for KeySpan. For Astoria, profits with the contract are deterministic and represented by the solid vertical line. Profits are in million USD.



holds and firm j is aware of the contract, firm i can credibly commit to always bid low. In this case, equilibria where firm i volunteers do not exist, and firm j always volunteers and bids the price cap. As a result, firm i loses money via the contract but its overall profits are positive given the equilibrium response of firm j to bid at the price cap. Also, the financial intermediary that agrees to sign this contract benefits as, anticipating equilibrium play, it receives contract payments. Hence unilateral contracting suffices.[11]

Second, we consider the case of non-binding price caps, as opposed to the binding price cap case that we have considered in the theoretical and empirical analysis. It is straightforward to show that firms can sign a contract that increases both firms' profits. If firms have similar offsetting forward positions as considered above, it is easy to show that contracting increases market price if the cap is non-binding. The volunteering bidder j signs a contract that guarantees transfer payments for higher prices than the strike price and is consequently willing to offer a higher bid as can be seen in equation (9), as $\frac{\partial b_j^V}{\partial s_j} > 0$. Crucially, the volunteering firm obtains the higher price not only for its sold units, but also for the swapped quantity specified in the contract. Moreover, the increased spot profit (due to the higher

[11] In line with this observation, FERC (2008) illustrates that the low-bidding firm Astoria was the first to search for counterparties for their contracting offer. KeySpan only later agreed to become the counterparty via signing the offsetting contract with the same financial intermediary.

market price) for the inframarginal firm is large enough to more than offset the contract payments it has to make to the pivotal bidder j. As in the case with binding price caps, there exists a critical contract quantity that solves the volunteer's dilemma. We provide a more formal proof of this result in Appendix A.5.

Third, our theoretical case with a non-binding price cap is related to a competitive setup with differentiated products and forward markets as studied by Mahenc and Salanié (2004). The similarity to pricing strategies in differentiated product markets arises as clearing price set by firm j uniformly applies to its rival firms. Our profit function in (2) is similar to the profit function in differentiated product markets, which typically can be represented by $\pi(b_i, b_j) = q(b_i, b_j)b_i$. In a differentiated product market each firm earns its own price, with price choices being strategic complements. In a uniform price auction, a higher clearing price set by one's rival directly translates into one's own higher profits. In this context, the rival's bids have a perfect complementarity with profits of inframarginal firms. Note that Einav and Nevo (2009) have already stressed the similarities between first-order condition in differentiated product markets and auctions.

6 Conclusion

This paper studies the use of forward contracts to coordinate on pricing strategies in product markets. Based on our empirical motivation, we model the product market as a multi-unit uniform price auction. We first characterize the volunteer's dilemma that firms are likely to face in multi-unit uniform price auctions with tight capacity constraints.

When only one firm (the "volunteer") is needed to increase the market clearing price, the firm setting this non-competitive price does not sell the entire capacity while the others do. Thus, it is individually more profitable if one of the other rival firms is the price-setter. Conversely, taking the role of price-setter is a best response if no rival does. Hence there is a multiplicity of Nash equilibria that differ substantially in individual firms' profit.

When firms face such a volunteer's dilemma, coordination failure can occur when no firm lifts the price above competitive levels. However, we show that with appropriate contract agreements, firms can solve this dilemma. We also provide a quantitative assessment of our theoretical predictions by using data from the New York procurement auction for power-generating capacity. In particular, we show that contracts, as signed by the two largest firms in the case we study, could be used as a coordination device to ensure and maintain a non-competitive market price.

The benefits of derivative markets, such as reduced price exposure, increased market liquidity, and enhanced information transmission, are well known. Nonetheless, we show that derivatives could facilitate anti-competitive behavior in a subtle way without affecting observed market prices. The possibility of using financial contracts as a coordination device should be considered by regulators when assessing market efficiency. Also, auctioneers selling or procuring items in multi-unit uniform price auctions have to consider the possibility that side payments increase bidder profits.

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A Appendix

A.1 Sufficient symmetry

The volunteer's dilemma exists if it is costly to volunteer but still a best response when the competing firm does not. It therefore suffices to show that volunteering profits are lower than non-volunteering profits, but higher than profits when no firm volunteers. We start by deriving the first condition, i.e., when volunteering profits are lower than free-riding profits.

Assume first that the price cap is non-binding. If firm j volunteers, it earns profit equal to $\frac{(a-k_f-k_i)^2}{4d}$. If, now, firm i volunteers, and firm j does not, profits for firm j would yield $\frac{a-k_f-k_j}{2d}k_j$. Volunteering profits are hence lower than non-volunteering profits for all

$$k_j < \hat{k}_j(k_i) = \frac{1}{2}\left(a - k_f + \sqrt{4(a-k_f)k_i - (a-k_f)^2 - 2k_i^2}\right),$$

which follows from equating volunteering and non-volunteering profits and solving for the critical k_j.

Assume now that the price cap is binding for firm j but not for firm i. Everything is the same but the profits when firm j volunteers (and firm i does not) become $\bar{p}(D(\bar{p}) - k_f - k_i)$. The above inequality can be rewritten as follows:

$$k_j < \hat{k}_j(k_i) = \frac{1}{2}\left(a - k_f + \sqrt{(a-k_f)^2 + 8d(k_f + k_i - D(\bar{p}))\bar{p}}\right).$$

Note that if the price cap is binding for firm j with $k_i < k_j$, it must also be binding for firm j. Hence we ignore the case where the price cap is only binding for firm i. If the price cap is binding for both firms, the volunteer's dilemma always exists.

Finally, for the second condition, that profits in each case need to be lower than profits when no firm volunteers, consider the case where both firms free-ride and set maximum bids $b_i^F = \bar{b}_i$. By construction of $\bar{b}_i$ as defined in equation (5), it must always be beneficial for one firm to deviate and volunteer.

A.2 Critical contract quantity with $\pi_i(b_i^F, b_j^F) > 0$

As in Lemma 2, a necessary condition for coordination to be sustainable is that contracting induces commitment for one firm to always be the inframarginal bidder. For positive miscoordination profit, condition (11) translates to the inequality

$$\pi_i(b_i^V, b_j^F) + (\bar{p} - p^s)s_i < \pi_i(b_i^F, b_j^F) + (p^* - p^s)s_i,$$

which can be reformulated to

$$s_i < -\frac{\pi_i(b_i^V, b_j^F) - \pi_i(b_i^F, b_j^F)}{\bar{p} - p^*}.$$

Any s_i satisfying the above condition must be negative and hence the inframarginal firm is a net seller. Furthermore, the following argument shows that the sufficient contract with $b_i^F = b_j^F = 0$ of $s_i^* = -D(\bar{p}) + k_f + k_j = -\frac{\pi_i(b_i^V, b_j^F)}{\bar{p}}$ suffices for commitment also at any positive miscoordination price. First note that for any positive miscoordination price $p^* < \bar{p}$, firm i at least sells $D(\bar{p}) - k_f - k_j$. It will sell more because, first, for any $p^* < \bar{p}$ we have $D(p^*) > D(\bar{p})$, second, firm i may sell its entire capacity k_i at price p^*. Using these lowest miscoordination sales of $D(\bar{p}) - k_f - k_j)$, we conclude that miscoordination profit must at least be $(D(\bar{p}) - k_f - k_j)p^*$. Using this lowest bound for miscoordination profit, the critical contract can be reduced to $s_i^* < -\frac{\pi_i(b_i^V, b_j^F) - \pi_i(b_i^F, b_j^F)}{\bar{p} - p^*} < -D(\bar{p}) + k_f + k_j$, which equals exactly the critical contract with $b_i^F = b_j^F = 0$. Now, if firm i indeed sells more and $\pi_i(b_i^F, b_j^F) > (D(\bar{p}) - k_f - k_j)p^*$, the nominator of $-\frac{\pi_i(b_i^V, b_j^F) - \pi_i(b_i^F, b_j^F)}{\bar{p} - p^*}$

must decrease, and with it the critical short position. Thus the critical contract quantity with $\pi_i(b_i^F, b_j^F) = 0$ suffices for committing to free-ride for any $\pi_i(b_i^F, b_j^F) \geq 0$.

A.3 Mixed strategies

Resolving equation (12) yields the following optimal mixed strategy, i.e., probability of volunteering:

$$\rho_j = \frac{\pi_i(b_i^V, b_j^F)}{\pi_i(b_i^V, b_j^F) + \pi_i(b_i^F, b_j^V) - \pi_i(b_i^V, b_j^V)}.$$

We can write firm i's mixed-strategy profits as follows:

$$\rho_i \left(\rho_j \pi_i(b_i^V, b_j^V) + (1-\rho_j)\pi_i(b_i^V, b_j^F) \right) + (1-\rho_i)\rho_j \pi_i(b_i^F, b_j^V) =$$

$$\frac{\pi_i(b_i^V, b_j^F)\pi_i(b_i^F, b_j^V)}{\pi_i(b_i^V, b_j^F) + \pi_i(b_i^F, b_j^V) - \pi_i(b_i^V, b_j^V)} = \rho_j \pi_i(b_i^F, b_j^V).$$

A.4 Mixed-strategy profit with $\pi_i(b_i^F, b_j^F) > 0$

With positive free-riding bids $b_i^F > 0 \; \forall \; i = 1, 2$, the mixed-strategy of firm j derives from

$$\rho_j \pi_i(b_i^V, b_j^V) + (1-\rho_j)\pi_i(b_i^V, b_j^F) = \rho_j \pi_i(b_i^F, b_j^V) + (1-\rho_j)\pi_i(b_i^F, b_j^F),$$

where the left- (right-)hand side represents profits when firm i volunteers (free-rides). Solving for firm j's probability to volunteer yields

$$\rho_j = \frac{\pi_i(b_i^V, b_j^F) - \pi_i(b_i^F, b_j^F)}{\pi_i(b_i^V, b_j^F) - \pi_i(b_i^F, b_j^F) + \pi_i(b_i^F, b_j^V) - \pi_i(b_i^V, b_j^V)}.$$

Equilibrium mixed-strategy profit of firm i then becomes

$$\rho_i \left(\rho_j \pi_i(b_i^V, b_j^V) + (1-\rho_j)\pi_i(b_i^V, b_j^F) \right) + (1-\rho_i) \left(\rho_j \pi_i(b_i^F, b_j^V) + (1-\rho_j)\pi_i(b_i^F, b_j^F) \right) =$$

$$\frac{\pi_i(b_i^V, b_j^V)\pi_i(b_i^F, b_j^F) - \pi_i(b_i^V, b_j^F)\pi_i(b_i^F, b_j^V)}{\pi_i(b_i^F, b_j^F) - \pi_i(b_i^V, b_j^F) - \pi_i(b_i^F, b_j^V) + \pi_i(b_i^V, b_j^V)}.$$

The first derivative of this last expression with respect to $\pi_i(b_i^F, b_j^F)$ is strictly negative. This implies that mixed-strategy profits with $\pi_i(b_i^F, b_j^F) = 0$ constitute an upper bound.

A.5 Non-binding price caps

Consider the case where the price cap is non-binding prior to contracting. Contracts in this case increase producer rent by increasing the clearing price: The price-setting firm j increases the clearing price to some $b_j^V(s_j > 0) > b_j^V(s_j = 0)$. The inframarginal firm i writes a contract with $-s_j = s_i < 0$. When the forward price is set such that $b_j^V(s_j > 0) > p^s$, firm i transfers rents to firm j as compensation for reducing its sales.

In contrast, firm i earns additional rents on its full inframarginal capacity (without reduced sales). Hence the contract transfers parts of these additional rents to firm j. Note that in this case the condition for a sufficiently large contract also changes. Specifically, the condition that leads to Lemma 2 in the main text changes to

$$\frac{(k_f + k_j - a)^2 - s_i^2}{4d} + s_i \left(\frac{(a - k_f - k_j) + s_i}{2d} - p^s \right) < -p^s s_i.$$

Rearranging yields

$$s_i < -a + k_f + k_j$$

as the critical contract quantity that guarantees equilibria where firm j volunteers. Note that in both cases with and without binding price caps, the optimal contract for the free-riding firm implies that free-riding firms sell forward their residual demand (residual demand at the price cap for binding price caps and residual demand at a price of zero when price caps do not bind).

B Figures

Figure B.1: Market prices and strike prices three seasons before and after contract start date. The respective strike prices are in dashed lines and signal the start date of the contract in May 2006.