Time-of-Use Rates and Real-Time Prices

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Electricity prices that describe marginal costs can vary substantially over time. Fixed rates ignore changing electricity system conditions. Setting prices that differ for certain periods is an approach to approximating the real-time price. If such time-of-use prices are set in advance, they will necessarily miss the full variability of real real-time prices. A simple index indicates that even very good time-of-use rates would miss the majority of the efficiency gain that would result with use of actual real-time prices.

Introduction

The organized markets in the United States all use some variant of real-time locational marginal price for wholesale electric energy. Real-time prices are volatile, although it is well known that the prices tend to be too low on average and are not volatile enough. (Hogan, 2013) The Federal Energy Regulatory Commission has embarked on an effort to improve wholesale electricity pricing models. (Federal Energy Regulatory Commission, 2014) In addition to improving pricing models, a policy goal is to take real-time prices as the best representation of efficient energy prices and make these prices available to retail consumers to support demand participation and distributed energy resources. For example, see (Massachusetts Department of Public Utilities, 2014). Applying the arguments of (Thaler & Sunstein, 2008) to apply a policy "nudge" to improve efficiency, Faruqui et al. recommend a move away from fixed rates by making time varying rates the "Smart by Default" policy. (Faruqui, Hledik, & Lessem, 2014)

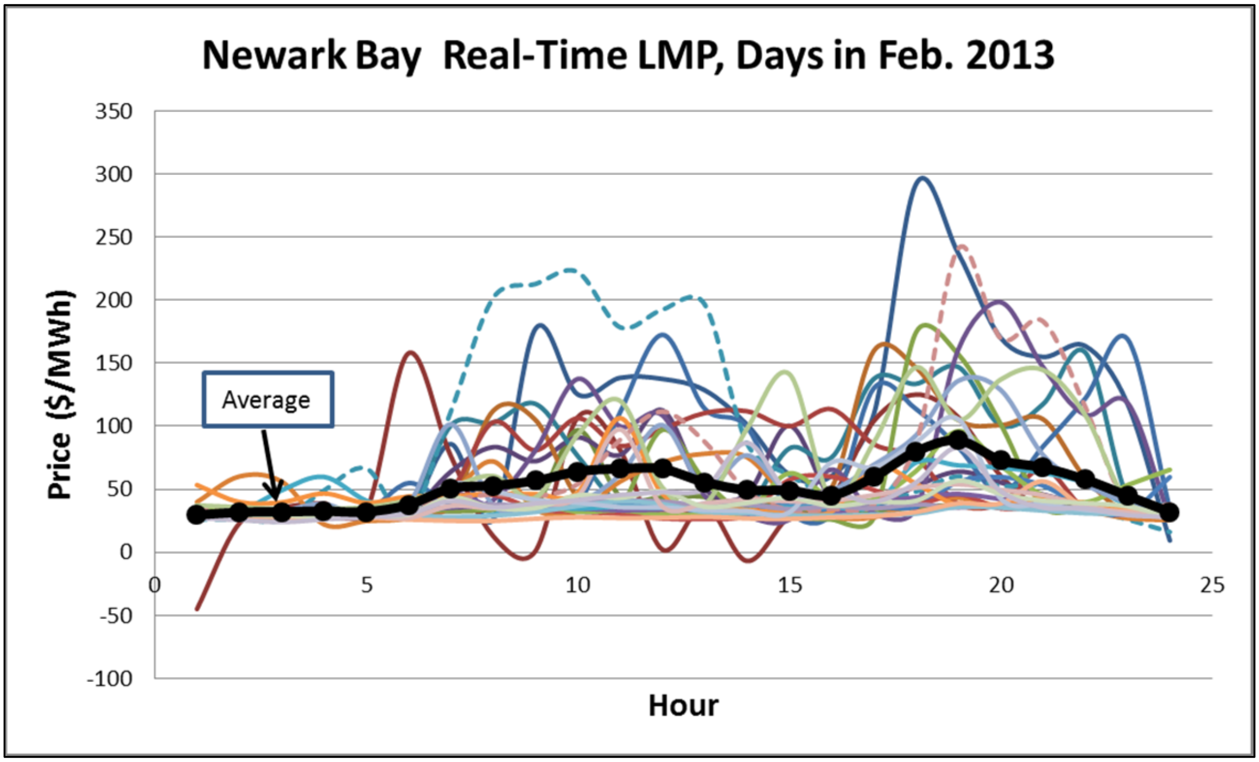
A full analysis of the different efficiency effects requires information about electricity demand and its components. Estimates of aggregate welfare effects show material efficiency gains in moving from fixed rates to real-time prices, as in (Borenstein & Holland, 2003) and (Newell & Faruqui, 2009). A common question arises about the possibility of going part way by incorporating something less than the full real-time price by designing rates that reflect time of use to some degree. (Holland & Mansur, 2006) The illustrative choices in (Faruqui et al., 2014) include several variants of time varying rates, but not full real-time pricing. How far to go towards real-time pricing depends in part on how much is lost by going only part of the way. The details can be important, but there is a simple efficiency index that can cut through much of the clutter without the complications of more elaborate simulation models. The approximate efficiency index is based on the price variance, which is easy to underestimate even though it is simple to calculate. The variance index makes clear why anything other than full real-time pricing will likely capture less than the majority of the potential efficiency benefits of energy pricing.

Time-of-Use Rates

The general category of Time-of-Use (TOU) rates for electricity customers often refers to prices set in advance but varying over the day to capture expected impacts of changing electricity conditions. (Faruqui et al., 2014) A characteristic of many TOU prices is that the prices are set well in advance of the period, and do not adjust to reflect actual conditions. By comparison, Dynamic or Real-Time Pricing (RTP) reflects the current conditions and provides the best available signal about the marginal value of power at a location. The various pricing approximations (e.g., Critical Peak Pricing, Variable Peak Pricing) move TOU to better representations of current conditions and closer to RTP. (Faruqui, Hledik, & Palmer, 2012) However, the efficiency of pricing is reduced when prices deviate from RTP. While a move to any type of TOU proposal is a positive step compared to the Flat or Fixed Rate (FR), where energy prices are the same for all hours, there is still a substantial amount of information lost in the difference between TOU and RTP. The price volatility of real-time prices has implications for the cost of the efficiency loss for any design other than RTP.

Price Volatility

An example from Newark Bay in New Jersey illustrates the variability of real-time prices.[1] The graphic shows the twenty-four hourly PJM-reported locational marginal prices (LMP) at Newark Bay for every day in February 2013. The "spaghetti" diagram of real-time prices provides a visual illustration of the variability of prices and the difficulty of defining in advance any model of TOU prices that will provide a good approximation of real-time prices.



Source: www.pjm.com

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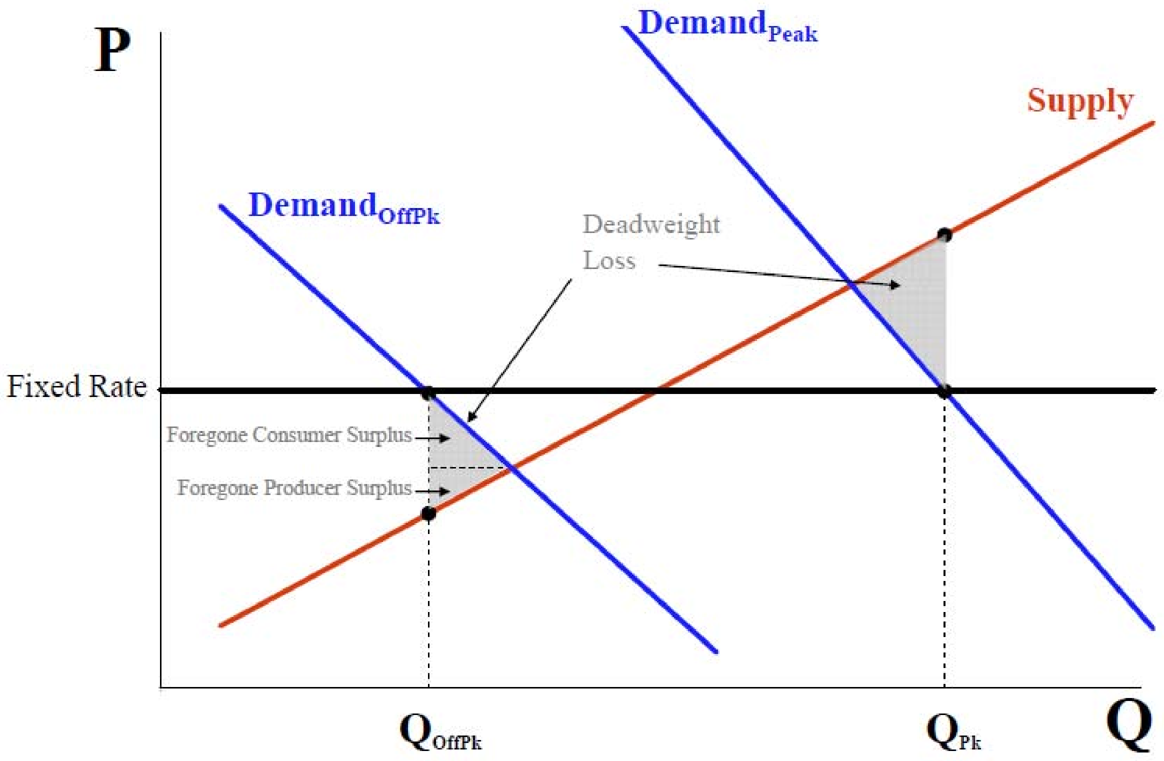
[1] This graphic updates a prior version prepared for "Fair Pricing: A Conference on Ethics and Dynamic Pricing," held at Rutgers University on April 9, 2010. (Hogan, 2010)

The variance in tariff rates can be described as a risk for customers, with FR prices having the lowest risk. (p. 17) (Faruqui et al., 2012) From another perspective, the variance in prices provides a connection to the efficiency of the pricing option.

A common simplification and illustration of the welfare analysis employs a diagram similar to that shown in the accompanying figure on economic inefficiencies; e.g., see (Borenstein, 2005) (Newell & Faruqui, 2009) or (Chao, 2010).

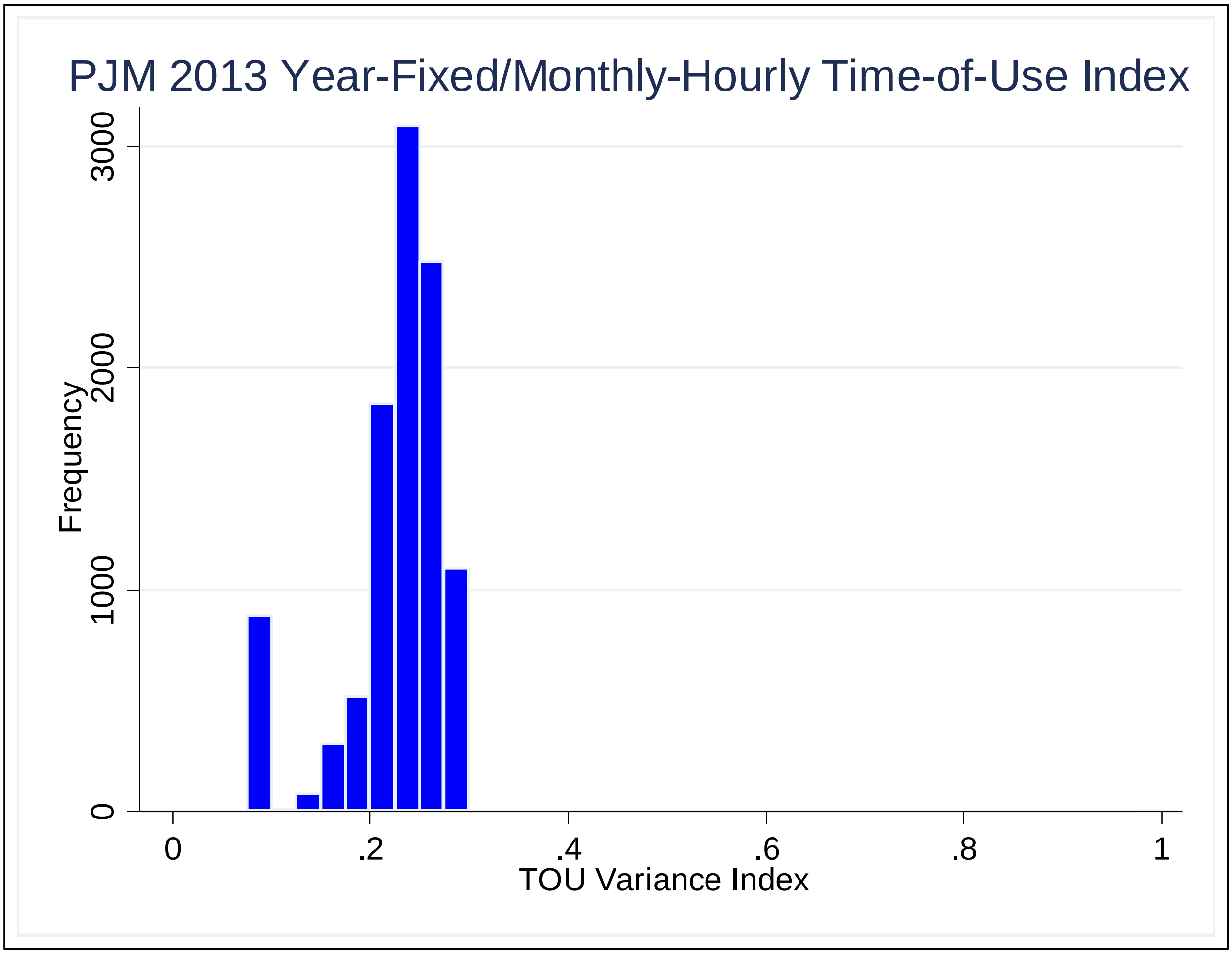
Economic Inefficiencies Caused by Fixed Retail Rates



Source: Figure 2 in (Newell & Faruqui, 2009)

For the illustration, the figure shows peak and off-peak conditions with a fixed rate. Off peak, the fixed rate is too high, and quantity consumed is too low. The reverse holds on-peak, when the fixed rate is too low, and quantity consumed is too high. In each case, the shaded triangle shows the textbook description of the efficiency loss of fixed rates which do not reflect actual real-time prices. From the basic geometry of the area of a triangle, for any given period with exogenous locational marginal price (LMP), the deadweight economic efficiency loss of the deviation from real-time price is half the change in quantity times the change in price. Hence, with the local linear approximation of supply and demand, the deadweight loss inefficiency of any price fixed *ex ante* is proportional to the square of the deviation from real-time price (see the Appendix for a further discussion). Equivalently, the expected deadweight loss is proportional to the residual variance of the price deviations from RTP. This conclusion does not depend on knowing the slopes of the supply and demand functions, and the calculation can be done by location without a full network simulation. This simplifies the analysis. A defining characteristic of TOU rates other than RTP is that they are always or nearly always fixed in advance. The FR is a special case of TOU with only one period. In February 2013, the average price over all hours at Newark Bay was $52.28/MWh. This is the efficient fixed rate for that month.

For hourly TOU rates set with perfect foresight at the start of the month, the price that minimizes the efficiency loss for each hour is the average price for the hour, as shown by the black marked line in the Newark Bay graphic. This Newark Bay hourly average price varies over the twenty-four hours and covers 18% of the price variance relative to the monthly FR. Hence, this is also an 18% reduction in the welfare loss index proxy defined by the sum of the hourly squared price deviations compared to the FR for the month. In other words, 82% of the benefit of going all the way from FR to RTP is lost by a decision to use the best hourly TOU rate rather than the RTP. As shown in the Newark Bay graphic, the real-time price is volatile. Real-time deviations from the TOU can be large and unpredictable if the TOU price is determined far in advance of real time.



The case of February in Newark Bay is not unusual. The situation repeats across the locations in PJM. Completing a similar calculation for every location reported in PJM in 2013, with the FR now set for the year and the hourly TOU rated changed every month, produces a distribution of the TOU variance index, as shown in the accompanying "PJM 2013 Year-Fixed/Monthly-Hourly

Time of Use Index" graphic.[2] The fixed rate is the average for the year. For each month, the hourly TOU rate is set at the average for that hour that month. The approximate efficiency index is the percent of the price variation explained by this TOU relative to the fixed rate.

The average PJM index value for 2013 is 23%, as compared to 0% for FR and 100% for RTP.[3] This is likely a conservative conclusion.[4] For example, setting the TOU as two different prices, one for peak hours and another for off-peak hours, will necessarily capture less of the variance and have a lower index value. Setting the separate TOU rates for every hour of the day and updated on a monthly basis, with the perfect foresight assumed here, may well be better than the best implementable TOU rates with prices set in advance.

Something is usually better than nothing. According to (Faruqui et al., 2014), "[a]bout a third of U.S. households are now receiving electric service through smart meters but only two percent are buying the energy portion of their electric bill on a time-varying rate, or TVR." (p. 25) Given the long history of the analysis and recommendations for moving away from flat rates, there may be an argument that any type of TOU rate would be an improvement and we should not be too concerned about how close we get to full RTP. However, a different interpretation of the history suggest that making such fundamental changes is so fraught with the challenges of a status quo bias, that if change is to be made it is best to follow first principles and use the best prices we have available. We may not get another chance soon. Whether to go so far as to make RTP the default, rather than an option, is a more complicated question. But it is not complicated to see why TOU compromises inherently fall well short of the efficiency gains from RTP.

Conclusion

The PJM experience in 2013 is likely to be representative of the volatility of real-time prices. If time of use rates are set much in advance, and fixed over the hours, these rates miss the majority of the potential gain as measured by the variance index. There is a substantial difference in efficiency between even the best TOU design and RTP. Where real-time prices are available, it seems worth the effort to remove obstacles from going all the way to RTP.

Appendix

Let the observed hourly real-time prices (RTP) be p and the time of use (TOU) prices be π. The TOU prices are restricted so that they are the same for certain hours, e.g. peak and off-peak. Here we focus on energy prices and costs, and set aside the discussion of capacity charges and other pricing issues. Ignoring cost shifts across different TOU periods, or assuming that cost shifts across types of periods are fixed, we focus on the price for the period that determines the TOU rate. This conditional pricing model avoids the complications of more general techniques such as Ramsey pricing. Assume the hourly real-time prices are efficient and that demand and

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[2] Sandesh Kataria assembled the www.pjm.com data for the 10,296 locations with complete records for year 2013. The TOU rate for each hour, excluding weekends, is set at the monthly average for the hour of the day.

[3] By comparison, (Holland & Mansur, 2006) find a range of 15% to 30% of short-run welfare for different TOU rates simulated for PJM for the period April 1998 to March 2000. Apparently the simulation does not account for locational price differences which can often be much more volatile.

[4] Performing the calculation on an annual basis for both the FR and hourly TOU rates, rather than monthly TOU updates, reduces the average efficiency index to 11%.

supply for the hour are approximated by linear functions. The slope of net demand is β . Then the deadweight loss of for the hour can be computed as $0.5\beta\left(p_i - \pi_i\right)^2$. (Chao, 2010) (Newell & Faruqui, 2009) If the net demand curve shifts over the hours, but keeps the same slope, then the total deadweight loss is proportional to $\left(p-\pi\right)^t\left(p-\pi\right)$.

The solution has the TOU price as $E\left(p\right)$, where the expectation is taken over the relevant hours of the period where the TOU price is the same. Hence, if the TOU price is the same over all hours of the month, a monthly flat rate, then the TOU energy price is the expected price over the month. If the monthly TOU differs for each of the twenty-four hours of the day, then the TOU is the expected price for that hour over the month. The conditional deadweight loss is proportional to the residual variance. With these approximations, the residual variance of prices over the TOU hours is a conditional index of the remaining welfare loss of the TOU. By construction, the RTP has a residual variance of zero. The proxy for the efficiency index is the fraction of the RTP variance captured by the TOU rate. Hence, a FR by construction has an index of 0%. And RTP has an index of 100%.

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Services, Inc. (f/k/a Aquila Power Corporation), JP Morgan Ventures Energy Corp., Morgan Stanley Capital Group, National Independent Energy Producers, New England Power Company, New York Independent System Operator, New York Power Pool, New York Utilities Collaborative, Niagara Mohawk Corporation, NRG Energy, Inc., Ontario Attorney General, Ontario IMO, Ontario Ministries of Energy and Infrastructure, Pepco, Pinpoint Power, PJM Office of Interconnection, PJM Power Provider (P3) Group, Powerex Corp., Powhatan Energy Fund LLC, PPL Corporation, PPL Montana LLC, PPL EnergyPlus LLC, Public Service Company of Colorado, Public Service Electric & Gas Company, Public Service New Mexico, PSEG Companies, Red Wolf Energy Trading, Reliant Energy, Rhode Island Public Utilities Commission, Round Rock Energy LP, San Diego Gas & Electric Company, Secretaría de Energía (SENER, Mexico), Sempra Energy, SESCO LLC, Shell Energy North America (U.S.) L.P., SPP, Texas Genco, Texas Utilities Co, Tokyo Electric Power Company, Toronto Dominion Bank, Transalta, TransAlta Energy Marketing (California), TransAlta Energy Marketing (U.S.) Inc., Transcanada, TransCanada Energy LTD., TransÉnergie, Transpower of New Zealand, Tucson Electric Power, Twin Cities Power LLC, Vitol Inc., Westbrook Power, Western Power Trading Forum, Williams Energy Group, Wisconsin Electric Power Company, and XO Energy. Sandesh Kataria provided valuable help in assembling the PJM data. The views presented here are not necessarily attributable to any of those mentioned, and any remaining errors are solely the responsibility of the author. (Related papers can be found on the web at www.whogan.com).