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Managing electricity procurement cost and risk by a local distribution company

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Abstract

A local electricity distribution company (LDC) can satisfy some of its future electricity requirements through self-generation and volatile spot markets, and the remainder through fixed-price forward contracts that will reduce its exposure to the inherent risk of spot-price volatility. A theoretical framework is developed for determining the forward-contract purchase that minimizes the LDC's expected procurement cost, subject to a cost-exposure constraint. The answers to the questions of "What to buy?" and "How to buy?" are illustrated using an example of a hypothetical LDC that is based on a municipal utility in Florida. It is shown that the LDC's procurement decision is consistent with least-cost procurement subject to a cost-exposure constraint, and that an internet-based multi-round auction can produce competitive price quotes for its desired forward purchase.

Keywords: Electricity procurement; Cost risk management; Electricity market reform

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1. Introduction

Electricity market reform and deregulation have created wholesale spot markets that are characterized by high price volatility (Woo, 2001; Borenstein, 2002; Wilson, 2002). In some instances that volatility can be attributed to the fact that electricity cannot be economically stored and must be generated instantaneously to meet real-time demand. Hence, a relatively small supply reduction, say due to forced plant outages, can cause sharp spot-price spikes that are traced out along what tend to be relatively price-inelastic spot-market demand curves. Conversely, when market supply approaches full generation capacity, relatively small demand increases, say due to rising summer temperatures or falling winter temperatures, can result in substantial price increases that are traced out along the full-capacity inelastic supply curve.

Local distribution companies (LDCs) have the mandate to supply electricity, upon demand, to the customers with whom they have contracted. An LDC has three basic options for acquiring that electricity: (1) generation through its own plant facility; (2) spot-market purchases; and (3) fixed-price forward contracts. The last option is brought into play, and the LDC satisfies some of its anticipated future requirements through forward contracts, in order to better manage the electricity *procurement*-cost risk that stems from spot-price volatility. By entering into a forward contract, the LDC may be able to avoid the potentially disastrous financial consequences of over-reliance on the spot market, which were so dramatically evidenced by the April 2001 bankruptcy of Pacific Gas and Electric Company (PG&E), one of the largest utilities in the United States.

The California electricity crisis of 2000-2001 led to Governor Davis signing Assembly Bill 57 on September 25, 2002, which requires each of the three large investor-owned utilities, PG&E, Southern California Edison (SCE), and San Diego Gas and Electric (SDGE), to file a procurement plan to achieve the goal of stable, just and reasonable rates. Each plan must contain the filing utility's risk-management policy and strategy, the cost risk of the utility's resource portfolio, the quantity and type of hedging products to be procured (e.g., forward contracts and options), and the competitive process (e.g., bilateral negotiation, brokerage service, or auction) for procuring such products.

The idea of using forward contracts to manage procurement-cost risk is intuitively appealing. Nevertheless, its implementation necessitates a decision as to the *amount* of forward electricity the LDC should purchase. The decision can be based on subjective managerial judgments, on simple rules of thumb (e.g., not less than 95% of the LDC's forecast total electricity requirement (CPUC, 2002, p. 32)), or, as proposed in this paper, on the solution to a risk-constrained least-cost procurement problem. After deciding on the least-cost forward purchase, the LDC then makes the purchase via a competitive procurement process.

This paper defines the LDC's procurement problem, which is succinctly described by two related questions: "What to buy?" and "How to buy?" We show that the answer to "What to buy?" solves a risk-constrained expected-cost minimization problem. The answer provides the optimal forward-contract purchase, given management's perception of the LDC's customers' risk tolerance, its projection of spot prices and their volatility in a future delivery period, and the range of likely forward-contract price quotes from prospective sellers.

Knowing what to buy, however, does not guarantee least-cost implementation, because the forward-contract price quoted by a prospective seller may not be the "best deal" that the LDC could have obtained. To see this, consider the standardized forward contracts for next-month delivery that are actively traded at major electricity hubs in the United States (e.g., Mid-Columbia in Washington, California-Oregon-Border in Oregon, and Palo Verde in Arizona). These standardized contracts apply to a multiple of a 50-megawatt (MW) energy block size for (6x16) delivery at 100% rate during 06:00-22:00, Monday through Saturday. If its desired purchase is a standardized forward contract, the LDC can simply buy from the actively traded forward market with many competing sellers.

The forward contract of the LDC's interest, however, often deviates from a standardized contract. Common deviations include: (a) a delivery point different from a major hub; (b) a contract period longer than the next month; (c) daily delivery pattern different from the (6x16) specification; and (d) an MW size that is not a multiple of 50 MW. Trading for non-standardized contracts is either non-existent or very thin. As a result, the LDC may not easily receive a competitive price quote for non-standardized contracts without using an auction.[1] This paper answers "How to buy?" by describing an internet-based multi-round auction.

The answers for "What to buy?" and "How to buy?" are illustrated through an example of a hypothetical LDC that is based on a small utility located in Florida. They show the LDC's procurement decision to be consistent with least-cost procurement subject to a cost-exposure constraint, and that an internet-based multi-round auction can produce competitive price quotes for its desired forward purchase.

The paper proceeds as follows. Section 2 characterizes the constrained least-cost electricity procurement that answers "What to buy?" Section 3 implements the answer for our hypothetical LDC. Section 4 describes the internet-based auction that answers "How to buy?" Section 5 concludes.

2. Constrained Least-Cost Electricity Procurement

Consider an LDC that is legally obligated to provide electricity to its customers during some future period t_1. For simplicity, we assume that the LDC has neither existing power-purchase contracts nor generation capacity. Thus the LDC relies on either the spot market in period t_1 or a forward contract entered into in period t_0 to acquire the electricity that it resells to those customers. Incorporating existing contract costs or fuel costs associated with generation adds computational complexity without substantially improving our understanding of the procurement problem.

Suppose the LDC meets 100% of its total electricity requirement of Q megawatt hours (MWh) for period t_1 via spot-market purchases at an average price of P. The *ex post* procurement cost of those purchases will be:

$$C = P\,Q. \tag{1}$$

Relying exclusively on the spot market to acquire Q exposes the LDC to what are potentially very high costs. Those costs, however, can be capped when management has the option to hedge its electricity purchases through fixed-price forward contracts. In particular, suppose management has purchased q MWh in period t_0 at the fixed forward per-unit price F. The *ex post* cost of having done so is:

$$C = P(Q - q) + Fq. \tag{2a}$$

Equation (2a) shows that C converges to FQ as q approaches Q, and the forward contract approaches meeting 100% of the LDC's requirement. But while forward contracting can reduce the cost effects of unanticipated spot-price changes, it cannot eliminate the cost variations that are due to unanticipated changes in the consumer's *demand* for electricity, which the LDC is obligated to satisfy. That is, prior to its entering into any forward contract, LDC management is forced to recognize that both P and Q are random variables. Suppose for the moment that the expected values (variances) of those random variables are known to be μ_P (σ_P^2) and μ_Q (σ_Q^2), respectively, with a covariance of $\sigma_{P,Q} = \rho\sigma_P\sigma_Q$, where ρ is the correlation between P and Q. Casual observation leads us to hypothesize $\rho > 0$. That is, spot-market demand changes tend to be more responsible for spot-market price changes than supply changes. As we shall subsequently demonstrate, the hypothesis is supported by the sample data that underlie our empirical analysis.

At the time that it is considering its forward-contracting options, then, as far as LDC management is concerned, the procurement cost C is also and necessarily a random variable. When $Q \geq q$, the LDC will purchase $(Q - q)$ on the spot market at the price of P. Suppose, however, that $Q < q$. In this event, as the owner of excess electricity, the LDC enters the spot market as a seller, rather than as a buyer, and the $P(Q - q) < 0$ term in equation (2a) reduces the procurement cost.

Rewrite equation (2a) as

$$C = PQ + (F - P)q. \tag{2b}$$

Following Mood *et al*. (1974, p. 178), let $E[PQ] = \mu_{PQ} = \mu_P\mu_Q + \rho\sigma_P\sigma_Q$. The expected procurement cost, μ, is then readily determined to be:

$$\mu = \mu_{PQ} + (F - \mu_P)\, q. \tag{3}$$

Since the forward-contract seller bears the spot-price risk, F commonly includes a positive risk premium, so that $(F - \mu_P) > 0$. Competition among sellers, however, serves to drive F toward μ_P. Nonetheless, it is unlikely that F will be consistently below μ_P, because from a seller's perspective, the forward sale will on average be unprofitable relative to the default alternative of a spot-market sale. Hence, we would expect $d\mu/dq = (F - \mu_P) > 0$; or, μ increases with increases in q. To be sure, it is possible that a seller may occasionally underestimate μ_P and make a forward-price offer below μ_P, in which case $d\mu/dq < 0$ and μ declines with increases in q.

For the purpose of risk management, the variance of C, $\nu = \sigma^2$, as a proxy measure of risk, can be computed as follows (Mood *et al*., 1974, p. 179):

$$\sigma^2 = \sigma_{PQ}^2 + \sigma_P^2 q^2 - 2\rho_{PQ,P}\sigma_{PQ}\sigma_P q. \tag{4}$$

Here, σ_{PQ}^2 denotes the variance of PQ and $\rho_{PQ,P}$ denotes the correlation between PQ and P.[2] We expect $\rho_{PQ,P} > 0$ because P and Q are positively correlated.

The effect of the size of the forward contract on the procurement-cost variance is seen through $d\nu/dq = 2\sigma_P(\sigma_P q - \rho_{PQ,P}\sigma_{PQ})$, which is negative (positive) when q is less (greater) than $\rho_{PQ,P}\sigma_{PQ}/\sigma_P$. Moreover, σ^2 is strictly convex in q because $d^2\nu/dq^2 = 2\sigma_P^2 > 0$. Thus, starting from an unhedged position of $q = 0$, a small forward purchase by the LDC would reduce the cost variance. Additional forward purchases would minimize the cost variance at $q = \rho_{PQ,P}\sigma_{PQ}/\sigma_P$. Forward purchases beyond this level, however, would raise the cost variance.

Management's problem can be formulated in the most straightforward fashion by first making the convenient assumption that C is normally distributed. The validity of this assumption in any specific application is necessarily subject to empirical verification. The normality assumption is made here solely for expository purposes. If the normality hypothesis is rejected, other familiar distributions (e.g., the *t*, the *F*, the chi-square, the Gamma-2, etc.) can be put to the same test. Only the value of z_α (assigned below) will be affected. Indeed, in any actual application the distribution of *C* and the z_α in question can always be determined directly from the distributions of *P* and *Q* upon which management will rely when making its contracting decision.

Suppose that management sets an upper-limit threshold of *T* on its procurement cost *C*, such that the probability of *C* exceeding *T* is α. Denoting by z_α the standard normal variate so that, for example, at $\alpha = 0.05$, $z_\alpha = 1.645$:

$$T = \mu + z_\alpha \sigma. \tag{5}$$

Thus *T* is the cost exposure that an LDC would face under normal circumstances with a probability of $(1 - \alpha)$. This definition of cost exposure is analogous to the value-at-risk commonly used in financial risk management (Jorion, 1997).

How much forward electricity the LDC should buy depends on the risk tolerance of the LDC's customers, since the LDC only acts as a purchasing agent on their behalf. Absent precise knowledge of customer risk preferences, however, management can use a cost-exposure constraint to represent their risk tolerance:[3]

$$T \leq \theta\mu. \tag{6}$$

The multiplier θ reflects management's perception of its customers' tolerance for risk. If management perceives that the LDC's customers can tolerate a high cost exposure relative to the expected-cost level, it would select a θ value substantially above 1. If, however, management perceives low customer risk tolerance, it would select a θ value close to 1 to reflect customer preference for a relatively small σ for a given value of z_{α}.

Management's problem is to choose q to minimize the expected procurement cost described by equation (3), subject to the cost-exposure constraint given by equation (6), as shown in Appendix A. Such an approach, however, may be seen as rather complicated and abstruse by the LDC's management or regulator. Moreover, the LDC's procurement report should contain data on cost expectation and exposure. Alternatively, management can address the problem using a simple spreadsheet format that employs the following heuristic procedure:

1. Set q at $w\mu_Q$ for delivery period t_1, where $0 \le w \le 1$ is a fraction of the expected MWh requirement. In our illustration, we consider values of 0.0, 0.25, 0.50, 0.75, and 1.0.
2. Assume a forward price to compute the cost expectation and exposure for each q value from Step 1. The range of assumed forward prices should reflect μ_P and σ_P^2.
3. Tabulate the results from Step 2.

3. Empirical Answer for "What to Buy?"

Our answer is based on the data collected for a municipal utility (MU) owned by the residents of a city in Florida. (We cannot disclose the MU's identity for contractual reasons.) Interconnected to Florida Power and Light (FPL) and Florida Power Corp. (FPC), the MU has limited generation and must procure electricity to meet its obligation to serve its retail customers. With an annual peak of approximately 90 MW, the MU had historically been buying most of its electricity requirement from FPL and FPC and the remainder from the spot market. In August 2002, the MU decided to buy an energy block at fixed price for daily delivery in October 2002 to reduce its exposure to the spot market price volatility. The energy block is 20 MW for the peak hours of 12:00-20:00 and 15 MW for the shoulder hours of 07:00–12:00 and 20:00-23:00. Hence, the MU's intended purchase for October 2002 delivery is a *fixed quantity* of (20 MW x 8 hours per day + 15 MW x 8 hours per day) x 31 days = 8,680 megawatt-hours (MWh). Finally, the MU decided that the entire forward purchase should be at a fixed price to be determined in an auction to be held in September 2002.

We could have evaluated the MU's forward purchase decision based on the fixed quantity of 8,680 MWh. Such an evaluation, however, would not consider quantity uncertainty, an important dimension of a typical procurement problem. Hence, for the purpose of illustration, our example is a hypothetical LDC characterized by the following assumptions:

- Its MWh requirement is the MU's net MWh purchase (= total purchase less sale) from the spot market.
- It faces the same spot purchase prices as the MU.
- Like the MU, it decides to use forward purchase to meet 100% of the assumed requirement.
- Like the MU, it plans to use a procurement auction to find the "best" forward price offer.

To evaluate this hypothetical LDC's procurement decision, we first estimate the components of μ and σ^2, which, for our LDC, we denote u and s^2, respectively. The estimation entails the following steps:

- We follow Woo *et al*. (2001) to estimate (μ_P, σ_P^2). This entails estimating a spot-price regression that relates the MU's monthly average spot-purchase prices to monthly average spot prices in May 2000–July 2002 at the major trading hubs of Entergy (Louisiana) and ERCOT (Texas), which are geographically close to Florida. We then use the forward prices for October 2002 delivery at those hubs as the drivers to forecast the October 2002 spot price that the MU may face. We obtain the October price variance as part of the forecast process. Appendix B discusses the spot-price regression and its results and confirms that the forecast price is normally distributed.
- We apply an autoregressive method (PROC FORECAST in SAS) to estimate (μ_Q, σ_Q^2) using the MU's monthly net MWh purchases in May 2000–July 2002. We apply a normality test to confirm that the monthly net MWh purchases are normally distributed (see Appendix B, Table 3).
- We compute r, the estimate of ρ, the correlation between the MU's monthly spot purchase price and its monthly net MWh purchases using the data for May 2000–July 2002. We compute $r_{PQ,P}$, the estimate of $\rho_{PQ,P}$, the correlation between the MU's monthly spot-purchase cost and monthly spot price, using the data for May 2000–July 2002.
- We compute s_{PQ}^2, the estimated variance of PQ, based on the formula in footnote 2.[4] A normality test confirms that PQ is normally distributed (see Appendix B, Table 3).

Table 1 presents the estimation results for the components of u and s^2. They indicate that the October 2002 spot-price forecast is u_P = $43/MWh, with a standard deviation of s_P = \$12/MWh. The net-purchase expectation for the same month is 16,275 MWh, with a standard deviation of 4,037 MWh. The correlation coefficient between price and net MWh purchase is $r = 0.42$, suggesting that rising prices accompany rising net MWh purchases. The correlation between the MU's monthly spot-purchase cost and monthly spot price is 0.93, confirming the high correlation between spot-purchase cost and spot price. Finally, the forecast and standard deviation of spot-purchase cost are \$722,729 and \$475,062, respectively.

[Insert Table 1 here]

Table 2 presents the estimates for (μ, T) and $\theta = (T/\mu)$ under alternative pairs of (w, F). As would be anticipated from equation (3), if $F > u_P$ = \$43/MWh, an increase in forward purchases raises our hypothetical LDC's expected cost. When F = \$40/MWh < u_P = \$43/MWh, our hypothetical LDC's expected cost declines with increases in the forward purchase.

Table 2 is a forward electricity demand schedule. It shows the optimum purchase amount of electricity forward, given the forward price and the tolerance for cost exposure. For example, if the forward price turns out to be \$50/MWh and the θ value is 1.6, our hypothetical LDC should use electricity forward to meet 100% of the anticipated requirement.

[Insert Table 2 here]

Table 2 also helps us to infer our hypothetical LDC's perception of customer risk tolerance based on management's decision to use forward electricity to meet 100% of its electricity requirement. The last column of Table 2 indicates that the decision implies a θ value at or below 1.7.

4. Empirical Answer for "How to Buy?"

While our hypothetical LDC can use Table 2 to guide its forward purchase, it cannot make the final decision without a binding forward-price quote. We assume that like the MU, this LDC would hold an auction to obtain the quote. This section describes the MU auction that answers "How to buy?"

4.1 The MU's Extant Procurement Process

The MU held an internet-based procurement auction in September 2002, even though it could have used its extant process to procure its desired forward contract. The MU's extant process is a request for offers (RFO) that solicits sealed offers from suppliers, followed by final negotiation. Commonly used by LDCs for buying energy and capacity, this kind of RFO process is equivalent to a single-round sealed-offer auction.

A single-round sealed-offer auction, however, may have several shortcomings (Cameron *et al*., 1997). First, it may not inform a buyer like the MU of the "best deal" available from the auction participants. While negotiation improves the final offer, its outcome may still not be the result of the fierce head-to-head competition exemplified by an open-offer auction, where a seller submits a price quote to outbid its competitors.

Second, it does not afford each seller the immediate opportunity to revise its price offer to beat the offers from other sellers. Even if a seller regrets its high offer, it must await the LDC's notification for negotiation. But the notification may be a rejection of the high-offer seller from further consideration by the LDC.

Third, unaware of other sellers' offers that reflect their valuation of the forward contract in question, a seller may be excessively cautious to avoid the "winner's curse."

This is especially true for a non-standardized contract for which reliable market-price data do not exist due to thin or no trading.

Fourth, the final negotiation and its outcome have limited transparency and are subject to "second guessing" by the LDC's management and regulator. It is difficult to document every detail in a negotiation. As a result, the LDC may find itself defending a forward contract's *ex ante* fixed price that turns out to be much higher than the *ex post* spot price (Woo, *et al*., 2003).

Finally, the offer evaluation and final negotiation of the RFO process can be time consuming, and its frequent use is difficult for contracts with delivery that begins in the immediate future (e.g., one week from now) for a short duration (e.g., one month). The time-consuming nature of an RFO often results in a cost premium in the sellers' sealed offers for committing to those offers for a relatively long period (e.g., ten days), while an LDC such as the MU tries to nail down the best deal.

4.2 Internet-based Multi-round Auction

To remedy the potential shortcomings of the typical RFO process, the MU adopts an internet-based multi-round auction whose design follows the Anglo-Dutch auction that "often combines the best of both the [open-] and the sealed-bid worlds" (Klemperer, 2002, p. 182). The design allows for a time extension that eliminates the potential advantage of last-minute bidding by a seller in an eBay-style auction with a fixed time deadline. A likely cause for non-competitive quotes, the advantage enjoyed by the "bid sniping" seller includes (a) not giving other sellers enough time to respond, (b) winning without revealing its likely lower willingness-to-accept, and (c) avoiding a price war with inexperienced auction participants (Roth and Ockenfels, 2002).

The MU's auction aims to effect forward-price minimization, transparency, and price discovery. Forward-price minimization requires fierce head-to-head competition among a reasonably large number of sellers (e.g., 8 to 12). This degree of competition may not occur when the MU transacts with a seller via one-to-one contact and negotiation. Even if the MU can contact and negotiate with many sellers, the process is time consuming and may not overcome the asymmetric information advantage enjoyed by sellers who transact more frequently than the MU. Further, sellers are less inclined to lower offer prices in bilateral negotiation than when faced with low binding-offer prices in an auction. "[T]he value of negotiation skill is small relative to the value of additional competition" (Bulow and Klemperer, 1996, p. 180).

Active and aggressive bidding by sellers cannot occur without the transparency achieved when the auction rules are fixed in advance and applied to all sellers. An opaque design reduces the number of participating sellers and induces conservative bidding. An example of a transparent design is one that has the following properties: (a) clearly defined non-price terms of a forward contract (e.g., size, delivery point, delivery rate, contract period, etc.); (b) clearly defined auction rules that govern offer submission, offer announcement, auction duration, and auction close; and (c) a simple selection rule such as "Subject to the MU's benchmark for price reasonableness, the lowest price-offer wins."

A transparent design eliminates the post-auction allegation of biased winner selection. It also leads to transparent results with a detailed record that can withstand close scrutiny by a third party. For example, a regulator may audit the MU's procurement decisions. The regulatory audit includes a review of the procurement process and an examination of the procurement results.

Price discovery is important to both sellers and the MU. When sellers can see the evolution of competing price offers, they can better infer the common price expectation relative to their own private costs. The increased price information makes the sellers less inclined to bid conservatively so as to avoid the winner's curse, thus promoting price competition. From the MU's perspective, the auction helps uncover forward-contract prices that are otherwise unavailable or unreliable due to thin trading and other market imperfections (e.g., asymmetric information). This aids the MU to make a better-informed purchase decision.

To achieve the objectives of forward-price minimization, transparency, and price discovery, an independent auctioneer (www.genenergy.com), not affiliated with the auction participants, performs a number of key preparatory steps prior to the auction date:

- The auctioneer assists the MU to clearly define the forward contract, including the characteristics of electricity to be delivered and the relevant terms and conditions. Absent a clear definition, contract ambiguity can have two undesirable effects: (a) it can cause potential sellers to shade their price offers; and (b) it can hinder contract enforcement by the MU in case of seller non-performance.
- The auctioneer assists the MU to pre-qualify sellers, so as to only include credit-worthy sellers that have a strong interest in the auction. As part of the pre-qualification, the auctioneer requires sellers to contractually commit to the offers that they make in the auction. Binding offers inform all participating

sellers that a price offer observed in the auction is "real," an important input to each seller's own assessment of how low its offer must go to win the auction. Similarly, binding offers provide the buyer with the surety that the winning offer is indeed obtainable at the conclusion of the auction.

- The auctioneer assists the MU to set an objective price benchmark, undisclosed to auction participants, against which all offers may be considered. The MU's benchmark for price reasonableness was u_P = $43/MWh in its September 2002 auction.
- The auctioneer discloses the upfront and clear criteria for selecting a winning offer. If sellers know the criteria, they can control their fate and are likely to make their best offers. In the context of the MU's auction, the selection criterion is: subject to the MU's undisclosed price benchmark, the winner is the pre-qualified seller with the lowest price offer.
- The auctioneer tests the auction process by asking pre-qualified sellers to practice offer submission to its auction website. The test aims to ensure that all auction participants understand the auction rules and that the auction will proceed smoothly on the auction date.

Having completed the key preparatory steps, the auctioneer assists the MU to implement an internet-based multi-round auction:

<u>Round 1: Initial offering that lasts a preset duration (30 minutes)</u>. In Round 1, all pre-qualified sellers submit their initial anonymous offers on the auctioneer's auction website. Only the lowest prevailing offer is observable, thereby allowing the participants to assess the extent of price competition. During Round 1, pre-

qualified sellers may revise their initial offers. The revised offers are not required to beat the lowest prevailing offer so as to (a) keep the sellers' interest in participating in the next round, and (b) produce a range of price offers that approximates what may result from an RFO process. The range from (b) informs the LDC if the auction is in fact superior to the RFO. The *lowest* offer at the conclusion of Round 1 sets the *prevailing best* offer at the beginning of Round 2.

Round 2: Open offering that lasts a preset duration (15 minutes) with possible extension. In Round 2, each seller can see the prevailing best offer. A seller may choose not to submit a new price offer and its own lowest offer from Round 1 becomes its *de facto* Round 2 offer. Should the seller decide to submit a new price offer on the auctioneer's website, the new offer must beat the prevailing best offer. The auctioneer updates and posts the prevailing best offer in real time as a newly submitted valid offer arrives. A valid offer arriving in the remaining five minutes of Round 2 automatically extends the round by another five minutes. Round 2 closes at the later of the scheduled time or after five minutes of no bidding activity. The auctioneer then identifies the three sellers with the lowest price offers as the finalists for Round 3.

Round 3: Best and final sealed offering. In Round 3, the auctioneer invites the finalists to submit their best and last offers. Each seller's offer is "sealed," unobservable to the other two sellers. Each seller's sealed offer must not exceed the seller's own prior offers in Round 2. By not requiring each seller's sealed offer to beat the lowest offer found at the end of Round 2, the MU has two backup offers in the unlikely event that the winner with the lowest sealed offer in Round

3 fails to execute the transaction in a timely manner, despite the risk of legal actions by the MU. As Round 3 creates uncertainty of losing, it mitigates collusion and induces further price cuts.

The lowest forward-price quote at the end of Round 3 is \$39/MWh, below (but *not* statistically different from) the MU's price benchmark of u_P = \$43/MWh. The auction result of F = \$39/MWh < u_P = \$43/MWh occurs for one or more of the following plausible reasons. First, u_P is the MU's spot-price projection, while the F quote reflects the auction winner's spot-price forecast, one that is less than the MU's. Second, both u_P and F reflect the best judgments of the MU and the auction winner. The MU assigns $\mu_P = u_P$ based on the price forecast in Appendix B. The auction winner determines F based on its own assessment of future spot prices and what it may take to win. Randomness in these assignments can partly explain $F < u_P$. Third, the Round 3 winner may bid below u_P to secure a fixed price for its low-cost surplus generation. Finally, the F = \$39/MWh forward-price quote is a case of the winner's curse.

The MU's auction has yielded about 10% cost savings when compared to the MU's price benchmark. This percentage saving is acknowledged by an MU official who opined that "the auction resulted in a savings of about 10%, compared with what the muni[cipal utility] normally pays…" (*MegaWatt Daily*, 09/17/02, p.2). The same official further remarked "[t]he process worked tremendously for us. I see this as something that is going to catch on. … It's very good for competition. It's unmasking the prices and will save us between \$500,000 and \$1 million annually" (*Daytona Beach News Journal*, 09/17/02).

Given the attractive forward-price offer, the MU signed the forward contract for its desired electricity block on the same auction date. It took under four hours from the first offer submitted in Round 1 to the MU's contract execution. This is much shorter than the 7-10 days under the MU's extant RFO process. This shows the time-efficiency of the internet-based auction for procuring a non-standardized forward contract.

5. Conclusion

What would our hypothetical LDC management have done when faced with the same forward price quote of $39/MWh? Based on Table 2, it would have signed the forward contract for 100% of its expected electricity requirement. Hence, the LDC management's contracting decision is consistent with least-cost procurement subject to a cost-exposure constraint. Should the LDC management decide otherwise, Table 2 shows that the LDC would have a higher expected procurement cost and a greater cost exposure. This demonstrates the practical usefulness of our approach for managing electricity procurement cost and risk.

What can an LDC's management learn from this paper? First, a procurement solution requires answers for two related questions: "What to buy?" and "How to buy?" We answer "What to buy?" by solving a constrained least-cost procurement problem. We then propose an internet-based multi-round auction as the answer for "How to buy?"

Second, we show that implementing the procurement solution requires knowledge and skill that may exceed an LDC's in-house capability. Our simple example of a hypothetical LDC illustrates the complexities in the development and implementation of least-cost procurement. When unsure, management should seek outside assistance because of the potentially large monetary consequence of a procurement mistake.

Finally, we show that even though management may know little of the LDC's customers' risk tolerance, it makes procurement decisions to meet its obligation to serve. If the LDC could offer a menu of service options differentiated by price stability, its customers would have the opportunity to self-select their desired options. A simple menu might contain (1) service at the spot-market prices, and (2) service at a stable tariff indexed to the forward prices of contracts that are competitively procured. For customers choosing (1), the LDC would simply transfer purchases from the spot market. For customers choosing (2), the LDC would contract forward electricity to meet the bulk of their energy consumption. To be sure, the LDC would still face the cost risk due to the random difference between the energy requirement under (2) and the related forward purchases made.[5] Nonetheless, the LDC's pricing and forward-procurement decisions would reflect individual customer decisions, instead of an inaccurate perception of customers' risk tolerance.[6]

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Appendix A: Constrained least cost procurement

Management's problem is to choose q to minimize μ, subject to the constraint $T = \mu + z_\alpha\sigma \leq \theta\mu$. Equivalently, the problem can be written as follows:

$$\underset{q}{\text{Maximize}}\ -\mu$$

Subject to: $z_\alpha\sigma - (\theta - 1)\mu \leq 0$.

Let λ denote a Lagrange multiplier. The Lagrangian may then be written as:

$$L = -\mu - \lambda[z_\alpha\sigma - (\theta - 1)\mu]. \tag{A.1}$$

The solution to the problem will determine optimal values, q^* and λ^*, for the forward-contract purchase and Lagrange multiplier, respectively. Recall $\nu = \mathrm{var}(C) = \sigma^2$. Since $d\sigma/dq = (d\nu/dq)/2\sigma$,

$$d^2\sigma/dq^2 = [(d^2\nu/dq^2)\nu - (d\nu/dq)^2/2]/2\nu^{1.5} = \Delta/2\nu^{1.5}.$$

Thus, the sign of Δ will determine the sign of $d^2\sigma/dq^2$. Substituting the relevant expressions for the variance and its first and second derivatives, and after carrying out some uninteresting algebra, it is determined that:

$$\Delta = 2\sigma_P^2\sigma_{PQ}^2(1 - \rho_{PQ,P}^2) > 0.$$

Hence, like σ^2, σ is also a strictly convex function of q that takes on its minimum value where $q = \rho_{PQ,P}\sigma_{PQ}/\sigma_P$.

Because μ is a linear function of q and σ is a strictly convex function of μ, an optimal solution resulting in μ^* and σ^* exists at q^* and λ^*, where the following first-order Karush-Kuhn-Tucker conditions are satisfied (Hillier and Lieberman, 1986, p. 454):

$$-\partial\mu/\partial q - \lambda[z_\alpha(\partial\sigma/\partial q) - (\theta - 1)(\partial\mu/\partial q)] \leq 0; \tag{A.2}$$

$$\{-\partial\mu/\partial q - \lambda[z_\alpha(\partial\sigma/\partial q) - (\theta - 1)(\partial\mu/\partial q)]\}q^* = 0; \tag{A.3}$$

$$z_\alpha\sigma^* - (\theta - 1)\mu^* \leq 0; \tag{A.4}$$

$$\{z_\alpha\sigma^* - (\theta - 1)\mu^*\}\lambda^* = 0; \tag{A.5}$$

$$q^* \geq 0; \tag{A.6}$$

$$\lambda^* \geq 0. \tag{A.7}$$

If there is a feasible optimal solution, from (A.6) it will hold either at $q^* = 0$ or at $q^* > 0$. And in either case, from (A.7), it will hold either at $\lambda^* = 0$ or at $\lambda^* > 0$. Thus, four different sets (q^*, λ^*) must be evaluated.

(I) Zero forward purchase: $q^* = 0$, with $\mu^* = \mu_P\mu_Q + \rho\sigma_P\sigma_Q$ and $\sigma^{*2} = \sigma_{PQ}^2$. We explore two cases based on the possible values of λ^*:

Case (a): $\lambda^* = 0$. From (A.2) we determine that $-\partial\mu/\partial q = \mu_P - F \leq 0$; or, $F \geq \mu_P$. And, after minor manipulation, we determine from (A.4) that $z_\alpha \leq [(\theta - 1)(\mu_P\mu_Q + \rho\sigma_P\sigma_Q)]/\sigma_{PQ}$. Thus, a non-binding cost-exposure constraint, which requires $\lambda^* = 0$, is only compatible with a zero forward-contract purchase, when z_α is set sufficiently small, given the level of the risk parameter, *and* when the forward-contract price is at least as large as the expected spot price. Higher values of the risk parameter permit higher values of z_α.

Case (b): $\lambda^* > 0$. From (A.5) we determine that $z_\alpha = [(\theta - 1)(\mu_P\mu_Q + \rho\sigma_P\sigma_Q)]/\sigma_{PQ}$. Under a binding cost-exposure constraint, there is only a single value for z_α that can yield a zero forward-contract purchase, given the level of the risk parameter. Substituting that z_α back into (A.2) results in an additional inequality condition on the difference between

μ_P and F. Put otherwise, it would be a rare circumstance indeed if the zero forward-contract purchase went hand in hand with a binding cost-exposure constraint.

(II) Strictly positive forward purchase: $q^* > 0$ with $\mu^* = \mu_{PQ} + (F - \mu_P)q^*$ and $\sigma^{*2} = \sigma_{PQ}^2 + \sigma_P^2 q^{*2} - 2\rho_{PQ,P}\sigma_{PQ}\sigma_P q^*$. We explore two cases based on the possible values of λ^*:

Case (a): $\lambda^* = 0$. From (A.3), this solution can only hold when $F = \mu_P$. Further, from (A.4), the solution will hold for *any* positive q^* such that $z_\alpha/(\theta - 1) \leq \mu^*/\sigma^*$. And, with $F = \mu_P$, the expected procurement cost will be equal to $(\mu_P\mu_Q + \rho\sigma_P\sigma_Q)$ regardless of the amount of the forward-contract purchase. Further, the cost-exposure constraint may or may not be binding.

Case (b): $\lambda^* > 0$. In this case the cost-exposure constraint is necessarily binding and q^* is determined from (A.5) by solving the quadratic equation that results from setting $z_\alpha/(\theta - 1) = \mu^*/\sigma^*$. The solution for λ^* can then be determined from (A.3) to be:

$$\lambda^* = [\mu_P - F]/[z_\alpha(\partial\sigma/\partial q) - (\theta - 1)(F - \mu_P)].$$

Hence, a binding cost-exposure constraint will be compatible with a positive forward-contract purchase whenever $F < \mu_P$ and $\partial\sigma/\partial q \geq 0$, because then and *only* then are both numerator and denominator guaranteed to be positive. The former condition states that the forward-contract price is less than the expected spot-market price. The latter condition states that the forward-contract purchase will be at least as great as the variance-minimizing purchase of $q = \rho_{PQ,P}\sigma_{PQ}/\sigma_P$. When $F > \mu_P$, the numerator is negative. Hence, $q^* \leq \rho_{PQ,P}\sigma_{PQ}/\sigma_P$ will result in $\lambda^* > 0$, as will any q^* such that $z_\alpha(\partial\sigma/\partial q) > (\theta - 1)(F - \mu_P) > 0$.

Appendix B: Spot price regression

This appendix justifies our use of a spot-price regression to assign the hypothetical LDC's purchase-price expectation and variance, and reports the spot-price regression results.

B.1 Justification

Consider the simple case of a spot-price regression that relates the spot price P in the LDC's market without forward trading and the spot price S in an external market with forward trading:

$$P = \alpha + \beta S + \varepsilon..$$

Here, α and β are coefficients to be estimated, and ε is a random-error term with the usual normality properties.

The LDC's procurement cost per MWh can be reduced by its going to the external market, buying β MWh of forward electricity at a price G, taking delivery, selling β MWh at S, and earning a per-MWh profit of $\beta(S - G)$. The LDC's net per-MWh procurement cost then will be $[P - \beta(S - G)] = \alpha + \beta S + \varepsilon - \beta(S - G) = \alpha + \beta G + \varepsilon$. Thus, the LDC's net cost is the spot-price regression evaluated at the forward price G, justifying our use of a spot-price regression to assign the MU's purchase-price expectation and variance.

As (α, β) are not known, we use their OLS estimates (a, b) for the purpose of forecasting. The net-cost forecast is $(a + bG)$ whose variance is $[MSE + \text{var}(a) + 2\text{cov}(a, b)G + \text{var}(b)G^2]$, where MSE = mean-squared-error of the spot price regression (Woo *et al*., 2001).

B.2 Results

For our hypothetical LDC, the spot-price regression's dependent variable is the monthly average price for the MU's historic purchases and the explanatory variables (besides the intercept) are the monthly average of daily spot prices at Entergy (Louisiana) and ERCOT (Texas), where electricity forwards are traded. The sample period is May 2000 to July 2002.

The regression estimates, however, can be spurious if the price series are random walks, since they may drift apart over time (Davidson and McKinnon, 1993, pp. 669-673). To guard against this possibility, we compute the Augmented Dickey-Fuller (ADF) statistic to test the null hypothesis that a price series is a random walk. The critical value of the ADF statistic at the 5% significance level is –2.86.

Table 3 reports summary statistics of the MU, Entergy and ERCOT monthly average prices, the MU's spot MWh purchases, and the MU's spot purchase costs. The same table also presents Shapiro-Wilk statistics for testing the null hypothesis of a normally distributed price series, and the ADF statistics.

[Insert Table 3 here]

The summary statistics suggest that the distributions are skewed to the right, with medians falling below means. The Shapiro-Wilk statistics indicate that the MU and Entergy prices, as well as the MU's net MWh purchases and spot purchase cost, are normally distributed, while the ERCOT prices are not.

The ADF statistics indicate that all three of the price series follow random walks, suggesting the possibility of a spurious regression where the MU price series and the Entergy and ERCOT price series may diverge over time without limit. To test this possibility, we estimate the regression and then apply a cointegration test to see if the regression residuals are stationary rather than a random walk. The cointegration test statistic is an ADF statistic whose critical value at the 5% significance level is –3.34.

Table 4 reports the spot-price regression results and the corresponding ADF statistic. The adjusted R^2 indicates that the estimated regression explains 84% of the MU price variance. The coefficient estimates for the Entergy and ERCOT prices are significant at the 5% level. The mean squared error is large at $127/MWh because of the relatively small sample size. The ADF statistic of –5.4 indicates that the estimated regression is not spurious.

[Insert Table 4 here]

To forecast the MU price for October 2002 delivery, we use the coefficient estimates in Table 4 and the forward prices of $24.80/MWh and $27.80/MWh quoted on September 9, 2002 for October delivery at Entergy and ERCOT, respectively. As reported in Table 1, the resulting forecast is $43/MWh whose standard deviation is $12/MWh.

End Notes

1. Using auctions for electricity procurement is common in a wholesale market managed by a central agent. For example, the UK power pool in the early 1990s solicited supply bids to serve the projected next-day aggregate demand, with all winning bidders being paid the market-clearing price that equates the aggregate supply and demand (Wolfram, 1999). Another example is the now defunct California Power Exchange that invited supply offers and demand bids and set the single market-clearing price to equate the aggregate supply and demand (Woo, 2001). Also, the California Independent System Operator (CAISO) conducts daily auctions to procure capacity reserve and real time energy required by safe and reliable grid operation (Chao and Wilson, 2002). Finally, the New England Electric System conducted auction for standard offer service to large blocks of retail end-users (Cramton *et al*., 1997).

2. From equation (13) in Mood *et al*. (1974, p.180), $\sigma_{PQ}^2 = \mu_Q^2\ \sigma_P^2 + \mu_P^2\ \sigma_Q^2 + 2\ \mu_Q\ \mu_P\ \rho\ \sigma_P\ \sigma_Q - (\rho\ \ \sigma_P\ \sigma_Q)^2 + \mathrm{E}[(P - \mu_P)^2\ (Q - \mu_Q)^2] + 2\ \mu_Q\ \mathrm{E}[(P - \mu_P)^2\ (Q - \mu_Q)] + 2\ \mu_P\ \mathrm{E}[(P - \mu_P)\ (Q - \mu_Q)^2]$.

3. Equation (6) attempts to address the lack of evidence on consumer risk tolerance, a significant regulatory concern in California. “[I]n order to develop coherent procurement strategies, the utilities must be able to evaluate potential transactions in terms of the costs of the transaction against the elimination of potential price risk. Given the lack of record, we require the utilities to provide a level of consumer risk-tolerance, along with a justification for the level they propose…” Decision 02-10-062 (CPUC, 2002, p. 44).

4. The computation requires estimates for $\mathrm{E}[(P - \mu_P)^2\ (Q - \mu_Q)^2]$, $\mathrm{E}[(P - \mu_P)^2\ (Q - \mu_Q)]$ and $\mathrm{E}[(P - \mu_P)\ (Q - \mu_Q)^2]$. The estimation of $\mathrm{E}[(P - \mu_P)^2\ (Q - \mu_Q)^2]$ entails (1) computing (P -

$u_P)^2(Q - u_Q)^2$ for each observation in the MU sample, and (2) finding the simple average of the values found in (1). The other two estimates are derived in a similar manner.

5. This cost risk is likely small and its adverse effect on the LDC's financial viability can be eliminated by including a markup in the indexed tariff.

6. The LDC may first offer the menu as a pilot program for a sample of customers. Even if management later decides to terminate the program, the customer-choice data allows it to estimate its customers' risk tolerance. The estimation entails discrete-choice modeling, as done by Hartman *et al*. (1991) to infer consumer preference for reliability-differentiated service options.

Table 1: Estimates for computing expected cost and cost exposure

Variable	Estimate
u_P	\$43/MWh
s_P	\$12/MWh
u_Q	16,275 MWh
s_Q	4,037 MWh
$r_{P,Q}$	0.42
$r_{PQ,P}$	0.93
u_{PQ}	\$722,729
s_{PQ}	\$475,062

Table 2: Expected cost (μ), cost exposure (T), and θ (= μ/T) by forward purchase share of forecast electricity requirement and forward price

Forward Price (F) ($/MWh)	Share of forecast electricity requirement (μ_Q) bought at the forward price														
	0%			25%			50%			75%			100%		
	μ	T	θ	μ	T	θ	μ	T	θ	μ	T	θ	μ	T	θ
40	$722,729	$1,504,207	2.1	$709,737	$1,418,915	2.0	$696,746	$1,334,987	1.9	$683,754	$1,252,935	1.8	$670,762	$1,173,530	1.7
45	$722,729	$1,504,207	2.1	$730,081	$1,439,259	2.0	$737,434	$1,375,675	1.9	$744,786	$1,313,967	1.8	$752,138	$1,254,906	1.7
50	$722,729	$1,504,207	2.1	$750,425	$1,459,603	1.9	$778,122	$1,416,363	1.8	$805,818	$1,374,999	1.7	$833,514	$1,336,282	1.6
55	$722,729	$1,504,207	2.1	$770,769	$1,479,947	1.9	$818,810	$1,457,051	1.8	$866,850	$1,436,031	1.7	$914,890	$1,417,658	1.5
60	$722,729	$1,504,207	2.1	$791,113	$1,500,291	1.9	$859,498	$1,497,739	1.7	$927,882	$1,497,063	1.6	$996,266	$1,499,034	1.5

Table 3: Summary statistics for monthly average prices ($/MWh), MU's spot MWh purchase, and MU's purchase cost ($)

Statistics	MU price	Entergy price	ERCOT price	MU spot MWh purchase	MU spot purchase cost
Sample size	25	27	27	27	25
Mean	64.13	40.63	43.25	16,351	1,113,028
Minimum	25.09	18.90	18.35	10,289	276,207
First quartile	42.57	26.01	25.68	12,901	718,344
Median	61.76	40.65	45.13	15,180	870,171
Third quartile	88.25	50.88	50.65	20,129	1,483,377
Maximum	121.59	79.76	89.44	23,207	2,620,872
Standard deviation	27.79	17.01	20.40	3,967	626,694
Shapiro-Wilk statistic for testing null H_0: The data series is normal	0.95	0.93	0.91*	0.95	0.93
ADF statistic for testing H_0: The data series is a random walk.	-1.43	-1.76	-1.17	-2.80	-1.64

Notes: The MU price series only has 25 observations due to missing values.
* = "Significant at the 5% level"

Table 4: Spot price regression results

Independent Variable	Coefficient
Intercept	4.10
Entergy price	0.80*
ERCOT price	0.70*
Adjusted R^2	0.84
Mean squared error	127
ADF statistic for testing H_0:The price series drift apart without limit	-5.4*

Note: * = "Significant at the 5% level"