Dynamic Pricing of Electricity[†]

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Fred Kahn was a passionate advocate for using sound economic principles to determine prices for regulated services such as electricity. His magnum opus *The Economics of Regulation: Principles and Institutions* (Kahn 1970) devotes several chapters to the application of marginal cost pricing principles to the design of rate structures for regulated services. As the Chairman of the New York Public Service Commission (1974–1977) he endeavored to put his academic research into practice by initiating regulatory proceedings to reform electric utility rates to better reflect marginal cost pricing principles and more broadly to adopt regulatory policies that would increase the efficiency with which regulated services were supplied and priced.

Kahn's interest in pursuing regulatory reforms to improve the efficiency of utility rate structures made him an active proponent of peak-load pricing for retail electricity consumers in the United States. He understood that more efficient prices would reduce peak demand, and the need to build enough capacity to meet it, and would lead to an overall increase in economic welfare. He also understood that there would be winners and losers from such pricing changes and examined less distortionary mechanisms than uniform pricing to cushion the adverse impacts on disadvantaged consumers (e.g., nonlinear tariffs).

In his 1979 Ely Lecture to the American Economic Association, Kahn wrote:

"One of my proudest accomplishments … was the progress we made [as regulators]

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in requiring electric and telephone companies in New York to introduce marginal cost related prices. If you are a large residential user of electricity on Long Island, you will soon … pay rates varying between 2½ cents at night to 30 cents on summer days when the temperature gets above 83°" (Kahn 1979, p. 2).

I. Progress on Peak-Load Pricing of Electricity in the United States

The idea of moving from time-invariant electricity prices to "peak-load" pricing, where prices are more closely tied to variations in the marginal cost of generating electricity, has been around for at least 50 years (e.g., Boiteux 1960; Kahn 1970). The marginal cost of electricity varies widely over time because (a) the demand for electricity varies considerably; (b) it is uneconomical to store electricity in most applications; and (c) the optimal mix of generating capacity to balance supply and demand at all hours given (a) and (b) includes a combination of base load capacity with high construction costs and low marginal operating costs, intermediate capacity with lower construction costs but higher marginal operating costs, and peaking capacity with the lowest construction costs and the highest marginal operating costs. When demand is low it is cleared with base load capacity, and as demand rises, generating capacity with higher marginal operating costs is called upon to balance supply and demand. In general, marginal costs are low at night and high during the day, low when temperatures are moderate and potentially very high when temperatures are either extremely high or extremely low, depending on the price of substitute fuels and the attributes of the appliance stock in a region.

If end-use consumers face retail prices that do not reflect these variations in marginal generation costs, they will consume too much when marginal costs are higher than retail rates, likely during peak periods, and too little when marginal

costs are lower than retail rates, likely during off-peak periods. Distortions in consumption lead to distorted investment in and utilization of generating capacity.

In regions with deregulated wholesale electricity markets, power prices reflect differences in marginal costs as well as time-varying differences in firms' abilities to push prices above marginal costs by exercising market power. In this context, moving end-use customers to time-varying prices can also reduce firms' incentives and ability to exercise market power by increasing the elasticity of their residual demand (Borenstein and Holland 2005).

Until fairly recently, the application of marginal cost pricing principles to electricity had been limited to a few countries in Europe (Mitchell, Manning, and Acton 1978), to larger customers for whom the costs of metering and data processing were thought to be relatively low compared to potential efficiency gains, and to a small number of pilot programs designed to measure consumer responses. So, despite Kahn's efforts as a teacher, scholar, and regulator, the diffusion of time-varying electricity pricing arrangements has been especially slow in the United States. A 2010 survey conducted by the Federal Energy Regulatory Commission (FERC 2011, pp. 28, 99) indicated that only about 1 percent of residential consumers are billed based on time-of-use rates and only a handful of utilities offered "dynamic" pricing, where rates vary with real time or close to real time changes in marginal costs. Accordingly, almost all residential and small commercial consumers in the United States buy electricity on rate structures that do not vary with changes in overall supply and demand conditions, marginal costs, or wholesale market prices from either an ex ante or real time perspective.

II. Opportunities and Pressures to Expand Dynamic Pricing

Several developments over the last decade have elevated interest in dynamic pricing. First, the evolution of competitive wholesale markets for generation services, where spot prices change as frequently as every ten minutes, has made it clear that there are wide variations in prices that reflect changing supply and demand conditions. Retail prices could be based on these transparent wholesale market prices rather than on marginal cost estimates. The wholesale market prices for electricity also have made it clear that traditional time-of-use (TOU) pricing, which used prices set ex ante based on expected generating costs during a small number of different time periods, only very roughly reflected varying marginal costs as conceived by Kahn and other scholars. Wholesale spot prices are extraordinarily high during a relatively small number of hours on hot summer days and vary relatively little during the rest of the days of the summer. If peak-load pricing simply established all summer weekdays as a high-price period ex ante based on expectations, as almost all early applications of peak-load pricing did, consumers would not face powerful incentives to consume less when the system was highly stressed and wholesale prices were extremely high.

The second set of developments is associated with communications and metering technology. Internet and wireless communications did not exist when Kahn promoted peak-load pricing in New York, but technologies for real-time two-way communications between consumers and central data collection locations are now widely available. Further, technological progress continues to drive down costs and increase functionality for communications, as well as data storage, processing, and acquisition. "Smart meters" (AMI) send real-time consumption data to the utility and enable various forms of dynamic pricing. Smart meters and associated communications and data acquisition and processing technologies also allow the utility, the consumer, or third parties to send signals back to the customer's home or business to respond to price signals by controlling energy use (e.g., turning the air conditioning down), which can reduce peak demands when wholesale prices are high.

Finally, at the federal level and in a growing number of states, policymakers are promoting a more modern and automated electric power network (Joskow 2012, MIT 2011). The federal government has provided significant incentives for utilities to adopt "smart grid" policies, including smart meters and variations on real-time pricing. The American Recovery and Reinvestment Act of 2009 (ARRA) provided about $5.0 billion for smart grid demonstration and technology deployment projects http://www.smartgrid.gov/federal_initiatives (November 29, 2011). About 130 projects have been funded under these ARRA programs with about $5.0

billion of matching funds from utilities and their customers. A large fraction of the funds awarded by the DOE from its ARRA smart grid subsidy program are for smart meters, supporting IT and billing software, communications capabilities, and other distribution network enhancements to take advantage of smart meter capabilities (http://www.smart-grid.gov/recovery_act/overview, November 29, 2011). The DOE funds have also supported several randomized control trials involving smart meters and variations on real-time pricing, including simpler "critical peak period" real-time pricing mechanisms (http://www.smartgrid.gov/recovery_act/program_impacts/consumer_behavior_studies).

Twenty-five states have adopted smart metering policies varying from pilot programs to mandates that smart meters be installed in all homes over a period of time (http://www.ncsl.org/?tabid=20672). It is estimated that over 20 million smart meters had been installed at residential and small commercial locations at the end of 2011, though real-time pricing has diffused much more slowly than have smart meters (http://www.edisonfoundation.net/iee/issueBriefs/SmartMeter_Rollouts_0911.pdf).

The interest in automating the local distribution grid with these new technologies has been stimulated by two additional factors. First, many portions of the US electricity infrastructure, especially the lower voltage distribution network, are aging and need to be replaced. If long-lived replacement investments are made, there are good arguments to invest in cutting-edge technologies such as smart meters. Second, the federal government and about 30 states have adopted policies to promote renewable energy technologies in an effort to reduce CO_2 emissions. Wind and solar technologies have received the bulk of federal support and interest from the states. While many of these technologies are connected to the high voltage network, solar photovoltaic (PV) technology is being promoted as a distributed generation source located on customer premises or in small "farms" and connected to the local distribution system. The output from PV systems varies widely with insolation conditions, and the economic value of this kind of "intermittent" generation varies from hour to hour as market prices change. Smart meters and dynamic pricing will promote efficient use of PV technology and efficient use of new demand-side technologies, such as electric vehicle charging.

III. Unresolved Issues

Given the interest in dynamic pricing, it is useful to consider why it has not been adopted more widely. The historical arguments against introducing dynamic pricing were that (a) metering would be too costly for residential and small commercial customers given the potential for reducing deadweight losses, (b) meter reading and billing costs would increase with more complex rates, (c) retail consumers would not understand or effectively utilize complex rate designs, and (d) changing rate designs would lead to large redistributions of income reflecting the wide variations in consumption patterns across individuals.

The first two arguments appear largely irrelevant given current metering and billing technologies. Smart meters have certainly become technically and potentially economically attractive devices that, in addition to facilitating dynamic pricing, can significantly reduce meter reading costs, provide two-way communications capabilities and a wide range of other functionalities that can enhance information about demands and outages on the distribution grid, and use real-time communications and control capabilities to help to manage new remote "smart" monitoring and control capabilities being installed on distribution networks.

In terms of customer response to time-varying pricing, there has been evidence dating back to the 1970s from well-designed TOU experiments and experience in other countries that consumers respond more or less as expected to price incentives (Aigner 1985), suggesting that at least for a fraction of residential consumers the benefits of TOU rates exceed their costs (Mitchell and Acton 1980). Results from more recent pilot programs suggest that consumers similarly understand and respond to critical-peak pricing programs (e.g., Faruqui and Sergici 2010; Wolak 2010). Existing studies have focused on consumers who voluntarily participate in dynamic pricing programs, so care must be taken before extrapolating to the entire population.

Armed with estimates of likely customer responses as well as engineering estimates of

the costs of smart meter rollouts, Faruqui et al. (2011) perform cost-benefit analyses of smart meters for several prototypical utilities. Their estimates suggest that savings derived from lower meter-reading costs and increased ability to detect outages will cover at least one-third and for some utilities as much as 80 percent of the direct costs of installing smart meters. They simulate customer benefits by modeling several categories of consumers with different levels of awareness of and responsiveness to prices as well as different uses for electricity (e.g., space conditioning versus electric vehicle charging). While the benefits outweigh the costs for each of the modeled utilities, a large share of the benefits accrues to a small number of consumers who are very responsive and own electric vehicles.

While some customers will likely benefit from dynamic pricing, other customers will see higher bills. The fear of large redistributions across customers is possibly the largest impediment to further adoption of dynamic pricing. Under flat-rate pricing, customers whose demand is relatively constant across hours are subsidizing customers whose demand is "peakier," i.e., who consume a greater share of their energy at times when wholesale prices are the highest. If those customers do not change their consumption patterns under dynamic pricing, their bills may go up considerably. Borenstein (2007) analyzes customer-level billing data for almost 1,200 commercial and industrial consumers in Northern California and finds large redistribution from switching from flat-rate to real-time pricing, although most of the redistribution happens when utilities replace flat-rate pricing with simple time-of-use rates. Using similar data from the residential sector, Borenstein (2011) shows that most customers would benefit from critical peak pricing, and low-income households would not be systematically hurt by it. A small share of customers could see greater than 20 percent bill increases. Recent experiences suggest that the press and consumer advocates will focus attention on consumers who are hit adversely by the change. Accordingly, more research is needed to better understand the attributes of winners and losers in additional areas of the country to encompass a full range of demand and rate design characteristics.

Redistribution effects may be tempered if customers with peaky demand respond to time-differentiated prices and cut their peak-period use. Most existing studies on price responsiveness have focused on demonstrating that the average demand elasticity is nonzero and less on understanding heterogeneity across customers. Wolak (2010) is one exception and he finds that low-income consumers are more responsive than higher-income consumers. As the two-way capabilities of smart meters are developed further and the set of home-energy management tools expands, it becomes easier for customers to respond, although there is no guarantee that customers likely to be hurt the most by dynamic pricing will take advantage of these options.

It is most likely that dynamic pricing programs will evolve slowly, and that most utilities will begin by allowing volunteers to opt on to alternatives tariffs while leaving flat-rate pricing the default option. Borenstein (2011) analyzes the impacts of allowing fewer than 20 percent of the customers to opt on to dynamic pricing. If customers whose demand is already flat are most likely to move away from flat rates, the cost of serving the households who remain on flat rates increases, since they will on average consume more during expensive peak periods. Borenstein (2011) finds that this effect is likely to be small. He does not model the offsetting effect, which is that as the first set of customers opt on to dynamic pricing and reduce their peak-period consumption, average prices fall, as do differences between peak and off-peak wholesale prices (Borenstein and Holland 2005). This second effect suggests that the efficiency gains from forcing the remaining, unwilling customers onto dynamic pricing are smaller than the gains as the first customers move off flat-rate pricing. Particularly if mandatory changes face strong political opposition, this may not be a fight worth having.

IV. Conclusions

Fred Kahn strove to apply sound economic principles to important public policy decisions. One of his many contributions highlights the benefits of dynamic pricing. Many industries have taken advantage of the ability to amass and analyze real-time information about variations in supply and demand conditions and have used it to adopt sophisticated pricing strategies. Though recent technological advances have dramatically lowered the costs and expanded the

capabilities of doing this in electricity, very few US residential customers even have the option to pay dynamic prices.

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