Uniform-Pricing versus Pay-as-Bid in Wholesale Electricity Markets: Does it Make a Difference?[1]

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Electricity prices have been rising. Over the last decade, average electricity prices in the U.S. have increased by one-third.[2] These price increases coincide with policy changes in many parts of the country that introduced greater reliance on market forces into the electric industry. Although today's electricity prices are still relatively low in historical terms (about two-thirds of their 1980s levels when adjusted for inflation[3]) and rising electricity prices have been largely the result of movements in global markets for fossil fuels, these price increases have nonetheless placed pressure on policy makers in a number of recently restructured electricity markets to question whether power prices have increased due to the design of competitive markets. Some observers have begun to push for redesign of market rules or even a return to elements of traditional cost-of-service regulation in the electric industry.[4]

Among the proposed reforms are changes to the design of auction processes used in various wholesale electricity markets. These auctions involve offers to supply power, and, potentially, bids to buy power. The auction determines the identity of the "winners" – those competitive suppliers selected to provide power supply in any given time period – along with the price and other terms of the power sale. Sometimes the bids into the auction are supplies to meet a given amount of demand; sometimes there are bids/offer from both demand and supply. Typically, the buyer is some entity with responsibility to supply power to end-use consumers of electricity. Notable examples of such auctions in the power industry are the "organized" energy and capacity markets administered by

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[2] Energy Information Administration, monthly Form 826 electricity data for the period from 1995 through April 2007, the last year for which data are available as of this writing.

[3] Energy Information Administration (2007).

[4] See, for example, Burkhart (2007).

various Regional Transmission Organizations ("RTOs"), operating in different regions of the U.S.[5] Additionally, in some states with retail choice (like New Jersey), the electric distribution utilities have used auctions as the means to obtain power supply for their basic service customers. As prices have risen in the some of these markets, some observers advocate a switch from the *uniform-price auctions* (also called *single clearing price auctions*) relied on almost exclusively in all organized wholesale power markets in the U.S., to *pay-as-bid auctions.*[6] These alternatives differ in the way in which the price awarded to winning suppliers is determined. Under uniform-price auctions, all suppliers receive the same market-clearing price which is set at the offer price of the most expensive resource chosen to provide supply.[7] In contrast, in a pay-as-bid auction, prices paid to winning suppliers are based on their *actual* bids, rather than the bid of the *highest* priced supplier selected to provide supply. For this reason, pay-as-bid auctions are also known as "*discriminatory auctions*" because they pay winners a different price tied to the specific prices offered in their bids.

At first blush, the intuitive appeal of a pay-as-bid auction is obvious. Why pay a higher price to a supplier than the price at which he or she offers to sell the product? Wouldn't doing so simply impose higher-than-necessary costs on the buyer – and by extension, to the consumer? Wouldn't switching to a pay-as-bid model produce lower electricity costs for consumers?

This paper considers these two alternative designs for wholesale electricity markets, including their implications for prices and efficiency.[8] Although pay-as-bid auctions are frequently promoted as a way to reduce consumers' overall expenditures for wholesale power, we conclude that switching to a pay-as-bid approach would likely produce just the opposite result. This counter-intuitive outcome stems from the propensity for strategic bidding behavior, as well as the resulting inefficiencies in plant dispatch and capacity investment. A change in auction design would do little to address other pressing market concerns, including ensuring adequate transmission and generation resources and increasing the role of demand response,[9] and could even exacerbate these

[5] The so-called "organized" wholesale markets are those that rely principally on a bid-based, centralized energy spot markets, including PJM Interconnection ("PJM", in the mid-Atlantic states and parts of the Midwest), the New York Independent System Operator ("NYISO"), the California Independent System Operator ("CAISO"), the Electric Reliability Council of Texas ("ERCOT"), the MidWest System Operator ("MISO"), and the Independent System Operator – New England ("ISO-NE")..

[6] Laffer and Giordano (2005).

[7] In so-called second-price auction, the market clearing price is determined by the next highest bid after last supplier selected to supply.

[8] For similar assessments, *see* Kahn et al. (2001), Cramton and Stoft (2006b), Newbery and McDaniel (2002), and Wolfram (1999).

[9] For example, *see* Joskow (2006) and Cramton and Stoft (2006a).

investment challenges in light of the on-going concern that continued changing of market rules creates regulatory uncertainty and fears of regulator opportunism that may discourage investment in new generation facilities and transmission.[10] This paper discusses these issues, focusing on applications in centrally administered wholesale energy markets such as exist in various RTO regions around the U.S. However, some of the lessons may be relevant to other electricity auctions, such as procurements for full service requirements.[11]

The starting point: the goal of economic efficiency in the production of power

As we set out to examine these two approaches, we start with a reminder of what "market designs" are attempting to accomplish in the electric industry. Based on long-standing principles, even when it was composed of highly regulated utilities providing power under a government-authorized monopoly structure, the electric industry's clear goal has been to provide reliable power as efficiently as possible.[12] In theory, efficiently

[10] Tierney (2007). This is not to say that changes in market rules are undesirable. However, because such changes may discourage investment by increasing regulatory uncertainty, such changes should be undertaken judiciously when there is confidence that the benefits of revised regulations will outweigh these (and other) costs.

[11] To a large extent, our assessment applies to those wholesale electricity markets in which the auctions occur with great frequency. For example, in most RTO-administered electric energy markets, the auctions occur daily for the 24 hours of the next day and the same day's energy markets. Auctions for full-service requirements, such as procurements of power supply to meet the needs of basic service customers served by an electric distribution company, are held more infrequency, and, consequently, face different design issues. These auctions often rely on a variant of a uniform-price auction, called the descending clock auction, in which multiple rounds of bidding occur until the auctioneer obtains a quantity of supply just sufficient to meet demand at a stated price. Because bidders in such auctions have limited information about market prices due to the infrequency at which auctions are held, it is important to help them develop information on likely market clearing prices. Because bids in these markets reflect forecasted market prices in future periods, rather than facility marginal costs, such information can provide valuable feedback from other market participant's on market prices and ameliorate the "winner's curse", which would cause bidders to raise offers to supply power due to the fear that, after the fact, their bid would appear to low compared to the bids of other participants. The multiple rounds of bidding – in which bidders have the incentive for bid to reflect their expected market prices – facilitate such price discovery. In contrast, pay-as-bid auctions provide no comparable mechanism for price discovery. *See* Ausubel and Cramton (2006). (Note that "full-requirements service" is typically a wholesale electricity product where the supplier must provide a portion of the buyer's demand for firm electricity service, and the supplier must assemble a portfolio of generating resources to provide supply as demand for electricity rises and falls over the course of any day. The portfolio is – of necessity – composed of various components (energy, capacity, ancillary services) to satisfy the various requirements of firm supply. This is in contrast to RTO-administered energy, ancillary service and capacity markets, which provide single products, rather than a portfolios of products.).

[12] "The capitalistic free-market system, which normally set prices, output levels, and general terms of trade in society, is generally unworkable in the case of some services provided by public utilities because utility services are largely monopolistic in nature (for example, energy distribution and transmission). That is, they do not experience full competition in a particular market area or in dispensing a particular service. As

produced and supplied power supports the goal of providing electricity to consumers at the lowest price.

But what does "efficiency" mean for electricity markets? First, it's important to distinguish between short-run (static) efficiency and long-run (dynamic) efficiency. Static efficiency means: 1) output is produced by the least-cost suppliers; 2) it is consumed by those most willing to pay for it, and; 3) the right amount is produced. Achieving short-run productive efficiency (for a given load) has essentially devolved into the problem of operating existing power resources (i.e., existing plants and dispatchable demand-side resources[13]) according to the principal of economic dispatch—that is, running plants in a dispatch order so the ones with lowest operating costs (i.e., short-run marginal costs) are dispatched ahead of others with higher operating costs. [14]

The nature of the electricity grid – including transmission constraints, reliability requirements, demand-response notice periods, and resource constraints, such as plant start-up costs or ramping times – adds many wrinkles to achieving least-cost dispatch, but does not fundamentally change the problem. Solving this problem effectively depends on information that allows control operators to order plants and other resources from least-costly to most-costly – and a host of other things, such as the degree of control operators have to minimize system costs over a wide geographic grid, issues that are not greatly affected by choice of auction design.

Even as some parts of the country have shifted control of the grid from regulated utilities to RTOs, the basic process by which least-cost dispatch is implemented has not

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a result, public utility regulation replaces the free market system by establishing allowable prices for the rendering of public services. The purpose of regulation is to replicate the results that the competitive market system would achieve in the way of reasonable prices and profits. This view was eloquently expressed by Bonbright (1966 [page 3]): 'Regulation, it is said, is a substitute for competition. Hence its objective should be to compel a regulated enterprise, despite its possession of complete or partial monopoly, to charges rates approximating those which it would charge if free from regulation but subject to the market forces of competition. In short, regulation should be not only a substitute for competition, but a closely imitative substitute.' " Morin (2006), page 1, citing J.C. Bonbright, Principles of Public Utility Rates, New York: Columbia University Press, 1966.

[13] Dispatchable resources—whether from available generating units or demand-side resources—are the tools available to the dispatcher to meet electricity demand at least-cost at any point in time. For simplicity, in the rest of this paper we discuss the dispatch of power plants, while recognizing that many of these same discussion points apply to the dispatch of certain demand-side resources and even of certain controllable direct-current transmission facilities capable of making certain remote generation available for dispatch to a system.

[14] This economic dispatch is typically called economic merit order, with plants dispatched in a way that minimizes the start-up and operating costs of plants run for energy and operating reserves, based on plants' operating efficiency (their heat rate) and their variable operating costs (e.g., fuel, variable operations and maintenance, emissions allowances costs).

changed dramatically. In all regions, control area operators minimize system costs given the security constraints of maintaining system reliability—that is, satisfying all demand for power. An important difference emerges, however, in the information used by control area operators to minimize costs. While non-RTO regions rely upon cost data provided by the utilities, RTO regions rely on auction-based bids from suppliers. While there are many important differences between RTO and non-RTO models affecting economic dispatch—e.g., the effectiveness of resource "pooling" across states and utility service areas and access to transmission rights —an important issue differentiating alternative auction designs is their ability to elicit accurate information about the relative costs of operating power plants.

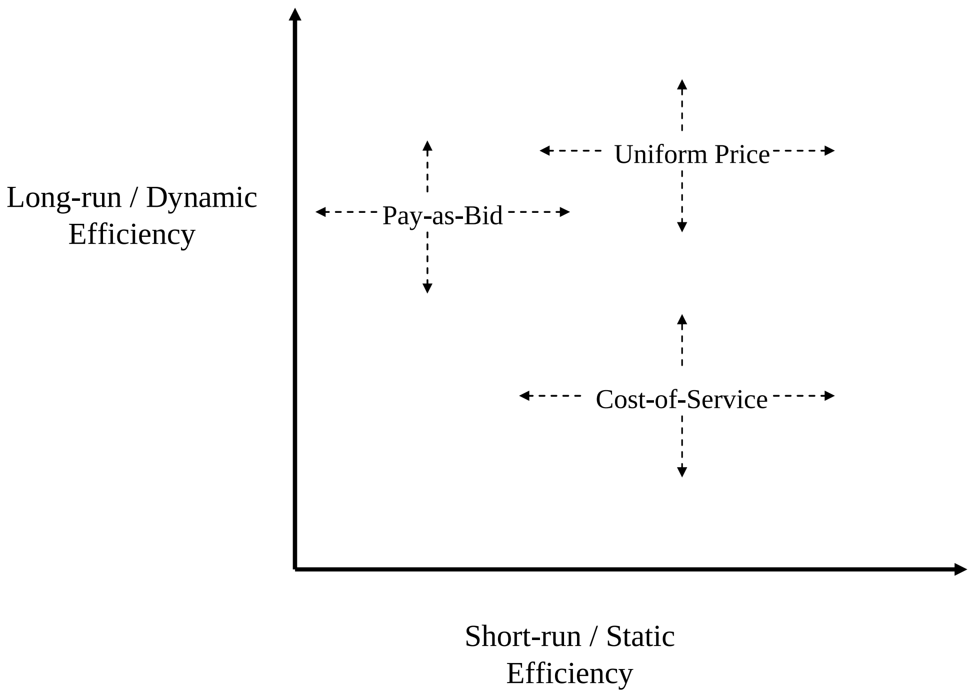
While economic dispatch is designed to produce power as efficiently as possible given the generating and other resources that already exist in the system, there is still the critical question of whether the market system provides the incentives for development of the most efficient generation, transmission and demand-side infrastructure. Achieving long-run, dynamic efficiency thus requires developing the right amount and type of resources, such as generation facilities, in the right locations. To create this infrastructure, the system must create price signals that encourage the right incremental investment. It must also provide incentives that promote a competitive market structure, and provide sufficient confidence that the system of pricing and compensation for power production will afford a reasonable opportunity for investment recovery given the capital intensity of and multi-year lead times for plant construction.

In traditionally regulated markets, the principal mechanism used historically to compensate the utility for its investment in electricity resources (such as power plant capacity) is the placement of investment dollars in the utility's rate base and the establishment of customer rates that provide the opportunity to recover a return of and on investment. Such compensation is in addition to recovery of operating expenses, fuel costs and other variable costs associated with producing and/or buying power.

A major objective of industry restructuring has been to improve the price signals and other financial incentives for efficient operation and use of existing resources, and efficient investment in new resources. These competitive markets rely on different mechanisms for compensation of investment costs and operating expenses, as compared to the approaches used in traditional regulation. For example, bilateral contracts for sales of power under market-based rates sometimes provide payment terms to support investment recovery – such as through payments tied to a power plant being available to run, or through payments for output that are designed to cover more than the unit's marginal cost of production. Also, in centrally administered wholesale markets where compensation in energy markets is tied to being selected to produce power, there are a typically a variety of other means – including some combination of payments for performance in energy, ancillary service and capacity markets. Depending upon the structure of these markets, much of the compensation for investment and other non-variable costs of operation necessary to maintain plant availability typically comes to the supplier through a combination of payments from offers accepted in energy, ancillary service and capacity markets.

Figure 1

Static and Dynamic Efficiency of Alternative Market Designs – Illustrative



In principle, differences in the potential level of static and dynamic efficiency emerge for each of these regulatory models (as illustrated conceptually in Figure 1). Setting aside the question of whether restructuring has increased electric market efficiency, several important factors influence an analysis of auction design alternatives.[15] First, there is an important difference in how investors are compensated under the new RTO markets. While independent power producers ("IPPs") in RTO markets rely upon revenues from energy, ancillary service and evolving capacity markets, they do not—unlike generators under cost-of-service regulation—receive compensation for fixed costs (including return on investment) through rate base or through depreciation

[15] Note that Figure 1 is only intended to provide insight into the orientation—but not necessary the relative magnitude—of economic efficiency under alternative regulatory/market models.

charges in base rates.[16] Second, the price signals created by alternative auction approaches have important consequences for the efficiency of resulting investment incentives. Uniform-price auctions develop these price signals differently than pay-as-bid auctions do.

How, then, do these such differently structured wholesale markets provide for supporting a power plant's combined investment and operating costs? Does one overpay suppliers compared to another? These questions can be answered by comparing single-clearing-price auctions and pay-as-bid auctions, and considering the implications for prices and investment.

Pay-as-bid is unlikely to have *any* significant effect on market prices for electricity

Much of the rationale for reliance on uniform-pricing arises from the basic economic incentives created under typical competitive conditions. Under these conditions, suppliers bidding in a uniform-price auction have the incentive to bid their marginal opportunity cost of producing electricity, which reflects variable expenses incurred in producing electricity or the foregone opportunity to sell electricity at another time or into another market.[17] This incentive arises because suppliers, unable to affect the eventual market clearing price, have no incentive to bid above marginal costs. Bidding above marginal costs reduces the likelihood that they will be selected to supply electricity, while bidding below marginal costs would result in a financial loss. As a result, their bids largely reflect these marginal (opportunity) costs.

Figure 2A illustrates how the system operator ranks offers from Suppliers A through F according to their bid prices, and selects (or dispatches) the least-costly resources until there is sufficient supply from the designated "winners" to meet total customer demand. The market-clearing price received by all suppliers is set at the bid of the most expensive resource necessary to meet total customer demand. Consequently, except for the price-setting supplier, suppliers receive prices above their actual bids. The system dispatches the resources in a cost-minimizing way because when suppliers bid their marginal costs, the least-costly resources are chosen to supply before turning to more costly resources.

T[16] Capacity markets that are part of some organized wholesale markets provide investors with some fixed payments outside of energy and ancillary services markets, although the levels of and financial risks associated with such revenue streams differ substantially from those provided by regulated returns on investments in rate base.

[17] Suppliers that can export to a neighboring market for a price above its variable costs would bid in its "home" market at the expected level of prices in that neighboring market. Similarly, hydro-electric facilities incur an opportunity cost because the physical limits of reservoir capacity limit the total generation the facility can produce. Consequently, generation in any given hour eliminates the option to supply in a future hour, and the facility should bid based on this option value.

Figure 2:

Supplier Bids and Market Prices Under Uniform-Price and Pay-as-Bid Auctions

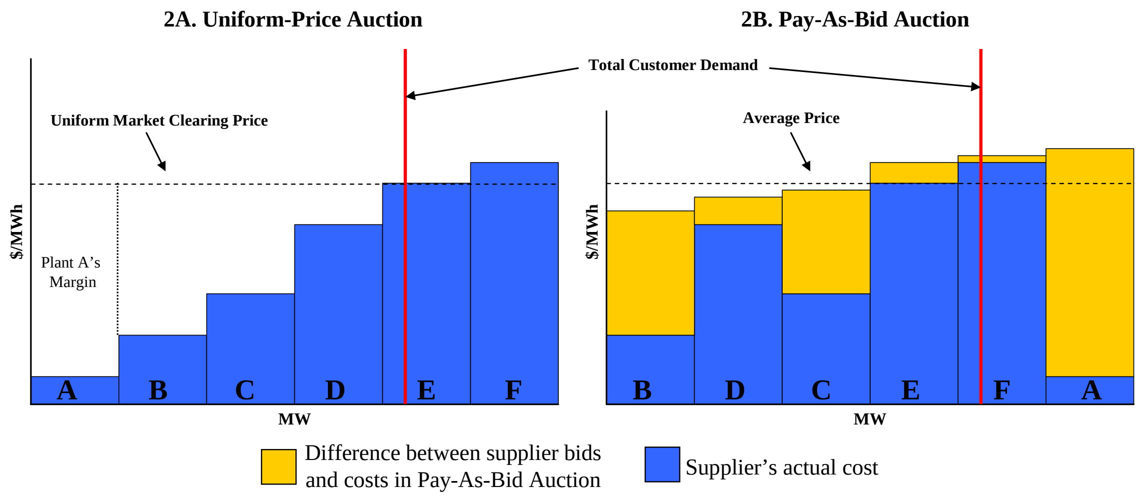


Figure 2 holds an enticing – deceptively so, unfortunately – prospect for those seeking to reduce electricity prices. Could total payments to suppliers (and, in turn, consumers' electricity rates) be reduced if supplier's payments were based on their actual bids, rather than the market-clearing price? If under a pay-as-bid auction, Plant A, for example, were paid an amount corresponding to its offer price (the blue square) rather than the uniform market clearing price (as shown in Figure 2A on the left), then it would seem to be a lower-cost solution for the buyer.

However, this hoped-for outcome would be unlikely to occur. Figure 2B provides insights into why. If Plant A knew that a winning offer would only be paid the amount he or she bids, then Plant A's bidding strategy is likely to change. Unlike in a single-clearing price market, the bidder would not have the incentive to bid at his or her marginal cost. Instead, s*uppliers in a pay-as-bid auction will bid their best-guess of the market-clearing price in order to maximize their revenues.* They will try to pick an offer price that balances their chance of winning (by being at or below the offer price of the last bidder whose supplies are needed to meet customer demand) against the decreased profits from bidding a lower offer price. Consequently, the offer prices suggested by Figure 2A never materialize, and will, in fact, be quite different. Figure 2B illustrates this change in bidding strategy.[18] Suppliers who previously bid their marginal costs under the uniform price auction (as in Figure 2A) now bid based on their individual forecasts of the market clearing price. Thus, under pay-as-bid, variation in individual supplier forecasts will lead to differences in bids irrespective of the costs of producing power.

A pay-as-bid auction also leads logically to higher overall bids as well, as shown in Figure 2B (comparing the top of the yellow bars in 1B against the blue bars in 2A).[19] That said, while suppliers' change in bidding strategy leads to a set of offers that are higher overall and that differ little in price, it is not immediately apparent whether the price *level* is affected by the auction choice. In fact, most analyses suggest that, *under competitive conditions, market prices are unlikely to materially differ between uniform-price and pay-as-bid auction formats, and analyses differ on the likely direction on average (and however small) of such an effect.*[20] While small differences may emerge due to factors particular to the market setting, structure, and design, the literature would not support a conclusion that a pay-as-bid auction will produce lower overall prices in competitive markets.

Even so, many observers point to the potentially large differences between supplier bids and prices in a single-clearing-price auction as an inherent flaw in that market design (if not in wholesale market themselves) that results in excess payments to suppliers. Many observers view these payments as profits, and see these margins as

[18] Although Figure 1 depicts the market-clearing price in a uniform-price auction and the average price from a pay-as-bid auction as equal, this need not be the case. It is also worth noting that the market-clearing price under a pay-as-bid auction is greater than that under a uniform-price auction. Consequently, with downward-sloping demand (i.e., there is some response of demand to price), the quantity supplied would be lower under pay-as-bid auctions.

[19] Suppliers in a pay-as-bid auction will always bid above their marginal costs, because bidding at a plant's short-run marginal costs guarantees that it will not only fail to earn a profit but also lose money given a plant's fixed and capital costs (such as debt which must be paid whether the plant operates or not). Thus, being paid only a price that's actually bid will assure that the bidder *must* bid above its short-run marginal cost if he actually wants to stay in business.

[20] Bidding behavior in experimental electricity markets designed to replicate real-world bidding situations suggest that pay-as-bid auctions would raise prices above uniform-price auctions. Mount et al. (2001), Abbink *et al*. (2003), and Rassenti *et al.* (2003). Some theoretical analyses analyzing the effect of auction format on market outcomes find that, under competitive conditions, pay-as-bid auctions will result in short-run lower prices than uniform price auctions. For example, Federico and Rahman (2003), and Fabra, von der Fehr, and Harbord (2006). Others theoretical analyses find no difference between auction format. Kremer and Nyborg (2004). Fabra, von der Fehr, and Harbord (2002) caution against drawing conclusions from these theoretical models to the design of real-world markets: "Careful theoretical work and experiments have so far yielded no strong reasons for preferring discriminatory to uniform price auctions for electricity." Although its market structure is much simpler than that of electricity, experience with U.S. treasury auctions, where the auction mechanism was switched from pay-as-bid to uniform-price, suggests that the switch had little consequence for market prices. Binmore and Swierzbinski (2000).

unacceptably high for the suppliers with low marginal costs. This viewpoint entirely overlooks the fact that in this market design, this margin is necessary for suppliers to recover their fixed costs – all those "other" but real expenses necessary to recoup the investment made to construct the power plant, to employ people to work in it, to maintain it in safe working order over time, and to pay property taxes. Typically, these expenses do not vary with the output of the plant and therefore do not figure into an economically rational bid in a market with a single-clearing price auction in which the producer only gets paid when selected to produce power. The margin earned in that hour – above the plant's variable cost – contributes to keeping his plant open by covering taxes, salaries, debt repayment, investors' returns, and the like.

Thus, while some observers simply equate the margins earned in wholesale uniform-price markets as pure profits, they ignore these other costs incurred by plant owners which somehow must be collected in the market for the plant to stay in business. Under traditional cost-of-service regulation, such fixed costs were collected in rates through return on investment in utility rate base, depreciation expenses, labor expenses, and so forth. In a pay-as-bid auction, these costs would be reflected in the higher bid prices, as illustrated in Figure 2B. These margins may include profits (i.e., a return to investors), but it would be incorrect to conclude that the entire margin is profit.

Limiting supplier payments to a price tied to facility variable cost of generating electricity would guarantee that no power plant could stay in business and no investor would ever build a generation facility. Investors could never recover their capital costs of construction, pay their property taxes or compensate their staff. Consequently, the opportunity to earn revenues above short-run marginal cost is necessary to maintaining reliable power supply at present as well as creating an incentive for future investors to develop new generation facilities.[21]

In this manner, a switch to a pay-as-bid auction does little to address concerns about either the affordability of electricity rates or the reliability of power supplies. The hoped-for outcomes are illusory.

[21] In fact, many suggest that the margins earned in current electricity markets, which are often subject to price caps, provide insufficient investment incentives to maintain adequate resources to meet growing demand, maintain the security of supply, and avoid periods of scarce capacity that may increase opportunities for the exercise of market power. For example, *see* Joskow (2006), Cramton and Stoft (2006a), Tierney (2007).

The Consequences of Auction Design for the Efficiency of Electricity Markets

Although pay-as-bid auctions are unlikely to have any impact on short-run prices in wholesale electricity markets, a switch to a pay-as-bid auction may have adverse consequences for market efficiency by reducing the efficiency of plant dispatch. Earlier, we described that an overall economic objective of power system operations is to produce power at the lowest total cost. A system design – or a market structure – that relies on economic dispatch of power resources based on their short-run marginal cost is one that accomplishes that result. A single-clearing-price auction is aligned with this goal, because of the financial incentives for suppliers to bid their short-run marginal cost.

A pay-as-bid auction design does not create incentives for bids tied to marginal costs, as we have discussed above. The need for suppliers to guess the market clearing price under pay-as-bid auctions introduces randomness to supplier bids because of differences in their forecasts of market prices, which are unrelated to the underlying costs of generating electricity. Consequently, the plants with the lowest bids may not reflect the plants with the lowest marginal costs. For example, a plant with low variable costs and an overly optimistic forecast of clearing prices may inadvertently bid above the eventual market-clearing price. As a result, this low-cost plant would not be selected to supply electricity while other plants with higher costs would be chosen and dispatched. Figure 2B illustrates this inefficiency: the lowest cost plant (Plant A) is not a winning bidder and does not supply electricity because its price forecast (and its offer price) was above that of the eventual market-clearing plant (Plant F). In that example, dispatching Plant E in full and Plant F in part, while not dispatching Plant A, produces power less efficiently from society's point of view, because these plants having higher costs than Plant A. Consumers pay no less, but society's resources have been used less efficiently. While not costing consumers in the short-run, such inefficient use of resources will eventually lead to reduced incentives for investment and higher consumer costs. By contrast, under uniform-pricing (Figure 2A), because supplier bids reflect their marginal costs (about which they have very good information), the least-cost resources are selected to generate power. Consequently, the resulting production is efficient in both the short-run and long-run.[22]

[22] Some suggest that the competitive market standard is rarely (if ever) attained in real-world markets, because suppliers have some degree of ability to influence price. From this perspective, while individual supplier bids will be related to their marginal costs, the markup of prices above costs may not be the same across suppliers. Consequently, some inefficiencies may exist under uniform-pricing. Cramton (2004). As we describe below, market monitoring is an essential function to examine the patterns of prices relative to short-run marginal costs and the net revenue needed to attract entry of new generation investment over the long-run.

In electricity markets, the extent to which such forecasting "noise" enters into supplier bids may be significant given unique circumstances that greatly increase the complexity and uncertainty of price forecasting. Bidders interact in a repeated bidding environment, involving multiple markets that are inter-related over time, space and across commodities, including markets for generation, transmission, capacity, emission allowances, and ancillary services. Idiosyncrasies in power production (such as the costs to start-up a plant once it has been shut off, or to maintain its operations at less than full output so that it can increase output quickly) create interactions between an individual supplier's bid across the day or week. Because electricity cannot be stored, unanticipated shifts in supply (e.g., unforeseen power plant outages), demand (e.g., unexpectedly hot and humid weather), or the behavior of other suppliers can dramatically shift prices from day to day, or even hour to hour. These complications and uncertainties increase the scope of inefficiencies that may occur under pay-as-bid that are absent under uniform-pricing.[23]

These dispatch problems that may be introduced by pay-as-bid auctions were not present under even the traditional cost-of-service model. In fact, in a traditional power-pool model, as long as data provided by the vertically regulated utility were accurate, power pools were designed to minimize costs across utility service areas, and all suppliers had non-discriminatory access to transmission, the traditional cost-of-service model did a fairly good job of minimizing overall power production costs, at least for the generating resources available to the dispatcher—typically those in the supply mix of the utility.

Impacts on technology choice

Auction design may also have unintended consequences for the investment incentives for different types of technologies. Under a pay-as-bid auction, technologies with low variable costs – including baseload generation technologies and some renewable technologies – may bid more conservatively than technologies with high variable cost.[24] Because low-cost plants earn large margins when they are selected to produce power,

[23] In addition to these consequences for short-run efficiency, pay-as-bid auctions will affect the long-run efficiency of generation resource investments. Pay-as-bid auctions require that suppliers engage in market forecasting in order to compete in pay-as-bid markets. This added cost, which is not present under either uniform-pricing or even cost-of-service regulation, increases the long-run cost of generation, and is likely to be passed on to consumers (in the long-run) through higher wholesale market prices.

[24] Baseload technologies, such as nuclear power and coal-fired generation, rely on near-continuous operation to earn sufficient margins to offset high capital and fixed operations costs. Some low-variable-cost renewable technologies, such as hydropower, face less incentive to shade bids because generation in any hour typically imposes an opportunity cost of reducing generation in some future hour.

these plants face a greater (opportunity) cost if their bid is inadvertently above the eventual clearing price.[25] To avoid this risk, owners of low-variable-cost technologies may reduce (or shade) their bids below their price forecast. Figure 3 illustrates how bids for the lowest cost plants (Plants A, B, and C) may be systematically lower than for higher cost plants. By shading their bids, owners of low-cost plants increase the likelihood that they will earn margins while sacrificing only a small discount on price. Systematic bid shading would partially reduce dispatch inefficiencies by reducing the likelihood that higher-cost plants would be dispatched before low-cost plants. In Figure 3, for example, the lowest cost plants (Plants A, B and C) all bid below the clearing price set by Plant E, although there continue to be inefficiencies, as Plant D bids higher than lower cost Plants E and F.

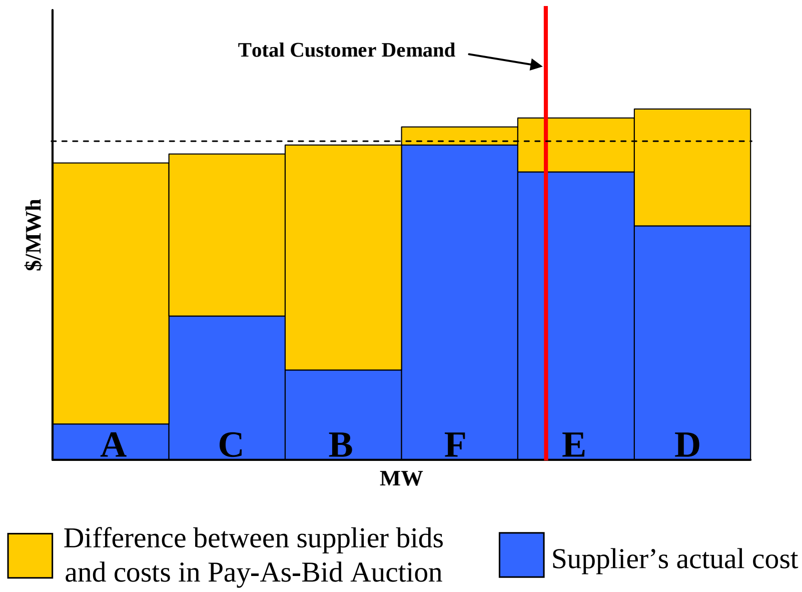
However, systematic bid shading by owners of low-cost technologies creates a new problem. Long-run plant revenues and the incentives for development of low-variable-cost technologies would be reduced relative to technologies with higher variable costs. Thus, a pay-as-bid auction may inefficiently shift the composition of generation technologies, by reducing the share of baseload and certain renewable technologies, and increasing reliance on shoulder and peak generation technologies (e.g., natural gas-fired combined cycle and combustion turbines).[26] Such a shift would increase the long-run cost of electricity generation and, as a result, likely lead to corresponding increases in prices.

[25] In addition, baseload plants face a significant cost to temporary shutdowns due to ramping costs. Consequently, owners of such plants would likely bid below the forecast prices to insure that such temporary shutdowns are avoided.

[26] Investments in such baseload and renewable technologies may, in fact, become more important over time as they interact with some other efforts aimed at increasing market efficiency, such as efforts to shift load from periods of high demand to low demand which aim to smooth out daily load profiles.

Figure 3

Supplier Bids under Pay-As-Bid Auction with Bid "Shading"



Consequences for Price Volatility

Some analysts have suggested that a switch to the pay-as-bid approach may reduce short-term price volatility – that is, variation in hourly or daily price as independent from the expected level of price.[27] Comparison of the bid supply curves in Figure 3 illustrate that bid curves under pay-as-bid are typically flatter than those in uniform-price auctions. As a result, price changes arising from unexpected shifts in market conditions – ranging from hot weather to unscheduled plant outages – would be smaller under a pay-as-bid auction, resulting in lower volatility. Some experimental studies report lower volatility in pay-as-bid auctions.[28]

Decreased price volatility may be beneficial for consumers by reducing undesirable price variation for those customers facing hourly or daily price and by reducing competitive supplier and LSE risk exposure for the for the portion of load (and supply) that is not hedged by forward contracts. While the extent to which suppliers and LSE's utilize such forward hedging varies across suppliers and markets, forward contracting (ranging from day-ahead to years ahead) often covers a large share of purchases by load serving entities.

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[27] *For example*, Mount (2000).

[28] Mount et al. (2001) and Rassenti et al. (2003).

By contrast, the effect of decreased price volatility on investment incentives is ambiguous. While a pay-as-bid approach may reduce short-term volatility—that is, volatility across hours or days—such volatility can be hedged through financial instruments. Further, volatility may promote investment in peaking technologies that rely upon price spikes in a few hours to justify initial capital investments. However, pay-as-bid auctions offer no panacea for reducing medium- to long-term price uncertainty that may act a deterrent to new generation investments or raise risks for consumer budgets.

Reductions in price volatility from pay-as-bid auctions may, however, have adverse consequences for efforts to encourage shifting and reduction of demand in periods of customers' peak use of power. Because prices reflect an average of the bids submitted, rather than the marginal bid, pay-as-bid auctions achieve reductions in price volatility at the expense of sending price signals that accurately reflect the marginal cost of generation. Price signals that reflect the true cost of generation are important to providing consumers with the correct incentives to reduce or shift demand (either directly, for those customers who may directly "see" prices on real-time meters, or indirectly, in those situations where, for example, smaller retail customers' appliances are pre-scheduled to respond automatically to prices that hit certain target levels, or where service providers bundle and manage certain aspect of customers' use of electricity). Effective demand reduction is increasingly recognized as an important means of meeting electricity supply needs cost-effectively, ensuring reliability and mitigating market power concerns.[29] Failure to develop such price responsiveness may only lead to adverse consumer impacts in the long-run.

Implications for Market Power and the Competitiveness of Electricity Markets

The prior discussion focused on market outcomes when market structure is sufficient to limit the opportunities for the exercise of market power through strategic withholding of capacity. However, some suggest pay-as-bid auctions are more effective at limiting supplier's ability to tacitly collude in an effort to raise prices.[30] Were this true, a switch to a pay-as-bid auction might reduce the extent of strategic withholding and reduce regulatory reliance on behavioral remedies (i.e., market monitoring and mitigation) that are subject to many uncertainties. To assess the implications of auction design for market competitiveness, we'll consider the impacts of auction design on a number of factors, including suppliers' ability to exercise market power, structural market conditions that may affect the frequency and severity of strategic withholding,

[29] See, for example, the remarks of FERC Commissioner Jon Wellinghoff (2008).

[30] For example, *see* Currie (2000).

and the regulators' ability to identify and mitigate the exercise of market power through market monitoring.

Limiting the Exercise of Market Power

Some proponents of pay-as-bid auctions suggest that suppliers' ability to exercise market power is greater under uniform-pricing than pay-as-bid. The basic intuition for this belief is illustrated by comparing the bidding behavior needed to raise prices above competitive levels under each type of auction. To raise prices under uniform-pricing, bids need to be increased for only the plants that are most likely to set the clearing price, often referred to as marginal plants. These marginal plants shelter plants with low variable costs from the risk of submitting bids that are above the market-clearing prices. In contrast, under a pay-as-bid auction, *each* plant must submit a high bid to raise its prices, so every plant faces the risk of bidding above the clearing price. This suggests that, because all plants – rather than only marginal plants – face the risk of bidding to high under a pay-as-bid auction, it will be more difficult to exercise market power under a pay-as-bid regime as compared to a uniform-price auction.[31]

Despite this basic intuition, various economic analyses suggest that bidding incentives and behavior are more complicated than suggested by this basic story. While it is generally acknowledged that the repeated interactions between bidders in wholesale electricity markets is conducive to the evolution of tacit collusion amongst suppliers, this problem (and its extent) arises for both uniform-price and pay-as-bid auctions.[32] As with the conclusions under competitive markets conditions, the effect of auction design on bidding behavior under market power is ambiguous. Studies of people's actual behavior in simulated electricity auction markets consistently find that prices would be *higher* under a pay-as-bid auction.[33] Some theoretical models suggest that uniform-price auctions are more susceptible to tacit collusion, while others suggest there is no difference.[34] Thus, research to date provides little confidence that pay-as-bid auctions would reduce suppliers' ability to raise prices through the strategic withholding of supply.

[31] For example, *see* Federico and Rahman (2003).

[32] Cramton et al. (2000).

[33] In fact, Rassenti, Smith and Wilson report that prices in pay-as-bid auctions under competitive conditions were as high as prices in uniform prices under conditions of market power. Rassenti, Smith and Wilson (2003). Also, *see* fn 20.

[34] See fn 20 for discussion.

Entry of New Capacity and Consolidation of Ownership

Auction design may have consequences for market structure that affect the opportunities for the exercise market power. A number of these effects have already been discussed. Bid "shading" by baseload technologies and some forms of renewable generation, and the additional market forecasting costs necessary to compete in a pay-as-bid market may reduce investment incentives, particularly for low-variable-cost resources. Less volatile prices may reduce incentives for demand-response and perpetuate the current situation in which load is fairly unresponsive to price and, as a result, less capable of disciplining offer prices from generators. Finally, reductions in price volatility may also lower individual suppliers' and LSE's incentives to enter into forward contracts, thus increasing the share of unhedged supply bidding into markets and potentially increasing supplier's incentives to raise prices through strategic withholding.

Auction design may also affect market concentration through differences in the incentives for suppliers with small generation fleets ("small suppliers") to participate in electricity markets. The costs of forecasting necessary to compete under pay-as-bid auctions are particularly burdensome to suppliers with small fleets of generation plants. Since the costs of developing these market forecasts can be shared across all of a larger company's generation capacity, larger suppliers are in better position to invest in higher quality forecasts that will place them at a competitive advantage. Furthermore, because they represent a larger share of the market and may own both low-cost, baseload facilities and high-cost, marginal price-setting facilities, larger suppliers are likely to have better information about market events that would result in unanticipated shifts in market-clearing prices. This advantage may reflect more accurate information about costs, plant availability (including the timing and duration of unanticipated maintenance outages), and even the timing of efforts to withhold supply. Consequently, larger suppliers will be in a better position to adjust their bids to account for these events than smaller suppliers.

Small suppliers also have a greater opportunity to "free ride" on the market withholding activities of larger suppliers under uniform-price auctions. Under a uniform-price auction, a supplier with a large share of total capacity has the greatest incentive to raise the bids of marginal units because all of its generation will receive the higher price. However, to receive the elevated prices, smaller suppliers (or large suppliers with small unhedged positions being bid into the market) need only bid their marginal costs and "free ride" on the market withholding activities of larger suppliers. Consequently, under uniform-price auctions, the exercise of market power creates market conditions that are conducive to the entry of small suppliers. In the long-run, encouraging participation of small suppliers in electricity markets may be one of the more effective means of reducing market concentrations and thereby reducing the opportunities for suppliers to exercise market power.

Implications for Market Monitoring

Because pay-as-bid auctions create the incentive for *all* suppliers to bid the *expected market-clearing price*, rather than submitting bids reflecting each facility's *individual marginal costs*, variation in bid prices within any given period is substantially reduced by a pay-as-bid auction. Reduced bid variation may have substantial effects on market monitor's ability to identify instances of market manipulation, and the available mechanisms to mitigate such market power. As a result of reduce bid variation, it may be difficult to distinguish between bids reflecting an effort to predict the market prices and those aiming at strategic withholding intended to raise the market price. Further, by eliminating any anticipated relationship between supplier bids and individual marginal costs, pay-as-bid auctions reduce the information available to regulators to determine whether particular bids appear to reflect withholding.

Because neither auction model is inherently immune to the exercise of market power by suppliers, market monitoring will remain an important element of any market design regardless of the choice of auction model. A pay-as-bid design, however, would potentially reduce the effectiveness of such monitoring and mitigation efforts by creating barriers to the identification of potential manipulation and complicating alternatives for subsequent price mitigation.

Conclusions – Implications for Market Power

In sum, there is little reason to believe that a switch to a pay-as-bid would have any immediate impact on suppliers' bidding behavior that would diminish their ability to exercise market power. However, the potential impacts of decreased ownership by small suppliers, reduced demand response, and greater exposure of supply to spot markets due to reduced forward contracting, such a switch may inadvertently increase conditions amendable to strategic withholding in the long-run. Furthermore, effective market monitoring and mitigation – critical in any centrally administered market – may be more challenging under a pay-as-bid auction. Consequently, to the extent that market-power is a significant concern in particular markets, a switch to pay-as-bid may exacerbate, rather than improve, market competitiveness.

Experience with Pay-as-Bid Auctions is Limited

While differences between uniform-price and pay-as-bid auctions have been the focus of much experimental and theoretical research, actual experience has been limited because uniform-price auctions are relied upon in nearly all wholesale electricity markets. Experience with the use of pay-as-bid auctions in electricity markets has largely been limited to the wholesale electricity market in the United Kingdom and Wales, which in 2001 switched from a uniform-price to pay-as-bid auction as one element of many changes in market design incorporated into the New Electricity Trading Arrangements ("NETA").[35]

Under NETA, the balancing (or real-time) electric energy market was shifted from a uniform-price to pay-as-bid auction, based on the regulators belief that the pay-as-bid format would reduce the exercise of market power that had become widely recognized as the primary contributor to high wholesale electricity prices.[36] In addition, the day-ahead market was eliminated in favor of requirements (and incentives) for suppliers and load-serving entities (retail electric suppliers) to engage in bilateral transactions for the majority of supply. Thus, the scope of market redesign in the U.K. in 2001 was broader than a simple change in the bidding format of existing markets, which makes it difficult to draw any conclusions about the performance of pay-as-bid auctions in isolation from the switch to a single-settlement auction and the U.K.'s particular design details. However, it is worthwhile noting that the U.K. regulator reached the judgment that a pay-as-bid auction would be inappropriate for a day-ahead market, and limited consideration of pay-as-bid auctions to a regime in which the vast majority of trades occurred through unregulated, bi-lateral markets and the balancing market covered only the limited volume of trades necessary to maintain the real-time supply-demand balance in the system.[37]

While prices clearly declined in the general time frame of the development and implementation of NETA, all analysts agree that other regulatory events and changes in market structure are responsible for a large portion of the reduction in wholesale market prices. These changes include reductions in barriers to natural gas entry and reductions in market concentration, partially the result of required divestments. In contrast, there is disagreement regarding whether NETA – which includes the switch to a pay-as-bid auction as one of many changes – contributed *at all* to the reduction in prices.[38] The lack of unambiguous reduction in prices from the implementation of NETA (and the fact that

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[35] For a discussion of NETA, *see* Newbery (2005).

[36] For example, *see* Wolfram (1998).

[37] Littlechild (2007). Footnote 22 refers to Offer (1998). *Review of Electricity Trading Arrangements: Proposals*. NETA includes various incentives to encourage LSEs to enter into bi-lateral contracts and avoid shortages of supply to the market in an effort to minimize volume in the balancing market. Interestingly, in 2000, a Blue Ribbon Panel of economists was asked to evaluate the efficacy of pay-as-bid for California's day-ahead market. Kahn et al. (2001).

[38] Newbury and McDaniel (2002) and Bower (2002) conclude that increased competition was the cause of declines in market prices, rather than the implementation of NETA. Evans and Green (2003) find no decline in price corresponding to the implementation of NETA, but suggest that the impending implementation of NETA may have caused suppliers to abort tacit collusion that was the cause of high prices. Fabra and Toro (2003) report mixed results, with NETA contributing to the decline in prices in some models, but not in others.

the U.K. regulator continues to revisit elements of the NETA rules to address apparent deficiencies, which, to date, are mostly unrelated to auction format) suggests that the NETA experience provides little reason to reassess the general conclusions reached by prior research regarding the differences between uniform-price and pay-as-bid.[39]

Conclusion

This paper has assessed the advantages and disadvantages of a switch from uniform-price to pay-as-bid auctions and reached a number of different conclusions:

- Pay-as-bid is unlikely to result in any immediate decrease in wholesale prices for generation through eliminating supplier margins or reducing opportunities to strategically withhold. The prospect that pay-as-bid auctions might offer immediate relief to consumers facing rising electricity prices is in fact illusory. Price increases are largely a consequence of market forces well beyond the control of those charged with regulating electricity markets.

- The margins that suppliers earn between their marginal generation costs and the market-clearing prices provides a means for plant owners to recover plant fixed and capital costs, and provides them with an incentive to improve plant performance.

- Pay-as-bid auctions may have adverse consequences for market efficiency, including inefficient plant dispatch, disincentives for demand response, and disincentives for investment in baseload and other low-variable-cost technologies that would lead to inefficient shifts in the mix of generation technologies.

- Pay-as-bid may have adverse consequences for efforts to reduce the exercise of market power by reducing incentives for small suppliers to participate in wholesale markets, by reducing reliance on forward contracting, by reducing incentives for demand response, and by potentially decreasing the effectiveness of market monitoring.

Interest in the redesign of wholesale electricity markets has arisen largely as a response to increases in electricity prices following the restructuring of electricity markets in many states. Although the cause of these price increases in largely the result of prices on global markets for fossil fuel used for power generation, which are well outside of the control of electricity regulators, the unfortunate coincidence of timing has tended to direct attention upon these recent restructuring efforts. While these markets still require continued

[39] See Cornwall (2007) and Littlechild (2007).

development, particularly to ensure sufficient and appropriate investment in generation and transmission resources, changes to the auction format for wholesale markets appear unlikely to either lower price or address other resource adequacy concerns.[40] In fact, such a switch would likely make conditions worse. Indeed, there is a risk that needed efforts and resources to improve facility siting, promote demand response, encourage (and determine) appropriate forward contracting, and refine capacity market design (to address the "missing money" problem) become diverted by an effort to an switch auction format that does not address any of these needs.

[40] Joskow (2007).

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