Market Failures in Real-Time Metering: A Theoretical Look

Timothy J. Brennan

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Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202-328-5000
Fax: 202-939-3460
Internet: http://www.rff.org

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Abstract

Restructuring the electricity market may secure efficiencies by moving away from cost-of-service regulation, with typically (but not necessarily) time-invariant prices, and allowing prices to reflect how costs change. Charging "real time" prices requires that electricity use be measured according to when one uses it. Arguments that such real-time metering should be a policy objective promoted by subsidizing meters or delaying restructuring until meters are installed, require more than these potential benefits. They require positive externalities to imply that too few meters would be installed through private transactions. Real-time metering presents no systematic externalities when utilities must serve peak period users, and may present negative externalities under some conditions. Positive externalities are likely when electricity is rationed through blackouts. Real-time metering may or may not increase welfare when peak period wholesale markets are not competitive; one might want to prohibit real-time metering in such situations even if metering itself were costless.

Key Words: real-time metering, electricity restructuring, deregulation, rationing, externalities

JEL Classification Numbers: D45, D62, L11, L94

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I. Why have real-time metering?

The marginal cost of producing electricity varies considerably over time. During off-peak times, the cost of supplying an additional kilowatt-hour of electricity can be as little as a penny or two. During on-peak times, prices can easily be many multiples of baseload levels, with reported price spikes of 100 or 200 times off-peak rates. One of the benefits associated with restructuring of electricity markets has been the potential efficiencies that would be secured by moving away from the current cost-of-service system, in which we typically (but not necessarily)[1] have time-invariant prices, to prices that reflect how costs change. With prices that vary by time in such a way to follow electricity prices, a homeowner might choose to dry clothes or run the dishwasher at night rather than during the day, or an office manager might turn up the thermostat during hot afternoons when electricity for air conditioning is in great demand.

A crucial feature in charging ideal prices is having use be assigned on virtually a minute-by-minute basis. Electricity demand is not accurately predictable. A relatively sudden change in weather can lead to a significant shift in demand, for example, when warmer than expected temperatures increase use of air conditioners. In those moments, electricity costs and prices can dramatically skyrocket.[2] A first contributing factor is that high electricity demand will invoke the

* Professor, Policy Sciences and Economics, University of Maryland Baltimore County, and Senior Fellow, Resources for the Future. Email: brennan@umbc.edu. Discussions with Dallas Burtraw, Joseph Doucet, Paul Joskow, Andrew Kleit, and Karen Palmer were very helpful. An earlier version of this paper was presented at the Rutgers University Center for Research in Regulated Industries 15th Western Conference Advanced Workshop in Competition and Regulation. Comments there from Fred Curry, Chris King, Colin Loxley, Paul Nelson, Mark Reeder, and Peter Schwarz were also very useful. None of those mentioned deserve blame or guilt by association with any errors in this paper, which remain the author's sole responsibility

[1] One could have time-varying prices under a regulatory scheme that holds overall prices constant. S. Borenstein, "Frequently Asked Questions About Implementing Real-Time Pricing in California for Summer 2001," March 2001, available at http://www.ucei.berkeley.edu/ucei/PDF/faq.pdf.

[2] D. Hunger, "Gas and Electric Convergence Mergers: A Supply Curve is Worth a Thousand Words," Advanced Workshop in Regulation and Competition: Competitive Challenge in Network Industries," 19th Annual Conference, Rutgers University Center for Research in Regulated Industries, Lake George, NY (May 26, 2000).

use of power plants with relatively high operating costs relative to capital costs.[3] Looking solely at operating costs, the supply curve for electricity would be expected to slope upward with output.

A second and even more important factor involves recovery of capital costs, particularly insofar as peak demand can take place over just a few hours in the year. Suppose that as little as a fourth of the costs of a marginal plant running full time are capital costs, as is the case for some modern natural gas plant designs.[4] Suppose further that such a plant runs only 1% of the time (about 90 hours per year). Even though a peaking plant would likely have lower capital costs relative to operating costs than would a baseload plant, expected prices during those peak hours would need to be about 25 times what such a plant operating full time would charge if it were to find entry to supply at those peaks profitable.[5]

A third factor is the alleged exercise of market power during peak periods, as has been alleged to have taken place in California[6] and UK electricity markets.[7] Whether such allegations are adequately supported empirically by comparisons of prices to average variable costs of the last plant used to supply power is a matter for debate elsewhere.[8] However, the allegations have

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[3] R. Dansby, "Capacity Constrained Peak Load Pricing," *Quarterly Journal of Economics* 92 (1978): 387–98, especially 394; M. Crew and P. Kleindorfer, *The Economics of Public Utility Pricing* (Cambridge, MA: MIT Press, 1986).

[4] M. Hutzler, "Annual Energy Outlook 2002," National Energy Modeling System/Annual Energy Outlook 2002 Conference, Crystal City, VA (March 12, 2002); esp. slide 17, available at http://www.eia.doe.gov/oiaf/aeo/conf/hutzler/overview.ppt.

[5] If a plant running baseload would cost $200, $150 variable and $50 capital cost, it would have to get a price of $2 for each percentage of the year it operates. If it operates only 1% of the year, it has to recover in that times $50 of capital cost, along with the $1.50 (1% of $150) in variable cost that it incurs, for a total of $51.50. That price is more than 25 times the price the generator would need to charge to cover costs if it were a baseload plant.

[6] S. Borenstein, J. Bushnell and F. Wolak, "Diagnosing Market Power in California's Deregulated Wholesale Electricity Market," Working Paper PWP-064, University of California Energy Institute (2000); P. Joskow and E. Kahn, "A Quantitative Analysis of Pricing Behavior in California's Wholesale Electricity Market During Summer 2000," Working Paper No. 8157, National Bureau of Economic Research (2001).

[7] C. Wolfram, "Strategic Bidding in a Multiunit Auction: An Empirical Analysis of Bids to Supply Electricity in England and Wales," *RAND Journal of Economics* 29 (1998): 703–725; R. Green and D. Newbery, "Competition in the British Electricity Spot Market," *Journal of Political Economy* 100 (1992): 929–53; J. Kwoka, Transforming Power: Lessons from British Electricity Restructuring, *Regulation* 20 (1997), available at http://www.cato.org/pubs/regulation/reg20n3e.html.

[8] T. Brennan, "Checking for Market Power in Electricity: The Perils of Price-Cost Margins," Discussion paper 02-50. Washington, DC: Resources for the Future.

sufficient backing both from theory and studies assessing withholding patterns to be a possibility worth examining, as we explain further below.

Charging "real time" prices requires that one's electricity use be measured according to when one uses it, through real-time metering (RTM). This is in contrast to the cumulative meters currently standard in the industry. Cumulative meters measure how much energy one uses over the course of a billing period, usually a month. They can tell how much one used, but not when one used it. They are not designed to be able to determine how many kilowatt-hours one consumed when the cost of producing energy was a $10 a megawatt-hour and how much one consumed when the cost was a $1000/MWh.

Earlier work has examined the potential efficiency gains from RTM. Theoretical analyses have identified, and in some cases questioned, the potential efficiencies from having customers pay prices reflecting costs at the time of use. [9] Numerous econometric and experimental studies go back to the early 1980s to examine how real-time (or time-of-use) pricing would affect demand from industrial, commercial, or residential customers.[10] Simulation studies have examined the potential benefits and costs in terms of reallocating the risk of price variance from suppliers to buyers.[11] Some experimental work suggests that the incentives for buyers to bargain created by RTM could lead to a significant reduction in electricity prices at peak periods.[12]

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[9] J. Mackie-Mason, "Optional Time of Use Pricing Can Be Pareto Superior or Pareto Inferior," *Economics Letters* 33 (1990): 363–67; W. Vickrey, "Efficient Pricing of Electric Power Service: Some Innovative Solutions," *Resources and Energy* 14 (1992): 157–74; C.-K. Woo, R. Orans, B. Horii, and P. Chow, "Pareto-Superior Time-of-Use Rate Option for Industrial Firms," *Economics Letters* 49 (1995): 267–72; D. Seeto, C.-K. Woo, and I. Horowitz, "Time of Use Rates vs. Hopkinson Tariffs Redux: An Analysis of the Choice of Rate Structures in a Regulated Electricity Distribution Company," *Energy Economics* 19 (1997): 169–85;

[10] Among the numerous studies are D. Caves and L. Christensen, "Econometric Analysis of Residential Time-of-Use Pricing Experiments," *Journal of Econometrics* 14 (1980): 287–306; D. Aigner and J. Hirschberg, "Commercial-Industrial Customer Response to Time-of-Use Electricity Prices: Some Experimental Results," *RAND Journal of Economics* 16 (1985): 341–55; T. Taylor and P. Schwarz, "The Long-Run Effects of a Time-of-Use Demand Charge," *RAND Journal of Economics* 21 (1990): 431–45; J. Herriges, S. M. Baladi, D. Caves, and B. Neenan, "The Response of Industrial Customers to Electric Rates Based on Dynamic Marginal Costs," *Review of Economics and Statistics* 75 (1993): 446–54; A. Henley and J. Pierson, "Time-of-Use Electricity Pricing: Evidence from a British Experiment," *Economics Letters* 45 (1994): 421–26; R. Patrick and F. Wolak, "Customer Responses to Real-Time Prices in the England and Wales Electricity Market: Implications for Demand-Side Bidding and Pricing Options Under Competition," in M. Crew (ed.), *Regulation Under Increasing Competition* (Boston: Kluwer Academic Press, 1999): 155–82.

[11] T. Taylor and P. Schwarz, "Advance Notice of Real-Time Electricity Prices," *Atlantic Economic Journal* 28 (2000): 478–88.

[12] S. Rassenti, V. Smith, and B. Wilson, "Turning Off The Lights," *Regulation* 24 (Fall, 2001): 70–76.

A second-best approximation to RTM would be block-of-time metering, that is, in which a meter registers how much power one used during times in which demand might be expected to be at peak levels. For example, one could systematically set higher rates for power on summer afternoons. Unfortunately, electricity demand is not perfectly predictable. Some summer afternoons may be milder than average, others may have very high heat and humidity. Moreover, conditions may change quickly, for example, when a thunderstorm reduces temperatures in just a few minutes. Ideally, one would not get an efficient response to the actual costs of electricity unless the prices changed as conditions changed, requiring that uses be timed precisely. Because even small variations in demand can lead to large changes in prices, block-of-time metering and billing would be an inferior substitute.

II. But is there an RTM externality?

Some researchers have identified potential gains to consumers from adopting RTM.[13] Others have suggested that a lack of real-time meters contributed substantially to the recent California crisis, and that electricity markets cannot work without RTM and thus should not be opened to competition until RTM is widely deployed.[14] Partly in response, the state of California instituted recently a $35 million program to install real-time meters at the sites of the 23,000 customers in the state with peak power demands exceeding 200 kilowatt-hours of energy a month.[15]

Arguments that RTM should be a policy target, for example, by subsidizing meters or delaying restructuring until meters are installed, require more than recognizing its benefits. First, positive benefits need not suffice, as the benefits are finite[16] and meters themselves are costly. Including the cost of the meters themselves, wireless transmission of usage data to the utility,

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13 K. Train and G. Mehrez, "Optional Time-of-Use Prices for Electricity: Econometric Analysis of Surplus and Pareto Impacts," *RAND Journal of Economics* 25 (1994): 263–83.

14 S. Stoft, "The Market Flaw California Overlooked," *New York Times*, Jan. 2, 2001, A19.

15 C. King, "California's Real Time Metering Program: Results to Date," presented at the Rutgers University Center for Research in Regulated Industries 15th Western Conference Advanced Workshop in Competition and Regulation, South Lake Tahoe, CA (June 20, 2002).

16 A. Tischler, "Optimal Production of Uncertain Interruptions in the Supply of Electricity: Estimation of Electricity Outage Costs," *European Economic Review* 37 (1993): 1259–74.

and providing price and usage data back to customers so they can adjust their consumption, the California program averaged about $1500 per site.[17]

Even if the benefits in improved energy management outweigh the costs, it is not enough to say that it would be a good idea for *me* if I were to adopt RTM. From an economic perspective, we need to explain why it would be a good thing for *you* if I were to adopt RTM. Without such a justification, there is no market failure and thus, on economic grounds, no warrant for policy intervention.

Posing the question about RTM in this way has elicited suggestions that there are supply-side externalities associated with it. The primary basis for these suggestions seems akin to arguments that delivery of mail is a natural monopoly—one "meter reader" can more economically take data from meters than could others. There might be direct scale economies in installing meters, perhaps reflecting some "learning by doing." Even if these accurately describe RTM technologies and processes, these do not seem to warrant policy intervention. Perhaps local mail delivery is a natural monopoly, because one person can deliver mail up and down a street at lower cost than could multiple delivery persons. But that does not mean that others benefit if I happen to get mail, and thus mail to me should be subsidized.

More generally, in the rest of the economy, prices are not necessarily sufficiently flexible to keep supply and demand continuously equal. Good examples might be the lines outside popular restaurants at peak dining times, or selling out of baseball games when an opponent with its own strong following comes to town. In some cases, visible excess demand might be a form of advertising. Consumers may see a line in front of a restaurant and infer that the food is sufficiently good relative to its price that people find it worth standing in line, increasing their willingness to pay to come to the restaurant at an off-peak time.

However, the line may simply be a byproduct of a restaurant's inability to set time-specific prices. If so, is there a cause for policy intervention? Need the government subsidize the

[17] C. Rochlin, "Is Electricity a Right?" presented at the Rutgers University Center for Research in Regulated Industries 15th Western Conference Advanced Workshop in Competition and Regulation, South Lake Tahoe, CA (June 19, 2002); also calculated from King, n. 15 *supra* ($35 million divided by 23,000 sites).

Returning data in real time to consumers is important; otherwise, real time pricing would have no direct effect on energy consumption. Whether consumers would be able and willing either to monitor prices and adjust use manually or to install automated system to change energy use if prices exceed a certain level, are important and open questions, particular for households and small commercial customers.

printing of peak and off-peak menus to reduce the size of the line on Saturday nights? That we do not adopt policy interventions in these circumstances may largely be because the restaurant line problem is relatively trivial; any governmental cure will be worse than any market failure-related disease. But the absence of any such initiatives might lead one to ask what if any conditions need to hold to warrant policy intervention when prices are less flexible than might be ideal.

The focus here will be on externalities relating to the electricity market itself, not on scale economies or network effects that might reduce the cost of RTM. This work follows on two recent analyses of such externalities. In a less formal analysis than will be presented here, I conjectured that RTM would not offer any positive externalities.[18] There would be no cause for policy intervention when those who supply electricity fulfill demands at peak periods, despite peak period prices charged to consumers being less than peak period costs. This result, however, did not necessarily hold when below-cost pricing at peak periods leads to rationing, for example, rolling blackouts.

Doucet and Kleit examine these questions through simulations of electricity markets.[19] Their simulations provide some support for Brennan's earlier conjectures and raise other possibilities. They first investigate the effects of RTM in competitive markets with no impediments to setting real-time prices. In that scenario, they generally find that the gain to the marginal consumer who adds a real time meter is about the same as the net gain to society as a whole, implying no positive externality with RTM.[20] I find a similar result, explored further below, for a case in which electricity suppliers are obligated and able to meet demand at a peak

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[18] T. Brennan, *The California Electricity Experience, 2000-01: Education or Diversion* (Washington: Resources for the Future, 2001), particularly the appendix. The inspiration for the idea that RTM may lack externalities, despite having potentially large benefits, came from a presentation by analysts for the PJM wholesale electricity power pool to the Electricity Working Group, an informal collection of researchers from government, academia, think tanks, consulting firms, and industry. During this presentation, these analysts were asked whether they thought mandates for real-time meters were necessary. To only slightly paraphrase, they responded that if a utility is buying electricity for $400 per megawatt-hour and selling it for $50, they already have a huge incentive to pay consumers to adopt RTM.

[19] J. Doucet and A. Kleit, "Metering in Electricity Markets: When is More Better?" mimeo, March 2002.

[20] Doucet and Kleit also find that increased RTM in this scenario reduces producer surplus. No specific reason is given, but a reasonable guess is that real-time pricing decreases peak period demand and, consequently, marginal production cost and prices. This, in turn, reduces peak-period rents earned by inframarginal generation units. Doucet and Kleit find that a consumer who adopts RTM generates additional surplus for other consumers, creating possible political pressures to subsidize (discourage) RTM to the extent that consumers (producers) have disproportionate political clout.

price below marginal production cost. One difference between the approach here and in Doucet and Kleit is that I assume here that in the competitive scenario, entry would constrain electricity retailers to earn zero profits.

Doucet and Kleit's second simulation allows peak period suppliers to exercise market power, simulated as a markup over the increment of marginal cost associated with on-peak production.[21] In this setting, they find that RTM generates negative externalities when the markup is fixed, although if RTM makes the wholesale market conduct itself more competitively, these negative externalities shrink. I did not explore this but turn to this case in the third model below. I employ a model in which a peak-period monopolist sets prices to maximize profits with retailers who either pass through price increases in real time (for RTM customers) or charge the same prices for peak and off-peak to maintain zero profits (for non-RTM) customers.

I find below some intuitive support for Doucet and Kleit's result, but it does not hold in general. The intuition is that without RTM, a peak-period monopolist sets the price as if it were facing simultaneously a weighted sum of peak and off-peak demand, while it sets separate prices with RTM. Enacting RTM allows pricing something akin to a move toward third-degree price discrimination and away from uniform monopoly pricing. As such a move reduces welfare by discouraging highly valued consumption on-peak while increasing less valued consumption off-peak, one would expect RTM to reduce welfare. But we will see that the case against RTM in this setting is weaker than that against third-degree price discrimination, all else being equal.

Doucet and Kleit's third model is most closely related to mine. They consider a price ceiling on-peak, which results in (competitive) supply less than demand. In such a case, they find that the decision of one customer to adopt real-time meters reduces his demand, leaving more supply to go to those who value the power more highly. I found the same. One analogy would be

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[21] Specifically, Doucet and Kleit assume that producers have a marginal cost of production MC(Q) given by:

$$MC(Q) = C + S(Q - \underline{Q}),$$

with a supply curve price set when sellers have market power is

$$P(Q) = C + \theta S(Q - \underline{Q}),$$

where $\underline{Q}$ is the point in the generation cost function where capacity is approached, $S > 0$, and $\theta > 1$. The form of this function is specified in advance; it is not derived from a monopoly or oligopoly model of price setting based on the peak period demand curve and the strategic game played by suppliers. In some simulations, they allow θ to shrink with increased adoption of RTM, reflecting a possibility that RTM improves competitiveness among wholesale energy suppliers.

to a line at a restaurant, where menu costs (literally) prevent charging higher prices at peak. If those in the front of the line had a method in which they paid the opportunity cost for meals, some would get out of the line, reducing the wait for others who might value meals more.

To summarize, I attempt to show below that RTM presents no positive externalities when utilities are obliged to serve peak period users despite losses. There are, however justifying externalities when electricity rationing takes the form of rolling blackouts, because such blackouts affect both high valuing uses and low valuing uses equally. We cannot say in general whether RTM increases welfare when peak period wholesale markets are not competitive. The tradeoffs appear to be somewhat more favorable in the case of RTM than in the formally similar issue of whether or not a monopolist should be allowed to "third degree price discriminate," that is, to set different prices for the same good in different markets.

III. General properties of the models

To model the use of RTM, we need to break down demand by customers, to reflect the possibility that some customers have real-time meters and face one set of prices, while those who do not have real time meters face another. In addition, to see whether real time meters are chosen efficiently in equilibrium, we need to determine which consumers get RTM and which do not within the model itself. To do so, assume that there is a continuum of N customers, indexed by i. Let $D^P(P, i)$ be the peak period demand for energy at price P by customer i; off-peak demand will be $D^{OP}(P, i)$.[22] We recognize that this bifurcation abstracts from a reality in which there is a continuum of demands depending on time-of-day, season, weather conditions, and other random factors.

For tractability, we assume that these demand functions are differentiable in both arguments, with

$$\partial D^P/\partial P,\ \partial D^{OP}/\partial P < 0;\ \partial D^P/\partial i,\ \partial D^{OP}/\partial i > 0.$$

The first set of partial derivatives is the standard assumption that demand curves slope downward. The second set is the common tractability assumption that demand curves do not

[22] Unless the letter P is a superscript, "P" will refer to price.

cross, that is, as we move up the index of consumers, the quantity that a consumer demands at any price increases, peak or off-peak.

We further simplify by assuming that the fraction of time T at which demand is at peak is exogenous, but that the specific times that are peak times are unknown in advance. In models of competitive markets, we generally set T = .5, that is, the length of time at which demand is at peak levels is the same as the time it is not. This is purely a notational convenience, to avoid carrying around terms reflecting weights in calculating endogenous prices or welfare; it will not change the qualitative conclusions.

An additional simplification, perhaps more critical in an analysis of RTM, is that demand off-peak is independent of peak period prices and vice versa. In other words, we rule out here the possibility that higher peak period prices would lead consumers to substitute off-peak uses for peak uses, for example, using dryers in the evening rather than the daytime. The possibility of efficient intertemporal substitution is a clear private benefit of RTM and would need to be incorporated into any estimation of the net benefits of an RTM program. However, as we discuss below, whether externalities exist, and which direction they may take, is unlikely to be affected by this assumption.

Reflecting our use of price rather than quantity, the gross measure of consumer benefit B(P, *i*) for consumer *i* buying at price P at time period X (peak or off-peak) will be

$$B^X(P, i) = \int_P^{\infty} D^X(z, i)dz + P\,D^X(P, i)\,. \tag{1}$$

Graphically the first term, the integral, would be the area between the demand curve and the horizontal line at price P. The second term is the revenue paid by the consumers for the product. It will be useful now to note that for consumer *i*, the change in the gross benefit from a change in price is

$$\partial B^X/\partial P = P[\partial D^X/\partial P] < 0. \tag{2}$$

This is the area under the demand curve lost when price increases incrementally.

On the supply side, we divide the industry into retail and wholesale markets. We assume for simplicity that the supply curve for the production of electricity at wholesale is given by a marginal cost curve that is the same on-peak and off-peak. This, too, involves some significant oversimplifications. First, we abstract from regulatory reserve and ancillary service requirements. Second, and perhaps more important, on-peak prices have to cover the costs of the additional generation capacity needed to meet demand.[23] Abstracting from that here, in the competitive cases we model a general wholesale supply curve S(P), where if C(Q) is the cost of producing energy,

$$C'(S(P)) = P,$$

that is, the marginal cost of the last unit supplied at a given price is that price.

The retail sector imposes no costs of its own,[24] but may be subject to a zero-profit free-entry constraint or face regulated retail prices and obligations. Retailers sell power to customers lacking RTM at the same price peak or off-peak. They cannot distinguish among customers on the basis of how much of that customer's demand is peak and how much is off-peak or on their level of overall demand, that is, where on the continuum between 0 and N they fall. Retailers cannot achieve something like RTM by agreeing to serve only customers whose demands are predominantly or exclusively at one period or the other.[25] For customers with real time meters, a retailer can charge separate prices for peak and off-peak power, and we will assume throughout that those prices equal the wholesale purchase prices of that power.

IV. Retailers obliged to serve

Our first case to talk about matches the initial situation in California, prior to and perhaps after the bankruptcy or near-bankruptcy of the major distribution utilities. During this period, utilities generally had to purchase wholesale power at very high prices and sell it at relatively

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[23] The appropriate "marginal cost" curve needs to include the long-run average cost of that capacity. Brennan, n. 8 *supra* and n. 18 *supra* at 37–40. The appropriate marginal cost calculation is further complicated by costs associated with starting up and shutting down capacity. S. Harvey and W. Hogan, "Identifying the Exercise of Market Power in California," Dec. 28, 2001, available at http://www.ksg.harvard.edu/hepg/Papers/Hogan%20Harvey%20CA%20Market%20Power%2012-28-01.pdf. Much of the controversy over the extent of market power in the wholesale electricity sector, and how best to measure it, is connected to the difficulty of ascertaining marginal cost in practice and whether available measures include capital as well as operating costs.

[24] I neglect marginal costs associated with transmission, distribution, and marketing. Incorporating those costs at this stage would only add a constant term to the retail price and would not have substantial effects on the conclusions I reach.

[25] We do not consider here that that time-of-day pricing could be an imperfect substitute for RTM, in particular, that those imperfections are sufficiently small in and of themselves to make the costs of installing real-time meters less than the benefits.

low prices, until their financial ability to purchase power ran out. To analyze this case, I describe the equilibrium amount of RTM that one would see and compare those equilibrium conditions to the conditions for a welfare maximum.

A. Market equilibrium

Define P* as the price charged at both peak and off-peak periods to customers without RTM, P^P as the price charged on-peak to those with RTM, and P^{OP} as the off-peak price RTM customers pay. Let R be the cost of installing an RTM for a customer, independent of the amount of energy uses. There will be a consumer K who is indifferent as to whether he adopts RTM. We assume (discussed below) that customers with $i < K$ do not get RTM, and those with $i > K$ do.

In equilibrium, the amounts demanded on-peak and off-peak have to equal the amounts supplied. With the specifications of the model, this implies

$$\int_0^K D^P(P^*, i)\,di + \int_K^N D^P(P^P, i)\,di = S(P^P) \tag{3}$$

and

$$\int_0^K D^{OP}(P^*, i)\,di + \int_K^N D^{OP}(P^{OP}, i)\,di = S(P^{OP}). \tag{4}$$

Applying the marginal cost function C' to the left and right sides of these equations gives the price equivalents of these supply and demand equations. The price on-peak and off-peak charged to RTM customers equals the marginal cost of supplying electricity to both RTM and non-RTM customers.

We can treat P* in one of two ways. One, akin to the California situation, would be to treat it as an exogenous parameter arising as a legacy of prior regulation and restructuring policies. A second would be to treat it as endogenously set to keep retailers whole. If we assume that retailers are unable to identify customer by type (between 0 and N), P* will be the price necessary to keep retailers who serve non-RTM customers profitable, that is, the price equal to the average cost of serving such users. That average cost is the weighted average of peak and off-peak prices P^P and P^{OP}, where the weights are the quantities demanded peak and off-peak by non-RTM customers. Equivalently, the total revenue paid by RTM customers would have to equal the total cost to retailers of the electricity provided to them over peak and off-peak periods. This condition, which defines P*, is

$$P^*\left[\int_0^K D^P(P^*,i)di + \int_0^K D^{OP}(P^*,i)di\right] = P^P\left[\int_0^K D^P(P^*,i)di\right] + P^{OP}\left[\int_0^K D^{OP}(P^*,i)di\right]. \quad (5)$$

To calculate K, the consumer indifferent about getting or not getting a real-time meter, we assume no transaction costs, so that the net welfare for customer K is the same with and without RTM. From equation (1), K's welfare without RTM will be $B^P(P^*, K) + B^{OP}(P^*, K)$. The cost to retailers of serving a customer of type K is $P^PD^P(P^*, K) + P^{OP}D^{OP}(P^*, K)$. Hence, the net welfare of serving K without RTM, W_{nonRTM}, will be

$$W_{nonRTM} = B^P(P^*, K) + B^{OP}(P^*, K) - [P^PD^P(P^*, K) + P^{OP}D^{OP}(P^*, K)].$$

The expression for net welfare if K uses RTM, W_{RTM}, is similar, except that one has to subtract the cost of the real-time meter, R.

$$W_{RTM} = B^P(P^P, K) + B^{OP}(P^{OP}, K) - [P^PD^P(P^P, K) + P^{OP}D^{OP}(P^{OP}, K)] - R.$$

Setting $W_{RTM} = W_{nonRTM}$, employing equation (1), and collecting terms, gives

$$P^P[D^P(P^*, K) - D^P(P^P, K)] - \int_{P^*}^{P^P} D^P(z,K)dz$$
$$+ \int_{P^{OP}}^{P^*} D^{OP}(z,K)dz - P^{OP}[D^{OP}(P^{OP}, K) - D^{OP}(P^*, K)] = R \quad (6)$$

The first two terms are the cost savings to the seller from reducing underpriced on-peak sales to K at the non-RTM average price, less the surplus K loses by having to pay the higher price. This is a net gain to the seller. Off-peak, the buyer gains from being able to purchase at a lower price with RTM, but one has to subtract the cost of supplying K with that additional output. For customer K, these two net gains have to just cover the cost of the real-time meter, R. Figure 1 illustrates these gains.

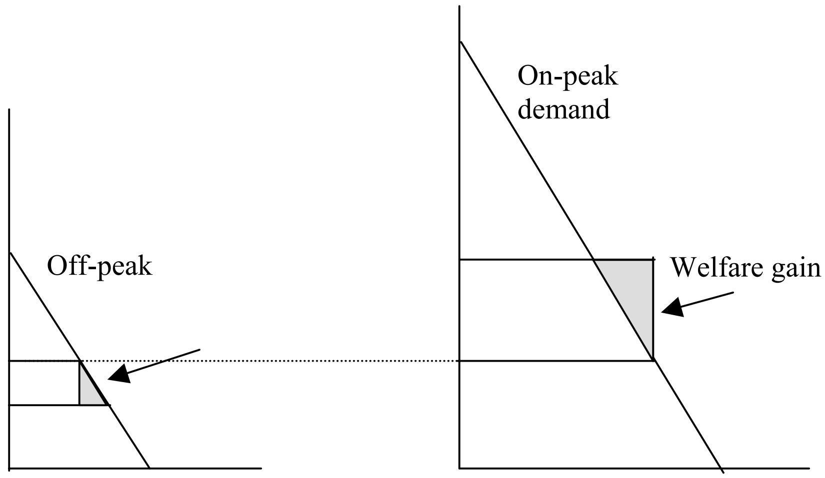

Figure 1: Welfare gains from adopting RTM

For tractability, we would like to be able to say that for customers with $i > K$, these gains exceed R, and they buy real-time meters. For customers with $i < K$, these gains are less than R, and they do not adopt RTM. This, however, need not be the case, even with non-crossing demand curves. Essentially, a customer with $j > i$ can have a smaller welfare gain from adopting RTM if her demands are significantly less elastic within the relevant price ranges than that of customer *i*.[26] To make the model feasible, we need to assume directly the supposition introduced at the beginning of this section: that the welfare gain from RTM, as well as demand, increases as the index *i* of customers increases. With that added assumption, equations (3)–(6) are four equations in the four unknowns K, P^P, P^{OP}, and P*, defining the equilibrium adoption of RTM and the associated prices.

B. Optimum conditions and implications for RTM policy

Whether we have the right amount of RTM in this case comes down to whether we would obtain the same K at the social optimum. Net economic welfare (NEW) is the total gross surplus

[26] To help see this, imagine the extreme case where j's demand exceeds i's, but is perfectly inelastic between the RTM and non-RTM price. The potential gains from trade from offering RTM to customer j are thus zero, as the gains to the seller would just match j's losses. However, if i's demand is not perfectly inelastic between these two prices, there are potential gains from trade in that case.

reaped by customers peak and off-peak, less the costs of producing output for them and the cost of supplying real time meters to those who use them. We want to choose K, P^P, P^{OP}, and P* (if endogenous) to maximize

$$\text{NEW} = \int_0^K B^P(P^*,i)di + \int_K^N B^P(P^P,i)di - C(\int_0^K D^P(P^*,i)di + \int_K^N D^P(P^P,i)di)$$

$$+ \int_0^K B^{OP}(P^*,i)di + \int_K^N B^{OP}(P^{OP},i)di - C(\int_0^K D^{OP}(P^*,i)di + \int_K^N D^{OP}(P^{OP},i)di) - R[N-K]. \quad (7)$$

The first line in NEW is the consumer benefit of non-RTM and RTM customers respectively on-peak, less the cost of providing them with energy on-peak. The second line is the same calculated off-peak, except for the last term, which is the cost of supplying RTM to N – K customers.

If P* is defined endogenously as a zero-profit condition for serving non-RTM customers, then P* is a variable of choice but the maximization is subject to equation (5) above, the defining condition for P*. If P* is defined independently of the other market variables, for example, as a regulatory price ceiling, no such condition is needed and P* can be treated as an exogenous parameter.

For simplicity, examine the second possibility first. It is straightforward to show that P^P and P^{OP} equal the respective marginal costs of producing electricity on-peak and off-peak. The first-order condition found by setting equal to zero the partial derivative of NEW with respect to K gives equation (6). These results together imply:

- **Proposition 1:** If retail utilities are obliged to meet demand at exogenously imposed prices, the market equilibrium amount of real time meters equals the social optimum.

The situation is slightly more complicated if P* is determined endogenously. The optimum is now to maximize the Lagrangian L given by

$$L(K, P^P, P^{OP}, P^*, \lambda) = \text{NEW}(K, P^P, P^{OP}, P^*)$$

$$- \lambda[P^*\left[\int_0^K D^P(P^*,i)di + \int_0^K D^{OP}(P^*,i)di\right] - P^P\left[\int_0^K D^P(P^*,i)di\right] - P^{OP}\left[\int_0^K D^{OP}(P^*,i)di\right]].$$

Setting the first-order condition for K equal to zero sets equation (6), the condition in the market equilibrium, equal to

$$\lambda[P^*[D^P(P^*, K) + D^{OP}(P^*, K)] - P^P D^P(P^P, K) - P^{OP} D(P^{OP}, K)]$$

This term will be zero if the zero profit condition that holds for serving all customers without RTM holds for the marginal customer without RTM. For example, if for all customers peak demand is the same multiple of off-peak demand, the zero-profit condition that holds for the average of all customers will hold for the marginal customer. If so, the first-order conditions satisfied in the market equilibrium will be the same as in the constrained maximization.

This only suggests the absence of externalities associated with RTM in this case. A first complication is that the zero-profit condition need not hold for the marginal consumer K. If not, there could be negative as well as positive externalities from RTM.[27] This effect would not appear to be large, as the difference between the marginal and average consumer in terms of the relative amounts of peak and off-peak demand would not seem to be predictably significant in either direction. This is, however, an empirical and not theoretical question.

The second complication is that if the constraint (5) binds, the optimal P^P and P^{OP} will be below marginal cost.[28] The wedge created by the cost of real-time meters may create an inefficiency. But the best response to that inefficiency may not be to subsidize meters, but to increase welfare at the margin by reducing prices, if retailers and wholesalers earn zero profits at the market optimum. As with the first effect, the direction is not clear and the magnitude does not seem great. We summarize these with:

- **Observation 1:** When retail utilities are under an obligation to serve but the non-RTM price is endogenous, there could be too little or too much RTM; in neither direction does the effect appear large.

[27] We expect that $\lambda > 0$, as λ is the shadow price of raising P^P and P^{OP} to ensure that the constraint is satisfied. If the first-order condition would appear to hold for the market equilibrium, $\partial L/\partial K$ will be positive (negative) if the profits of providing non-RTM service to customer K are positive (negative). This would imply that welfare would increase if K were to increase (decrease), hence that the market leads to marginally too much (too little) RTM.

[28] For the peak period price P^P, one can show that the first-order condition in the constrained maximization is

$$P^P - C^{P\prime} = \lambda \frac{\int_0^K D(P^*, i)\,di}{\int_K^N \frac{\partial D(P^P, i)}{\partial P^P}\,di} < 0,$$

As λ is positive, the integral in the numerator is positive, and the integral in the denominator is negative, on-peak price is less than on-peak marginal cost. A similar relation holds for off-peak prices.

V. Rationed energy

A. The potential positive externality

As we saw at times in California during the summer of 2001, the utilities may not always be willing or able to meet obligations to serve. Wholesalers may be capacity-constrained, unable to supply power at any feasible price equal to the amount demanded at the retail price utilities inherited under a regulatory scheme. In addition, as one might expect with retail deregulation, a retail utility will not purchase power at a cost above the (time-independent) price at which they can sell that power. A widespread absence of RTM would preclude separate on-peak and off-peak prices at which markets could be cleared in both periods.

A difference between demand and supply requires some form of rationing. In the case of electricity, when the price is the same both peak and off-peak, the rationing is two-sided. On-peak, demand would exceed supply if the legacy or rationed equilibrium price were, as one would expect, less than the price that would clear a market if a separate on-peak price could be charged. Off-peak, the amount firms would want to supply at the going price is likely to exceed demand, requiring rationing of buyers among sellers. In both situations, the welfare effects of rationing depend on how the supply is allocated among buyers on-peak, and how demand is allocated among sellers off-peak. Modeling rationed markets requires some assumptions as to how this allocation is done.

Off-peak, we will assume that the rationing takes place by having the least cost electricity produced to meet demand at the off-peak price, if that price exceeds the market-clearing price. This is a natural assumption if transaction costs among generators themselves are sufficiently low to allow them to minimize their collective costs of producing power, for example, by setting up a wholesale market to compete to serve the given demand.

Rationing on the buyers' side is not so easy to model. Transaction costs for the buyers to reallocate based on willingness to pay is not feasible, not least because of the lack of RTM that would enable such real-time reallocations to work. Moreover, as a technical matter, one cannot easily direct electricity to the higher valued uses and not to the lower valued ones. Demands for the lower valued uses need to be removed altogether. To get power for your refrigerator to keep food for your family, I have to agree not to turn my stereo on and thus risk blacking out your refrigerator.

These factors together suggest that rationing on the buyers' side will require cutting off sufficient numbers of customers altogether from getting power, until demand from the remaining customers no longer exceeds supply.[29] The likelihood π_B that any consumer will face a blackout is given by the fraction of the amount of electricity consumers demand in the aggregate that is not met by supply at the below market-clearing on-peak price. Using the notation from the previous sections, let aggregate on-peak demand DD^P at P* among all N consumers be given by

$$DD^P(P^*) = \int_0^N D^P(P^*, i)\,di \tag{8}$$

allowing us to set π_B equal to

$$\pi_B = \frac{DD^P(P^*) - S(P^*)}{DD^P(P^*)},$$

where S(P*) is the competitive supply curve at P*, equal to the inverse of the marginal cost curve. We assume here that P* is determined exogenously, to avoid the difficulties in calculating what it would be in equilibrium.[30]

To understand the potential externalities of adopting RTM, we need first to posit what happens to the market as a whole if someone adopts a real-time meter, and then see how that supposition affects the incentives for a buyer and seller to adopt RTM. We assume first that adopting RTM does not affect whether or not the adopter is rationed, but that as more customers adopted RTM, the degree of rationing would decline. The amount demanded on-peak will fall

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[29] This may be consistent with some sorting of demand. If cutting power to customers is feasible in real-time on a customer-specific basis, customers who most value the right to purchase electricity at the going price on-peak could pay to be included, leaving those for whom blackouts are less costly to bear them. To some extent, geographic concentrations of similar types of buyers could allow something like this, for example, if retailers could cut off commercial but not residential customers. Less equitably, socioeconomic concentration could allow power suppliers to cut off poor customers for whom the willingness to pay to avoid a blackout is presumably less than the rich customers it would continue to serve (and who would outbid poor customers to avoid being blacked out).

[30] These calculations are difficult if not indeterminate for at least two reasons. One is that we need to specify that the retailers are not contractually bound to supply power to their customers at the agreed-upon price during peak periods. If they are, the equilibrium would probably be equivalent to that in the previous section, in which retailers have contractually binding obligations to serve, yet earn zero profits. Second, if such contracts are nonbinding—perhaps because utilities could declare bankruptcy rather than honor them—one lacks a story without an upward-sloping supply curve, perhaps with capacity constraints. Such markets may have multiple or no Bertrand equilibria.

With some simplifying assumptions, one can obtain an equilibrium in which the output of electricity at all times equals the market-clearing amount off-peak. But this is an unsatisfactory result. It appears to hold regardless of the expected fraction of time at which demand would be peak (including, say, 99%) or the ratio of peak to off-peak demand (including, say, 100).

with a higher on-peak price, and the amount supplied off-peak would rise with a lower off-peak price.[31] It should become more profitable to purchase power and to sell it to customers able to pay a higher peak period price.

This indicates that RTM will be underpurchased relative to the socially optimal amount. Consider first an atomistic buyer, who takes not just prices but the probability of a blackout, π_B, as given. Such a customer's willingness to pay for RTM will be limited by the chance that even if she agrees to pay a higher price for electricity on-peak, she will not be able to make such a purchase π_B of the time. An individual's only incentive to cover the cost of RTM, and pay a (perhaps only slightly) higher peak period price, would be to become able to purchase off-peak energy at a price equal to its marginal cost of production, below P*. On the sellers' side, when they are not required to sell electricity on-peak at a price below the wholesale price, they lack the incentive of sellers under such an obligation to cover the cost of RTM in order to pay customers to demand less energy.

Not only is the incentive to adopt RTM smaller in a rationing model, but there are clear benefits to others if it were adopted. Positive externalities would be present if the more RTM is adopted, the more consumers there are who pay a higher price of electricity, reducing on-peak demand and thus π_B, the likelihood of a blackout. The consumer, however, does not take this blackout-reduction effect into account. Accordingly, rationing has two effects on the RTM market. It reduces the willingness of buyers and sellers to enter into RTM deals below what one would see if sellers were obliged to serve. It also creates an uninternalized benefit on others, through a reduction in the likelihood of a blackout. These suggest:

- **Observation 2:** If buyers are rationed in electricity markets through random blackouts, RTM will be undersupplied.

This observation appears to be relatively robust. First, weaken the assumption that a buyer is not atomistic, that is, allow a buyer to believe that if it adopts RTM, it will affect the likelihood of a blackout over the market as a whole. This would increase such a "big" buyer's willingness to adopt RTM. However, the remainder of the market would also benefit by this big buyer's adoption of RTM; hence, the positive externality would remain. Second, we might posit that even if buyers are atomistic, that the seller could internalize the benefits to its other

[31] Any intertemporal substitution of electricity demand between peak and off-peak periods would make these effects even more pronounced.

customers from encouraging them to adopt RTM and reduce π_B. However, this internalization will not be perfect, because the benefits would accrue to other sellers as well. Positive externalities will remain unless the electricity retailer is a monopolist with the ability to engage in sufficient price discrimination to capture the different gains different consumers would obtain from reducing the likelihood of a blackout.

B. Related conjectures

One might ask whether RTM would be adopted if it not only permitted high on-peak pricing but also, in so doing, reduced that consumer's likelihood of being in a blackout. If so, demand for RTM would increase greatly. I expect (but do not show here) that the largest buyers would purchase RTM and the smaller ones would choose to accept rationing. In such a case, RTM could have positive or negative externalities. The probability of a blackout, π_B, would depend on the difference between supply and demand for those customers still rationed. Those customers could see increased rationing, if the large customers have a proportionally smaller difference between what they demand on-peak and the electricity they were getting while rationed. Hence, one effect of a marginal increase in RTM could be to induce negative externalities, by making rationing more likely for the non-RTM customers.

However, in this setting the effects of RTM have little to do with regulating demand and more to do with sorting customers less willing to tolerate blackouts from those more willing to do so. The story would be much the same if we dropped the pricing aspect of RTM and regarded it simply a switch that consumers could buy to avoid being rationed. The effect of RTM in this case would be primarily to reallocate blackouts, not to alleviate them throughout the grid by bringing peak energy prices more in line with marginal production cost.

Next, suppose on-peak rationing were efficient in the sense that off-peak rationing is, namely, that electricity were allocated to satisfy those demands with the highest reservation prices. If so, there would be no inefficient substitution of low-valued uses for high-valued uses, and RTM would seem to produce no positive externalities. If the price of a meter were a constant fraction of the price of electricity, there would be no externality. RTM would be purchased up to the point where everyone's willingness to pay for the last MWh of electricity covers the cost of the energy itself plus, in effect, the cost of billing for it. No significant policy-relevant externalities would seem to arise if RTM has a fixed per-customer rather than per-unit cost and is priced accordingly.[32]

One might not want to spend a great deal of time on this conjecture. There is no practical method for allocating electricity according to reservation price and blacking out only low-valued uses when demand exceeds supply. In power outages, the refrigerators go out with the stereos. To the extent that blackouts can be directed toward particular regions an away from those with relatively high willingness to pay for electricity, for example, areas including hospitals, some locationally efficient rationing may be possible.[33] In addition, large customers who do not adopt RTM could have their demand "managed" via programs that cut energy use remotely, for example, cutting off residential air conditioner compressors for short periods during very hot days, or putting industrial customers on interruptible power.[34] However, energy distributors still could not selectively cut power only to those customers who had not adopted RTM.

VI. Market power

Many commentators have alleged that the rise in wholesale electricity prices in California during the summer of 2000 was due to the exercise of market power. Some suggest that RTM would introduce more resistance to paying higher prices on-peak than one would see when such prices are either absorbed by retailers or averaged in with off-peak prices to create the uniform price paid over time.[35] As noted above, Doucet and Kleit's simulations produced a contrary result, that RTM would reduce welfare.

To examine the effects of RTM with market power, I begin by focusing on the wholesale sector, assuming that the retail sector introduces no costs. To avoid getting bogged down in the menu of possible strategic models, I model wholesale market power as if the generators acted like a cartel on-peak. Because of the extent of industry capacity relative to off-peak demand, I take off-peak wholesale prices as competitively set. To avoid some notational complications, I assume that the competitive off-peak wholesale price of electricity is a constant, MC^{OP}. As in

[32] By analogy, there are no market inefficiencies simply because the cost of driving to the store is independent of the amount one spends on groceries.

[33] I thank Joe Doucet for this observation.

[34] I thank Paul Nelson for this observation. See also King, n. 15 *supra*.

[35] Borenstein, n. 1 *supra*.

Section IV above, with no RTM, the retail sector charges a uniform price on-peak and off-peak that guarantees zero profits with no rationing. With RTM, the peak and off-peak prices set at the wholesale sector get passed on to consumers directly. To simplify the analysis, we look at how the wholesale sector would perform with and without RTM, as if metering were costless. However, to make the analysis slightly more transparent, we reintroduce the variable T, the fraction of time demand is at peak, but we continue to treat T as exogenous (and on-peak and off-peak demand curves as independent of each other's prices).

As specified in equation (8), let DD^P be aggregate demand on-peak, and similarly let DD^{OP} be aggregate demand off-peak. In a world without RTM, we have that the price of electricity (neglecting any retail costs) meets the zero-profit condition for retailers, adapted from equation (5) above to reflect demand from all N customers and to include the fraction of time at which demand is on-peak:

$$P^*[T[DD^P(P^*)] + [1-T]DD^{OP}(P^*)] = P^P T[DD^P(P^*)] + MC^{OP}[1-T]DD^{OP}(P^*). \tag{9}$$

The on-peak monopolist wants to maximize its profit $\Pi(P^P)$

$$\Pi(P^P) = T[P^P DD^P(P^*) - C(DD^P(P^*))] \tag{10}$$

over the fraction of time T at peak demand, subject to how equation (9) defines P^* in terms of P^P.

To gain some insight, use (9) to rewrite (10) and collect terms to give

$$\Pi(P^P) = T[P^*[DD^P(P^*)] - C(DD^P(P^*))] + [1-T][P^* - MC^{OP}]DD^{OP}(P^*) \tag{11}$$

If retailers are averaging high peak period costs into an overall price, the peak period monopolist is essentially setting the constant price that maximizes the sum of peak and off-peak profits. The first group of terms on the right hand side of equation (11) is the profit on-peak at P^*; the second group is the profits off-peak at P^*. Without RTM, the on-peak monopoly acts as if it were a monopolist off-peak as well, albeit constrained to set price uniformly in the two markets, using P^P to set P^* as specified by equation (9).

One other result will prove useful. Let the relationship between P^* and P^P in equation (9) be given by $P^* = H(P^P)$. Then, setting P^P to maximize $\Pi(P^P)$ as defined in equation (10) gives the first-order condition

$$[P^P - C']DD^{P\prime}(P^*)H' + DD^P(P^*) = 0.$$

Let E_{PD} be the absolute value of the elasticity of peak demand and $E_{P*/P}$ be the elasticity of P* with respect to P^P, that is,

$$E_{PD} = -\frac{DD^{P}{}'P*}{DD^{P}} \text{ and } E_{P*/P} = \frac{H'P^{P}}{P*}.$$

The Lerner index for the on-peak wholesale electricity monopolist without RTM is

$$\frac{P^P - C'}{P^P} = \frac{1}{E_{PD}} \frac{1}{E_{P*/P}}. \tag{12}$$

If the ratio of on-peak to off-peak demand does not shrink much as P* increases, $E_{P*/P} < 1$.[36]

Suppose the market adopted RTM. Off-peak, consumers would pay MC^{OP}, the competitive price. On-peak, they would pay P^P as set by the wholesale electricity monopolist. That wholesale monopolist would maximize profits as given by equation (10), except that instead of peak demand being at P*, it would be at P^P. This gives a Lerner index at the profit maximum of

$$\frac{P^P - C'}{P^P} = \frac{1}{E_{PD}}. \tag{13}$$

If $E_{P*/P} < 1$, comparing equations (12) and (13) shows that the wholesale price set without RTM will exceed that set with RTM. This is not surprising; with RTM, the on-peak monopolist cannot force the off-peak purchasers to absorb its price increases.

A comparison of (13) with (11) shows that moving from no RTM to universal RTM transforms us from a market in which off-peak and on-peak are monopolized at a uniform price, to one in which the off-peak market is competitive but the profit-maximizing monopoly price on-peak. Under the assumption that the on-peak monopoly price is higher than the uniform profit-

36 The algebra is a bit gruesome, but if we let K(P*) = DDP(P*)/DDOP(P*), the ratio of on-peak to off-peak demand, then one can show that

$$E_{P*/P} = \frac{TK + [1-T][P*-MC^{OP}]/P*}{TK + 1 - T + TP*K'}.$$

If K' is positive or zero or if it only slightly negative—if the ratio of peak demand to off-peak demand increase with P*, stays constant, or does not fall by much, the numerator of the above expression is less than the denominator. If so, EP*/P < 1.

maximizing price across both on-peak and off-peak markets, RTM raises price on-peak to consumers and cuts it off-peak. This leads to:

- **Observation 3:** With market power in wholesale electricity, adopting RTM will reduce the price charged by wholesalers but raise the price paid by consumers during peak periods. It will, however, reduce prices off-peak, perhaps to marginal cost, if there is no market power off-peak.

Were the off-peak price with RTM the single monopoly price for off-peak power, we would have a situation somewhat akin to third-degree price discrimination. If that is an appropriate analogy, we would have the familiar set of ambiguities. Economic welfare with RTM could be higher or lower than without it. Welfare with RTM would be lower (greater) if the loss in output from the high price (on-peak) market equaled or exceeded the gain in output from the (off-peak) low price market.

The possibility that moving to RTM reduces welfare supports the result in Doucet and Kleit's simulation that RTM has negative externalities in the presence of market power. However, the intuition from third-degree price discrimination that supports such a conclusion needs to be qualified in two important respects. First, if T, the fraction of time demand is at peak levels, is small, the gains in output from lower off-peak prices would be more likely to outweigh the losses from charging high prices on-peak (although increasing T could increase P^P absent RTM). Second, the price-discrimination analogy does not apply directly in that the cost of supplying the marginal unit of energy on-peak is greater than the marginal cost of energy off-peak. The loss in welfare from an output reduction on-peak relative to off-peak will be lower than in price discrimination models in which marginal costs of serving all markets are the same. These suggest:

- **Observation 4:** The welfare effects of RTM are ambiguous, and its adoption could lead to reduced welfare overall. However, because on-peak marginal costs exceed off-peak, the off-peak price is competitive, and off-peak time is likely to be significantly longer in aggregate than on-peak time, the balance will tilt in favor of RTM more than intuition regarding third-degree price discrimination might indicate.

VII. Summary

Setting real-time prices for electricity, using real-time metering, could bring important benefits by encouraging consumers to recognize how much electricity costs when they use it.

Making consumers more sensitive to price will reduce the incentive of electricity generators and marketers to exercise market power during peak-demand periods. These benefits, however, need not imply that too few consumers adopt RTM because it creates positive externalities affecting non-RTM customers and their energy suppliers. Public policy to encourage more widespread adoption of RTM may be neither necessary nor desirable.

The adoption of RTM has predictable positive externalities when doing so reduces the probability of random blackouts. When utilities can meet obligations to serve customers under an exogenously set regulated price, they will adopt the socially optimal amount of RTM without policy intervention. RTM may be marginally undersupplied or oversupplied when the retail price is endogenously set to maintain zero profits in the downstream sector. If a consumer's adoption of RTM allowed him to specifically avoid blackouts, we find a similar marginal ambiguity, depending upon whether the non-RTM consumers are more or less likely to have blackouts restricted to their universe. In neither case, however, does the effect in either direction seem great.

When wholesalers have market power, the effects of RTM are also ambiguous, for much the same reason that third-degree price discrimination is. While RTM reduces the on-peak price of wholesale electricity paid by retailers, it raises the on-peak price paid by consumers, reducing on-peak consumption and welfare. On the other hand, RTM causes price to fall off-peak; under the assumptions of our models, the off-peak price falls to the competitive level. The trade-off for RTM is likely to be more favorable than the tradeoff typical for third-degree price discrimination. The marginal cost of on-peak price exceeds that for off-peak—reducing the overall welfare loss from reduced on-peak purchases—and the off-peak price is competitive rather than a lower monopoly price.

The models used to support these results adopted simplifications in the interests of tractability and clarity. These simplifications, however, do not seem to affect the qualitative results. In particular, neglecting intertemporal substitution, although a serious flaw for empirical estimation, does not seem to bias results regarding the presence and direction of any market failures. The first proposition, that there is no market failure when suppliers meet demand, is essentially that absent rationing, RTM is demanded up to the point where its marginal benefit equals its marginal cost. Intertemporal substitution might change the prices and quantities at which that equalization takes place, but it does not change the fact of the equalization and, hence, the absence of market failure.

When there is rationing, intertemporal substitution would, all else being equal, increase the benefits to the grid overall from one customer's adoption of RTM, as it presumably makes peak demand more elastic. That effect would increase the positive externality from adopting RTM, supporting the results in the paper. Similarly, this increased elasticity of on-peak demand would change the absolute magnitude of the results involving market power, but not the relative welfare levels associated with and without RTM, maintaining the ambiguity we found in that analysis.

More detailed and precisely analyzed models could shed additional light on the conditions under which we have too little RTM, and the conditions under which we have too much. Nevertheless, it does seem safe to say at this stage that there is no general case for encouraging additional RTM, except to encourage conservation in order to reduce the likelihood of random or rolling blackouts.