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Examining Real Time Pricing in Electricity Usage

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Abstract

Demand Side Management (DSM) has been proposed to reduce energy load and provide savings to customers in deregulated markets. Currently, United States residential electric prices are not based on real-time. This paper explores potential customer preferences to Real Time Pricing (RTP), or different prices for electricity based on time of day and weather. A survey of 147 residential customers examined willingness to shift demand to off-peak hours for 11 typical household appliances. Price differentials were then developed to analyze effects. These preliminary results demonstrate potential for residential customers to shift demand if RTP was enacted in the United States.

Keywords
Electric utilities, real time pricing, demand side management

1. Motivation
Real time pricing (RTP), if enacted in the United States for residential customers, will cause changes in on-peak and off-peak pricing. Understanding how customers may react to such changes is crucial to estimating the viability of sustainable demand side management (DSM) programs in the United States. If DSM is to be used as an alternative to building new generation, then customers will need to be open to changing their energy habits on a daily and sustained basis.

Therefore, the possibility of customers implementing DSM needs to be assessed. Such an analysis will enable policy decision makers to understand both potential receptiveness to DSM and the possibility for shifting energy demand to off-peak times. Furthermore, examining an assessment of sample customers and the related price differentials will further enable policy makers to comprehend the potential effects and outcomes of DSM and RTP if the programs are in fact fully implemented nationwide in the United States.

This preliminary research addresses these questions and provides insight into potential residential customer behavior and attitudes towards DSM. To do this, we have constructed a survey of residential customers and developed related price differentials for energy load shifts. Such data and analysis provide preliminary insight into potential DSM effects in the United States.

2. Survey
In order to assess actual consumer preferences of and willingness to shift energy demand, a survey was constructed and distributed to approximately 800 people. The object of the survey was to collect preliminary data on residential customer appliance usage and assess related savings that customers would need to realize before demand would be shifted. In essence, the survey aimed to assess potential customer price points that would cause customers to shift their energy demand.

2.1 Survey Structure
The survey examined customer willingness to shift usage of eleven household appliances from the afternoon to the late evening/early morning hours. Appliances considered were washing machine, dryer, dishwasher, microwave, vacuum cleaner, water heater, furnace fan, CPU and monitor, laptop, window air conditioner, and central air. These

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appliances were chosen for their high likelihood of possibly being used at another time of day. Other electric-run household items, such as televisions, are not likely to be shifted and were thus not considered. Willingness to shift was assessed by presenting five tiers of potential savings per appliance cycle. These tiers were less than 10 cents, 10 to 50 cents, 50 cents to $1, $1 to $2, and greater than $2. Time of day was chosen to reflect potential on-peak (afternoon) vs. off-peak (late evening/early morning) pricing. Survey respondents were instructed to select the savings they would need to incur per appliance cycle to shift demand. Not willing to shift usage was also an option. Table 1 lists each appliance considered, corresponding average wattage ranges, assumed cycle times for purposes of the survey, and average kilowatt-hour usages per cycle. Assumed cycle times are typical amounts of time an appliance may run during a single usage. A full copy of the survey can be found in [1].

Table 1: Appliances, assumed cycle times, and average kWh usage per cycle [2, 3]

Appliance	Minimum Wattage	Maximum Wattage	Assumed Cycle Time	Avg. kWh Usage Per Cycle
Clothes washer	350	500	1 hour	0.43
Clothes dryer	1800	5000	1 hour	3.40
Dishwasher	1200	2400	1 hour	1.80
Microwave	750	1100	5 minutes	0.08
Computer - CPU & monitor		270	1 hour	0.27
Computer - laptop		50	1 hour	0.05
Vacuum cleaner	1000	1440	1 hour	1.22
Water heater (40 gallon)	4500	5500	1 hour	5.00
Old central air (2500 sq. ft.)		10000	20 minutes	3.33
New central air (2500 sq. ft.)		5000	20 minutes	1.67
Room AC (12,000 BTU)		2000	20 minutes	0.67
Furnace fan		600	20 minutes	0.20

The survey was distributed to the Carnegie Mellon Tepper School of Business MBA student email lists and via Facebook to approximately 800 people, predominately university students and faculty. The survey was conducted online, and participants were provided a link to a form tied to a Google spreadsheet. Participants were given one week to anonymously respond, and 147 responses were obtained for a response rate of approximately 18.4%.

2.2 Survey Results

Survey results were tabulated and the percentage of respondents in each price tier is shown in Table 2.

Table 2: Percentage of survey respondents in each price tier

Appliance	< 10 Cents	10 - 50 Cents	50 Cents - $1	$1 - $2	> $2	Not Willing	Null	Total Responses
Clothes washer	6.8%	19.7%	19.7%	27.9%	15.6%	9.5%	0.7%	100.0%
Dryer	8.8%	18.4%	19.0%	28.6%	15.0%	9.5%	0.7%	100.0%
Dishwasher	17.0%	16.3%	16.3%	27.9%	16.3%	2.7%	3.4%	100.0%
Microwave	2.7%	3.4%	8.8%	10.2%	14.3%	58.5%	2.0%	100.0%
CPU	4.8%	2.7%	4.1%	10.9%	16.3%	59.2%	2.0%	100.0%
Laptop	2.0%	2.7%	5.4%	7.5%	13.6%	67.3%	1.4%	100.0%
Vacuum cleaner	9.5%	12.9%	15.0%	19.7%	22.4%	19.0%	1.4%	100.0%
Water heater	20.4%	17.7%	11.6%	17.0%	22.4%	9.5%	1.4%	100.0%
Central air	15.0%	15.6%	9.5%	17.7%	26.5%	14.3%	1.4%	100.0%
Window unit	12.9%	14.3%	13.6%	17.0%	23.1%	16.3%	2.7%	100.0%
Furnace fan	12.9%	12.9%	16.3%	14.3%	24.5%	17.0%	2.0%	100.0%

Corresponding histograms of each appliance and respondent data were tabulated. For illustrative, purposes, Figures 1 and 2 depict the histograms for microwave and clothes dryer, respectively. The histograms depict customers' sensitivity to shifting demand and do not necessarily exhibit normal distributions for each appliance. However, the resulting data and distribution is intuitive and based on the type of appliance. For example, a majority of customers are not willing to shift time of day when using their microwave, while they are more open to shifting demand of their dryer. This makes sense, because a microwave is used for cooking, which is usually done during specific times of the day, while a dryer can more easily be used at any point during the day and usage is not tied to a specific time window.

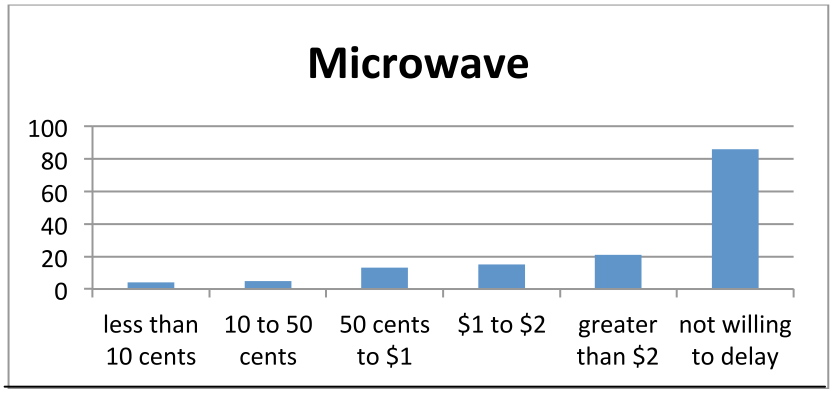

Figure 1: Histogram for microwave

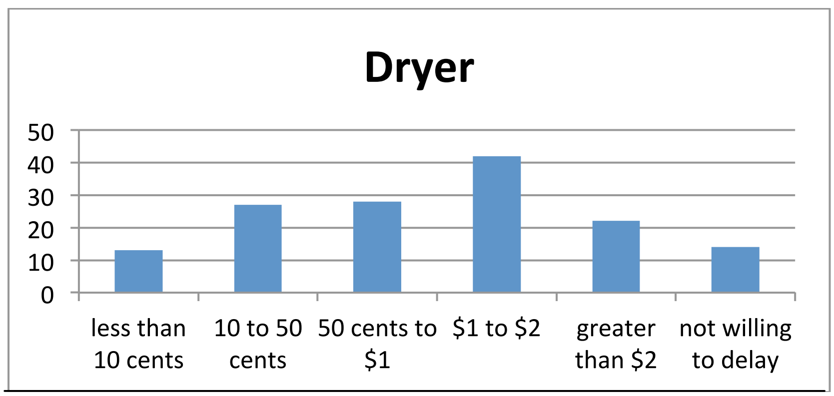

Figure 2: Histogram for dryer

Demand curve step functions were developed for each appliance [1]. The demand curves show the number of respondents versus price tier savings. These curves show how willing United States residential customers can be to changing when they use their appliances in order to save money per cycle of usage. The price tiers start low, at less than 10 cents of savings, but appliance average use shows that some appliances do in fact use rather few kilowatt-hours per defined cycle, leading to small savings per cycle.

Table 3 shows the corresponding price threshold differences between on-peak and off-peak locational marginal prices (LMPs) in dollars per megawatt-hour for consumers to realize the various price tier savings. LMPs are the real time prices at which power is sold by MWh at hubs in the electrical grid.

Clearly, any difference in LMP would cause a savings of less than 10 cents per cycle and some corresponding load shift. Some appliances would realize more corresponding shift than others, due to their realistic LMP differences. For example, there exists a greater likelihood that LMP differences can be between $20 and $100 than between $370 and $2855, causing more people to theoretically adjust their water heater temperature than delay using their CPU and monitor.

Examining the results of the survey shows that the likelihood that some customers will shift demand is very low. Customers are not very willing at this time to potentially shift load unless they realize very large savings. However, if real time pricing was enacted in the United States, customers would at a minimum gain a better understanding through practice of how such pricing affects their electric bills. Such experience may change the way they feel about shifting demand, causing different volumes of electricity demand to shift in practice versus what is exhibited through this survey. Because customers currently pay the same rate for electricity no matter the time of day or day of year, they have no current incentive to shift demand and may not have a clear understanding of how such shifts would actually affect their energy bill in practice. Furthermore, varying LMP prices may cause very expensive energy costs at some points in time, which is markedly different than the flat or blocked rate that residential customers pay now. Such changes would inevitably influence the way Americans approach their energy usage.

Table 3: LMP differences in $/MWh between on-peak and off-peak that will cause a shift in load

Appliance	< 10 Cents	10 - 50 Cents	50 Cents - $1	$1 - $2	> $2
Clothes washer	any	235	1180	2355	4710
Dryer	any	30	150	295	590
Dishwasher	any	60	280	560	1115
Microwave	any	1305	6515	13025	26050
CPU	any	370	2855	3705	7410
Laptop	any	2000	10000	20000	40000
Vacuum	any	85	410	820	1640
Water heater	any	20	100	200	400
Old central air	any	30	150	300	600
New central air	any	60	300	600	1200
Window unit	any	150	750	1500	3000
Furnace fan	any	500	2500	5000	10000

3. Price Differential Sensitivity

The measurement that results from this survey is the price differential at which consumers are willing to delay their consumption in order to switch from peak power to off-peak power. The respondents to the survey are currently paying the same price for peak and off-peak power, and their answers can be interpreted as a measure of their change in desire to consume peak-power in response to a drop in the price of off-peak power. Because peak power and off-peak power are substitutes, these values should be positive, indicating that the cheaper off-peak power becomes, the more customers will want to substitute off-peak power for peak power.

3.1 Price Differential Sensitivity for Each Appliance

For each appliance included in the survey, we can measure the price differential of peak power and off-peak power that will incentivize consumers to switch. Intuitively, we should expect these to be different across appliances, for example, people are likely to be more willing to delay doing laundry than microwaving lunch. To calculate these differentials, we graphed the number of respondents that would not shift their load as a function of the off-peak price of power. Using regression analysis we calculated the change in the number of respondents relative to the change in price. Multiplying this value by the current price divided by the total number of respondents results in the percentage of peak load that would shift relative to a percentage change in price differential for a given appliance. Figure 3 shows the comparison between appliances.

3.2 Appliance Load and Total Price Differential Sensitivity

Table 4 shows the load for each appliance as a percentage of the total US residential load [4, 5], as well as the ratio of load shift to price differential for each appliance. The total price differential sensitivity for all appliances was calculated as a weighted average of the load and price differential sensitivity for individual appliances. Refrigerators are included in the total load, although we did not survey for refrigerator data. We assume no price differential sensitivity for refrigerators, as consumers would be unlikely to turn off their refrigerators during peak hours. However, including refrigerators explains approximately 55% of the total United States residential load,

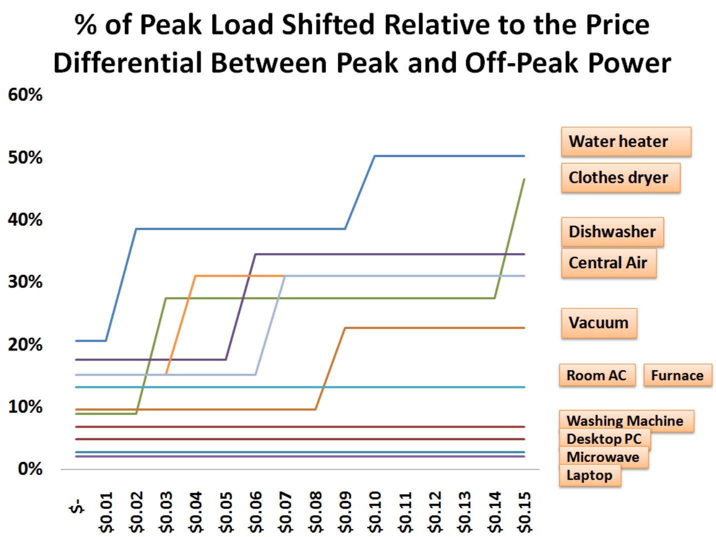

Figure 3: Appliance elasticity comparison

Table 4: Appliance load percentages and cross elasticity [4, 5]

Appliance	Price Differential Sensitivity	% of Load
Water Heater (40 gallon)	0.14	9.1%
Clothes Dryer	0.12	5.8%
Old Central Air (2500 sq. ft.)	0.10	7.1%
Dishwasher	0.06	2.5%
New Central Air (2500 sq. ft.)	0.05	7.1%
Vacuum Cleaner	0.04	0.3%
Room AC (12,000 BTU)	0.02	1.9%
Clothes Washer	0.01	0.9%
Furnace Fan	0.01	3.3%
Computer - CPU & Monitor	0.00	1.5%
Laptop	0.00	0.1%
Microwave	0.00	1.7%
Refrigerator*	0.00	13.7%
Total	**0.059**	**55.1%**

rather than just the approximately 45% that is comprised of the surveyed appliances. Understanding these results on a larger scale (considering more than 50% of load) allows a stronger inference with respect to potential effects on total United States residential load.

3.3 Implications on Load

Finally, the total price differential sensitivity value was used to calculate the impact that time-of-usage (TOU) metering could have on the total residential load. This data is summarized in Table 5.

The total price differential sensitivity represents the percentage of peak residential load that would shift to off-peak for each percentage change in price. Assuming current average retail peak and off-peak electricity prices of $0.11 and $0.09 respectively, the price differential is 18.85% [6, 7]. Multiplying this by our total price differential sensitivity value gives us the final result that 1.09% of the total residential load would potentially shift to off-peak times under TOU metering.

Table 5: Effect of cross elasticity

Peak Price	$0.11 / KWh
Off-peak Price TOU	$0.09 / KWh
% Peak / Off-peak Price Differential	18.85%
Total Price Differential Sensitivity	0.059
% of Residential Load Shifted Under TOU	**1.09%**

4. Future Work

Future work should extend the results of the preliminary survey to large random samples of Americans, broken down by demographics, geographical regions, and socioeconomic groups. Examining price sensitivity with respect to DSM and RTP or TOU may be dependent on congestion and grid hubs where LMPs are typically high. Future work should examine for evidence of such a link as well as evidence that consumers even understand the connection between LMPs and energy prices. Based on survey feedback and the preliminary results, it is obvious that more education about DSM and RTP or TOU is needed among consumers. Future research should examine the best way to educate the public and influence them to shift demand as well as marketing strategies for utilities to use for DSM.

Another survey that compares sample electric bills with and without RTP should be executed. Such a survey would present actual monthly bill differences under RTP with and without DSM. Survey respondents could then express their preferences to various scenarios and sample bills. Furthermore, questions regarding both the time of day appliances are currently used now and customer demographics should be included if the existing survey is utilized on a larger scale.

5. Summary

Overall, this preliminary research shows that residential customers are not very willing, under their current understanding of energy prices, to shift demand to off-peak hours. This sentiment may be moderated by the fact that current energy prices are constant over time of day and year. As a result, customers may not fully understand the implications of shifting demand. However, the survey results depict residential unwillingness to modify daily energy usage, unless large savings per cycle are obtained. Such savings may be unrealistic due to the corresponding difference in LMPs between on-peak and off-peak that would be necessary. Future research is needed to examine residential customer willingness on a national scale, broken down by both geography and demographics.

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References

1. Scala, N.M., Henteleff, S., and Rigatti, C., 2009, "Examining DSM Potential in the U.S.: Cross-price Elasticity of Demand for Peak Power Relative to Off-peak Power," University of Pittsburgh Industrial Engineering Technical Report, No. 09-3.
2. City of Roseville, California, "Electric Home Appliance Consumption and Cost," http://www.roseville.ca.us/civica/filebank/blobdload.asp?BlobID=7086
3. United States Department of Energy, 2009, "Estimating Appliance and Home Electronic Energy Use," http://www.energysavers.gov/your_home/appliances/index.cfm/mytopic=10040
4. United States Department of Energy, 2009, "End-use Consumption of Electricity 2001," http://www.eia.doe.gov/emeu/recs/recs2001/enduse2001/enduse2001.html
5. Geographic Research, Inc., 2008, "Census 2000*,"* from SimplyMap database.
6. United States Energy Information Administration, 2009, "Average Retail Price of Electricity to Ultimate Customers by End-use Sector, By State," http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html
7. Spees, K., 2008, "Meeting Electric Peak on the Demand Side: Wholesale and Retail Market Impacts of Real-time Pricing and Peak Load Management Policy*,*" PhD dissertation, Carnegie Mellon University.