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Behavior, Energy & Climate Change Conference
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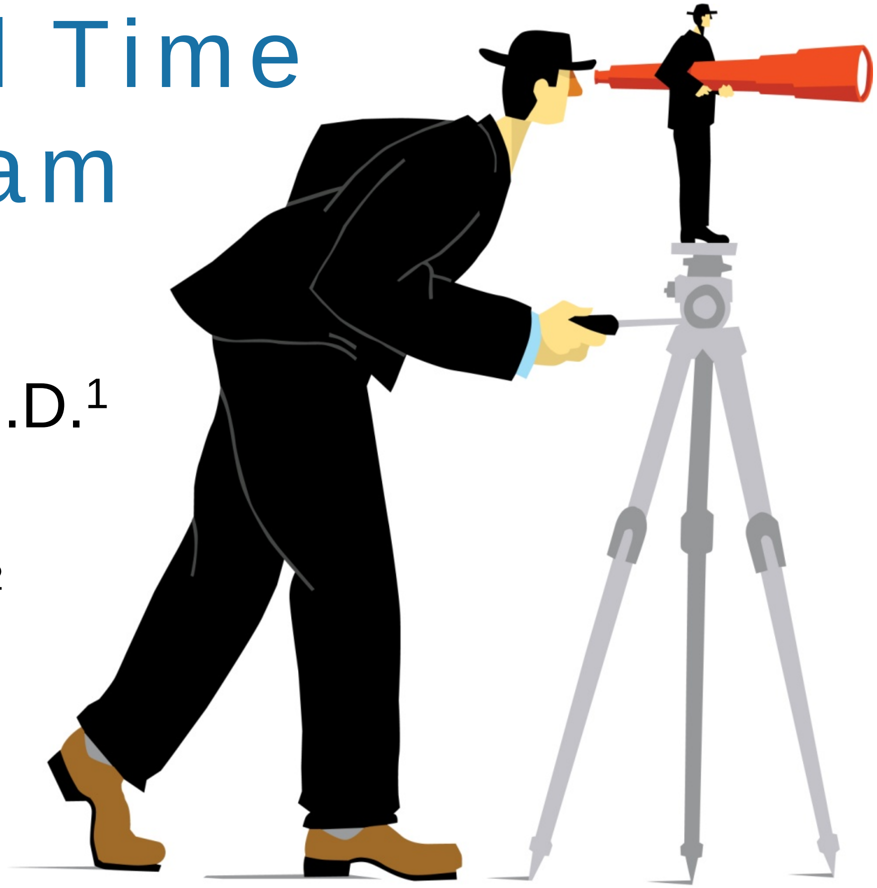
Residential Energy Demand in a Real Time Pricing Program



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Hypothesis

- The price elasticity of demand for residential consumers of electricity varies by time of day.
- Rationale:
  - Household occupancy and consumer behavior differs greatly throughout the day.
  - End uses of electricity vary throughout the day (AC, lights).
  - Willingness to pay (WTP) for a given amount of electricity will vary throughout the day, e.g., WTP for AC is higher in the afternoon.
  - Implies different demand curves are appropriate as the value of electricity use varies over different time periods.
- Other studies model electricity as a single good.

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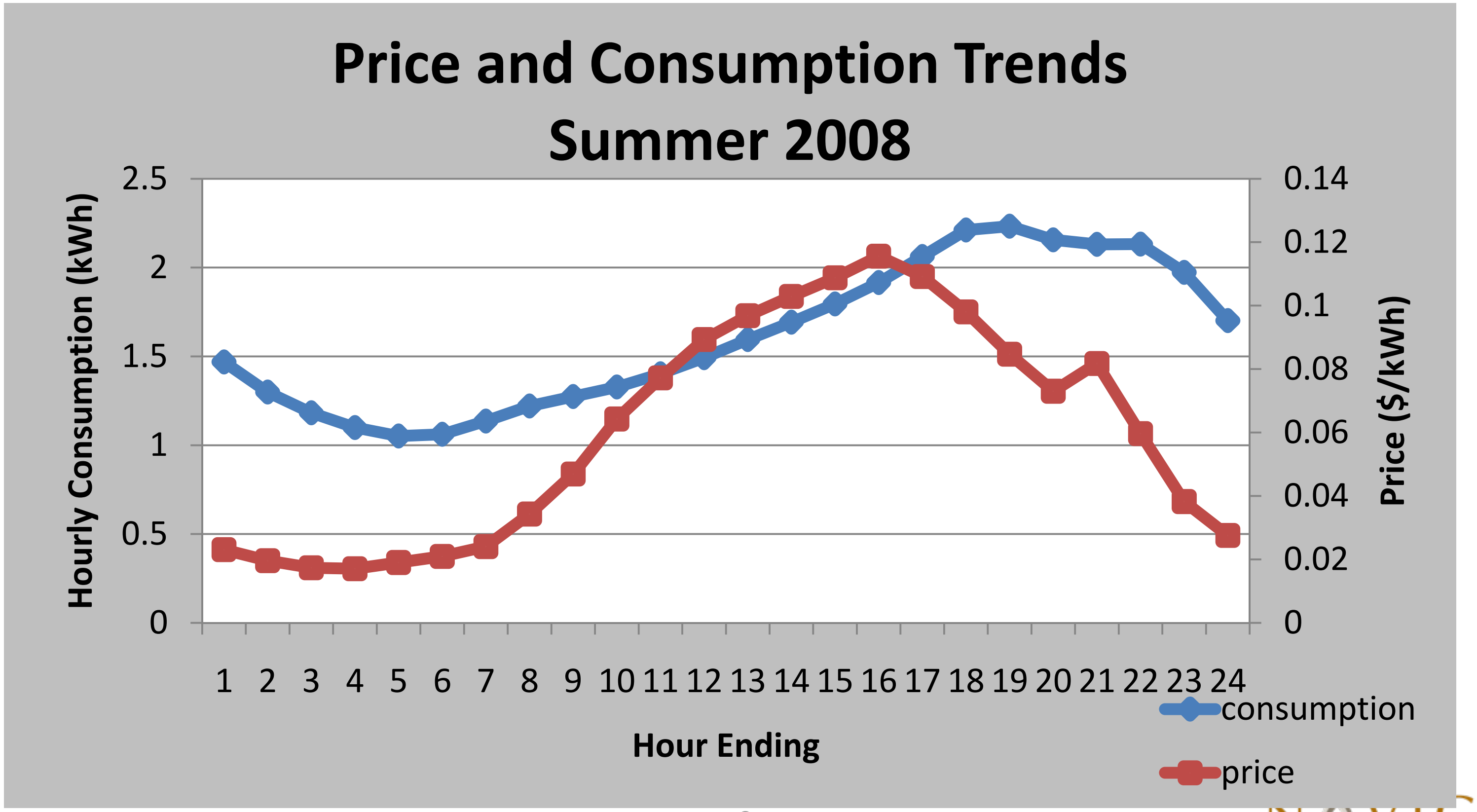
Why is this Important?

- Increased consumption occurs during periods with higher prices.
- This may bias estimates of price elasticity downward by not accounting for the change in WTP for electricity – the commodity has different properties.



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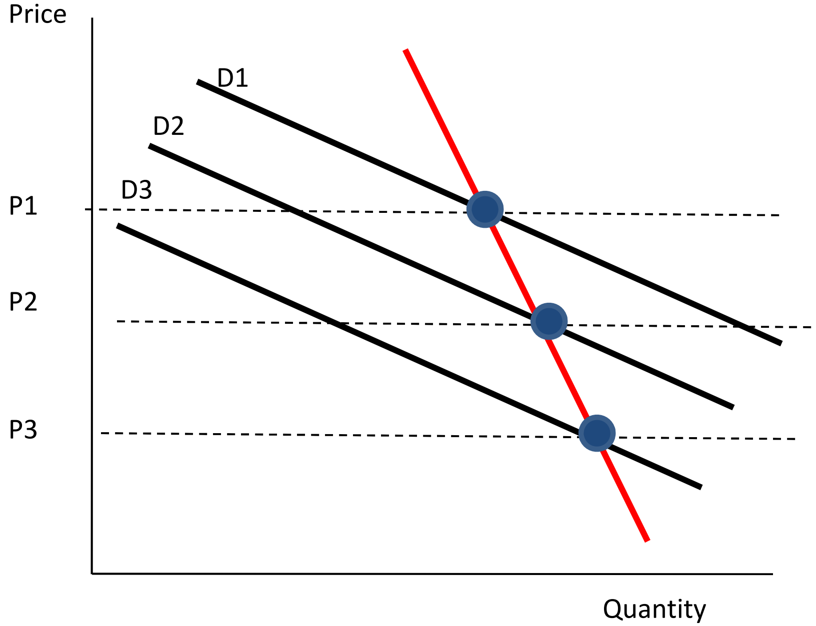
Consequences:

- The current industry approach generally uses single demand equation estimation approach
- Consequence -- Estimates of price elasticity may be low due to shifts in the demand curve reflecting electricity as a different good at different times of the day.



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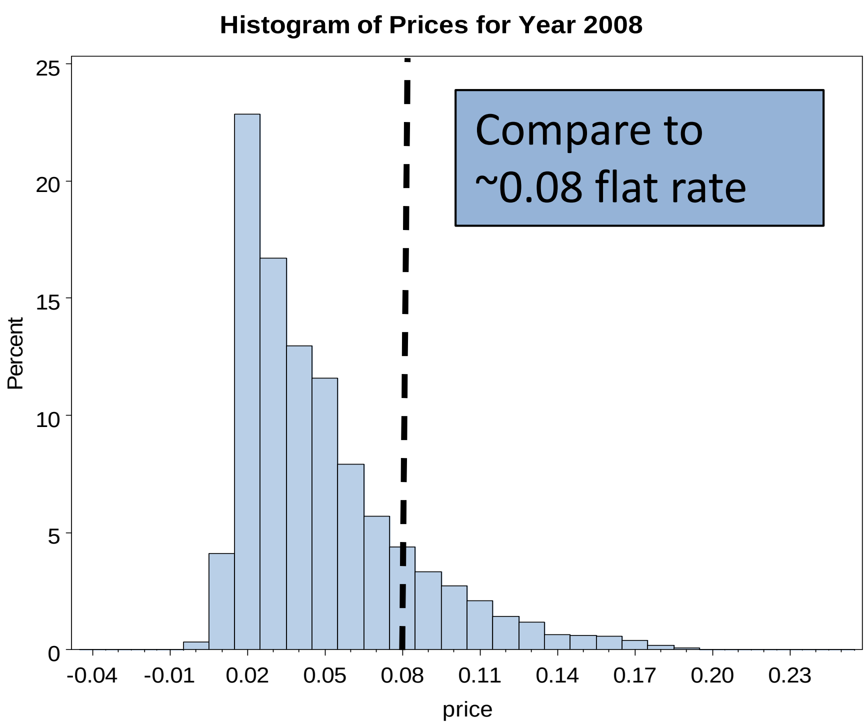
Selected Background Literature and Results

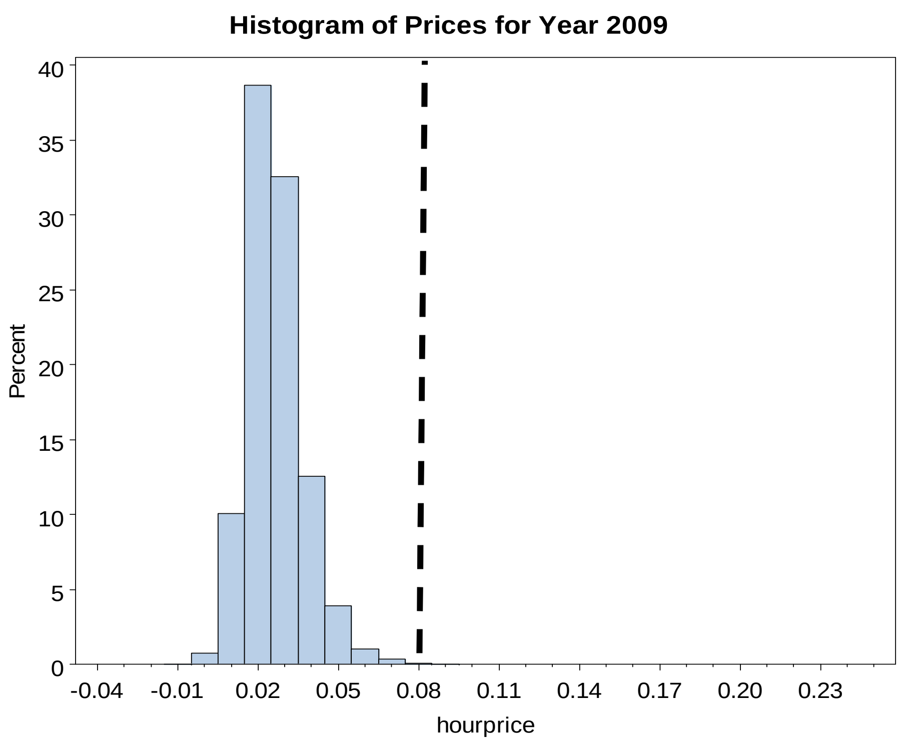
- **Henley & Peirson (1998) – Standard Approach**
  - » Residential TOU
  - » Translog, Fixed Effects model (peak & off peak)
    - lagged consumption, binary temperature variable, price, price squared, price * temp interactions, weekend, holiday
  - » Estimated own-price elasticities: -0.102 to -0.249
- **Filippini (1995) & Matsukawa (2001) – Demand Systems Approach**
  - » Residential TOU
  - » Almost Ideal Demand System (AIDS)
  - » Filippini's estimated own-price elasticities: -1.25 to -2.30
  - » Matsukawa's estimated own-price elasticities: -0.510 to -0.777

Application of a Demand Systems Approach

- Ameren pilot program on RTP
  - "Power Smart Pricing"
  - Illinois legislature and Illinois Commerce Commission ruling
  - One of the first large scale residential RTP programs
- Voluntary program (additional monthly fee = $2.25)
  - Self-selection bias?
- Panel Data
  - Began in 2007 (~3000 households); 2010 (~10,000 households)
  - Hourly price (*day ahead*) and consumption data
  - Weather data
  - Survey data for some households

Prices





- Year 2008
- Medium-Hot summer

- Year 2009
- Mild summer

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Model Approach

- Linear Approximate AIDS (LA-AIDS) with 24 equations
  - Linear approximation of the nonlinear price index is a standard approach to simplify the model
- Household fixed effects model
- Cooling degree hours (CDH)
- Binary variables for holidays and weekends

Details of the AIDS model

- The dependent variable is the share of daily electricity expenditures spent on electricity in hour i.

$$w_i = \frac{q_i * p_i}{\sum_j q_j * p_j} = \alpha_i + \sum_j \delta_{ji} CDH_j + \lambda\, WEEKEND + \theta\, HOLIDAY + \sum_j \gamma_{ji} \log(p_j) + \beta_i \log\left(\frac{x}{P}\right) + \epsilon_i$$

$$\log(P) \cong \sum_k w_k * \ln(p_k)$$

- w indexes share, q indexes consumption (kWh), p indexes price ($/kWh), CDH indexes cooling degree hours, and WEEKEND and HOLIDAY are binary variables

- Alpha is replaced with a fixed effects constant for each household

- Beta, alpha, beta, gamma, delta, lambda, theta are parameters to be estimated

- Elasticity of demand for electricity in hour i with respect to the price of electricity at hour j:

$$\eta_{ij} = -\Delta_{ij} + \frac{\gamma_{ij} - \beta_i w_j}{w_i}$$

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Preliminary Results: Own Price Elasticities

- All own-price elasticities are statistically significant, except the hours of 11am, 10pm, 11pm, and midnight.

Summer 2008 data; short run elasticities;
Fixed Effects with CDH and binary variables
for holidays and weekends

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Preliminary Results: LA-AIDS Elasticities

Marshallian Elasticities @ point of means																								
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1	-0.012	-0.017	0.012	-0.027	0.007	0.045	-0.041	-0.043	0.012	-0.039	-0.060	-0.051	-0.096	-0.060	-0.087	0.023	0.004	0.020	0.062	-0.126	-0.077	-0.063	-0.045	-0.024
2	-0.023	-0.079	-0.093	0.034	0.010	0.085	-0.035	-0.022	0.011	-0.028	-0.067	-0.033	-0.041	-0.140	-0.006	-0.095	0.012	0.030	0.020	-0.082	-0.167	0.016	-0.009	0.011
3	0.020	-0.115	-0.271	0.065	0.062	0.046	0.012	0.014	0.012	0.021	-0.095	-0.038	-0.094	0.058	-0.078	-0.104	-0.016	0.018	0.034	-0.127	-0.063	-0.046	0.006	0.028
4	-0.047	0.047	0.071	-0.383	0.077	0.036	-0.009	0.011	0.017	-0.051	0.064	-0.034	-0.070	-0.075	-0.026	-0.115	-0.068	0.068	-0.021	-0.148	0.051	-0.038	0.004	0.027
5	0.014	0.014	0.064	0.072	-0.333	0.008	0.099	-0.002	-0.009	-0.080	0.059	-0.015	-0.116	0.054	-0.101	-0.017	-0.092	-0.097	-0.005	-0.087	0.010	0.016	-0.024	0.008
6	0.068	0.096	0.043	0.030	0.007	-0.488	0.094	0.091	-0.098	0.070	-0.074	-0.046	0.069	-0.147	0.041	0.094	-0.163	-0.160	-0.248	0.181	-0.017	-0.034	0.070	-0.041
7	-0.048	-0.031	0.009	-0.006	0.072	0.077	-0.117	-0.006	0.074	-0.113	0.039	0.000	-0.014	0.089	-0.087	-0.101	-0.129	-0.201	0.088	-0.058	-0.109	0.052	-0.034	-0.035
8	-0.036	-0.014	0.007	0.004	-0.002	0.049	-0.005	-0.072	-0.026	0.020	-0.104	0.002	0.023	0.079	-0.036	-0.162	-0.109	-0.058	-0.090	-0.012	-0.004	-0.073	-0.020	-0.055
9	0.005	0.004	0.003	0.004	-0.006	-0.044	0.035	-0.022	-0.095	-0.134	0.040	0.030	0.013	-0.054	0.035	-0.083	-0.117	-0.146	-0.106	-0.022	-0.003	-0.071	-0.066	-0.020
10	-0.021	-0.012	0.003	-0.015	-0.025	0.018	-0.047	0.007	-0.100	-0.048	-0.051	0.042	-0.013	0.005	-0.110	-0.041	-0.092	-0.116	-0.096	-0.022	-0.049	-0.092	-0.031	0.004
11	-0.027	-0.022	-0.025	0.010	0.009	-0.023	0.007	-0.052	0.020	-0.044	-0.038	-0.074	-0.005	-0.065	-0.019	-0.044	-0.089	-0.098	-0.083	-0.092	-0.102	-0.057	-0.058	-0.002
12	-0.021	-0.012	-0.011	-0.010	-0.007	-0.015	-0.006	-0.006	0.010	0.025	-0.064	-0.061	-0.056	-0.099	-0.043	-0.053	-0.065	-0.106	-0.100	-0.126	-0.070	-0.035	-0.053	-0.040
13	-0.032	-0.013	-0.020	-0.015	-0.024	0.008	-0.009	0.001	0.000	-0.013	-0.007	-0.051	-0.129	-0.070	-0.083	-0.128	-0.010	-0.029	-0.108	-0.089	-0.103	-0.080	0.012	-0.058
14	-0.021	-0.031	0.005	-0.014	0.003	-0.030	0.012	0.016	-0.028	-0.003	-0.048	-0.081	-0.065	-0.061	-0.132	-0.058	-0.099	-0.061	-0.067	-0.085	-0.105	-0.049	-0.037	-0.043
15	-0.026	-0.006	-0.015	-0.008	-0.019	0.000	-0.023	-0.018	0.005	-0.061	-0.017	-0.035	-0.070	-0.120	-0.123	-0.118	-0.067	-0.056	-0.071	-0.075	-0.097	-0.026	-0.045	-0.018
16	-0.002	-0.019	-0.017	-0.017	-0.007	0.007	-0.023	-0.047	-0.034	-0.025	-0.029	-0.038	-0.095	-0.048	-0.104	-0.161	-0.096	-0.094	-0.015	-0.056	-0.072	-0.075	-0.049	0.005
17	-0.006	-0.003	-0.006	-0.012	-0.016	-0.027	-0.027	-0.033	-0.044	-0.046	-0.051	-0.044	-0.011	-0.078	-0.058	-0.094	-0.167	-0.099	-0.096	-0.036	-0.024	-0.104	-0.021	-0.013
18	-0.003	-0.001	-0.002	0.003	-0.017	-0.027	-0.039	-0.021	-0.053	-0.056	-0.056	-0.070	-0.024	-0.049	-0.048	-0.092	-0.100	-0.173	-0.112	-0.006	-0.086	-0.030	-0.030	-0.014
19	0.007	-0.001	0.000	-0.007	-0.006	-0.043	0.010	-0.032	-0.045	-0.053	-0.054	-0.074	-0.089	-0.060	-0.069	-0.015	-0.110	-0.126	-0.040	-0.088	-0.108	-0.042	-0.015	-0.029
20	-0.039	-0.020	-0.024	-0.025	-0.018	0.026	-0.018	-0.011	-0.016	-0.018	-0.067	-0.106	-0.084	-0.088	-0.084	-0.070	-0.045	-0.005	-0.101	-0.070	-0.047	-0.070	-0.039	-0.020
21	-0.023	-0.033	-0.012	0.003	-0.003	-0.007	-0.026	-0.007	-0.006	-0.028	-0.064	-0.050	-0.083	-0.092	-0.092	-0.075	-0.020	-0.093	-0.105	-0.038	-0.061	-0.018	-0.034	-0.040
22	-0.024	0.001	-0.012	-0.010	-0.001	-0.011	0.008	-0.032	-0.038	-0.064	-0.046	-0.031	-0.084	-0.053	-0.025	-0.105	-0.154	-0.036	-0.049	-0.076	-0.021	-0.028	-0.055	-0.015
23	-0.026	-0.006	-0.001	-0.001	-0.010	0.020	-0.018	-0.016	-0.055	-0.034	-0.075	-0.078	0.030	-0.062	-0.087	-0.107	-0.038	-0.060	-0.021	-0.065	-0.068	-0.086	-0.005	-0.032
24	-0.020	0.006	0.012	0.010	0.002	-0.023	-0.024	-0.052	-0.024	0.012	0.005	-0.086	-0.147	-0.113	-0.039	0.048	-0.021	-0.026	-0.077	-0.042	-0.116	-0.026	-0.044	0.022

Summer 2008 data; short run elasticities;
Fixed Effects with CDH and binary variables
for holidays and weekends

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Combining Hours into Periods

- Given the large number of parameters in the AIDS with 24 equations, grouping hours into blocks can improve estimates.
- Reasons to combine:
  - » Behaviorally: groups of hours as a homogeneous good?
  - » Econometrically: small price variation
    - High price correlation between hours, especially in the afternoon

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Price Correlation Matrix

hour	12	13	14	15	16	17
12	1	0.96	0.93	0.91	0.91	0.86
13	0.96	1	0.94	0.93	0.92	0.86
14	0.93	0.94	1	0.97	0.96	0.86
15	0.91	0.93	0.97	1	0.97	0.88
16	0.91	0.92	0.96	0.97	1	0.9
17	0.86	0.86	0.86	0.88	0.9	1

hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	0.84	0.87	0.83	0.8	0.64	0.57	0.63	0.64	0.58	0.52	0.43	0.37	0.31										
2	0.84	1	0.85	0.83	0.78	0.61	0.56	0.59	0.58	0.51	0.42	0.33	0.27	0.21										
3	0.87	0.85	1	0.87	0.82	0.68	0.63	0.63	0.61	0.52	0.42	0.3	0.23	0.16										
4	0.83	0.83	0.87	1	0.91	0.77	0.69	0.7	0.64	0.54	0.42	0.3	0.24	0.17										
5	0.8	0.78	0.82	0.91	1	0.85	0.76	0.77	0.71	0.6	0.47	0.35	0.3	0.22										
6	0.64	0.61	0.68	0.77	0.85	1	0.85	0.81	0.69	0.55	0.43	0.29	0.24	0.16										
7	0.57	0.56	0.63	0.69	0.76	0.85	1	0.87	0.75	0.58	0.43	0.3	0.23	0.13										
8	0.63	0.59	0.63	0.7	0.77	0.81	0.87	1	0.86	0.73	0.62	0.48	0.41	0.32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	0.64	0.58	0.61	0.64	0.71	0.69	0.75	0.86	1	0.85	0.77	0.68	0.6	0.52	0.45	0.46	0.52	0.64	0.68	0.72	0.66	0.65	0.71	0.65
10	0.58	0.51	0.52	0.54	0.6	0.55	0.58	0.73	0.85	1	0.87	0.81	0.76	0.7	0.65	0.65	0.68	0.72	0.73	0.75	0.77	0.73	0.7	0.62
11	0.52	0.42	0.42	0.42	0.47	0.43	0.43	0.62	0.77	0.87	1	0.89	0.86	0.82	0.79	0.78	0.79	0.77	0.78	0.77	0.82	0.8	0.72	0.6
12	0.43	0.33	0.3	0.3	0.35	0.29	0.3	0.48	0.68	0.81	0.89	1	0.96	0.93	0.91	0.91	0.86	0.81	0.81	0.8	0.86	0.84	0.69	0.57
13	0.37	0.27	0.23	0.24	0.3	0.24	0.23	0.41	0.6	0.76	0.86	0.96	1	0.94	0.93	0.92	0.86	0.77	0.76	0.76	0.84	0.8	0.64	0.52
14	0.31	0.21	0.16	0.17	0.22	0.16	0.13	0.32	0.52	0.7	0.82	0.93	0.94	1	0.97	0.96	0.86	0.77	0.75	0.75	0.83	0.8	0.61	0.48
15	0.28	0.17	0.13	0.12	0.16	0.08	0.05	0.25	0.45	0.65	0.79	0.91	0.93	0.97	1	0.97	0.88	0.76	0.74	0.71	0.8	0.78	0.58	0.44
16	0.31	0.19	0.15	0.14	0.18	0.09	0.06	0.25	0.46	0.65	0.78	0.91	0.92	0.96	0.97	1	0.9	0.79	0.75	0.73	0.81	0.8	0.61	0.48
17	0.42	0.31	0.29	0.28	0.3	0.21	0.18	0.35	0.52	0.68	0.79	0.86	0.86	0.86	0.88	0.9	1	0.9	0.82	0.77	0.82	0.84	0.66	0.57
18	0.57	0.46	0.47	0.45	0.44	0.35	0.36	0.49	0.64	0.72	0.77	0.81	0.77	0.77	0.76	0.79	0.9	1	0.9	0.81	0.81	0.85	0.75	0.7
19	0.57	0.5	0.49	0.5	0.48	0.4	0.42	0.55	0.68	0.73	0.78	0.81	0.76	0.75	0.74	0.75	0.82	0.9	1	0.85	0.81	0.85	0.76	0.74
20	0.58	0.49	0.48	0.49	0.51	0.46	0.45	0.58	0.72	0.75	0.77	0.8	0.76	0.75	0.71	0.73	0.77	0.81	0.85	1	0.86	0.83	0.76	0.69
21	0.5	0.4	0.37	0.39	0.42	0.34	0.35	0.5	0.66	0.77	0.82	0.86	0.84	0.83	0.8	0.81	0.82	0.81	0.81	0.86	1	0.88	0.78	0.65
22	0.56	0.46	0.42	0.41	0.42	0.32	0.32	0.47	0.65	0.73	0.8	0.84	0.8	0.8	0.78	0.8	0.84	0.85	0.85	0.83	0.88	1	0.84	0.71
23	0.69	0.57	0.59	0.55	0.54	0.46	0.46	0.57	0.71	0.7	0.72	0.69	0.64	0.61	0.58	0.61	0.66	0.75	0.76	0.76	0.78	0.84	1	0.83
24	0.73	0.65	0.67	0.67	0.63	0.54	0.51	0.6	0.65	0.62	0.6	0.57	0.52	0.48	0.44	0.48	0.57	0.7	0.74	0.69	0.65	0.71	0.83	1

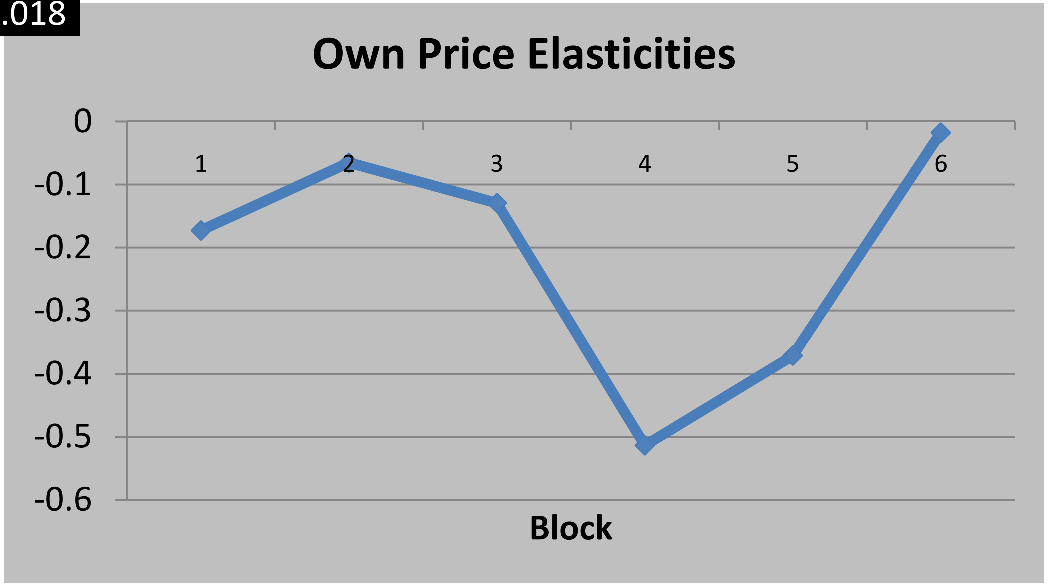
Preliminary Results: LA-AIDS Elasticities

Elasticities @ point of means

Block	1	2	3	4	5	6
1	-0.173	-0.131	-0.061	-0.246	-0.098	0.051
2	-0.108	-0.065	0.133	-0.369	-0.219	-0.057
3	-0.060	0.101	-0.129	-0.359	-0.405	-0.083
4	-0.057	-0.089	-0.079	-0.514	-0.319	-0.027
5	-0.038	-0.070	-0.102	-0.375	-0.371	-0.099
6	0.044	-0.086	-0.116	-0.112	-0.565	-0.018

Summer 2008 data; short run elasticities; Fixed Effects with CDH and binary variables for holidays and weekends

Block 1: midnight – 5am
Block 2: 5am – 9am
Block 3: 9am – 11am
Block 4: 11am – 5pm
Block 5: 5pm – 10pm
Block 6: 10pm-midnight



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Ongoing work with Ameren Project

- Investigating the block boundaries
  - » Test parameters from the hourly system. If no difference, then combine hours.
  - » Likely to have between 6 and 10 blocks.
- Examination of heterogeneity in customer responsiveness.
  - » How do customers respond to price changes , i.e., what actions are taken?
    - Frequent price checking and fiddling with appliances?
    - Rules of thumb? (i.e.: thermostat settings)
    - No response?
  - » How to identify responsive vs. unresponsive customers?
    - Use of billing data?
      - – compare bills and usage before and after joining program

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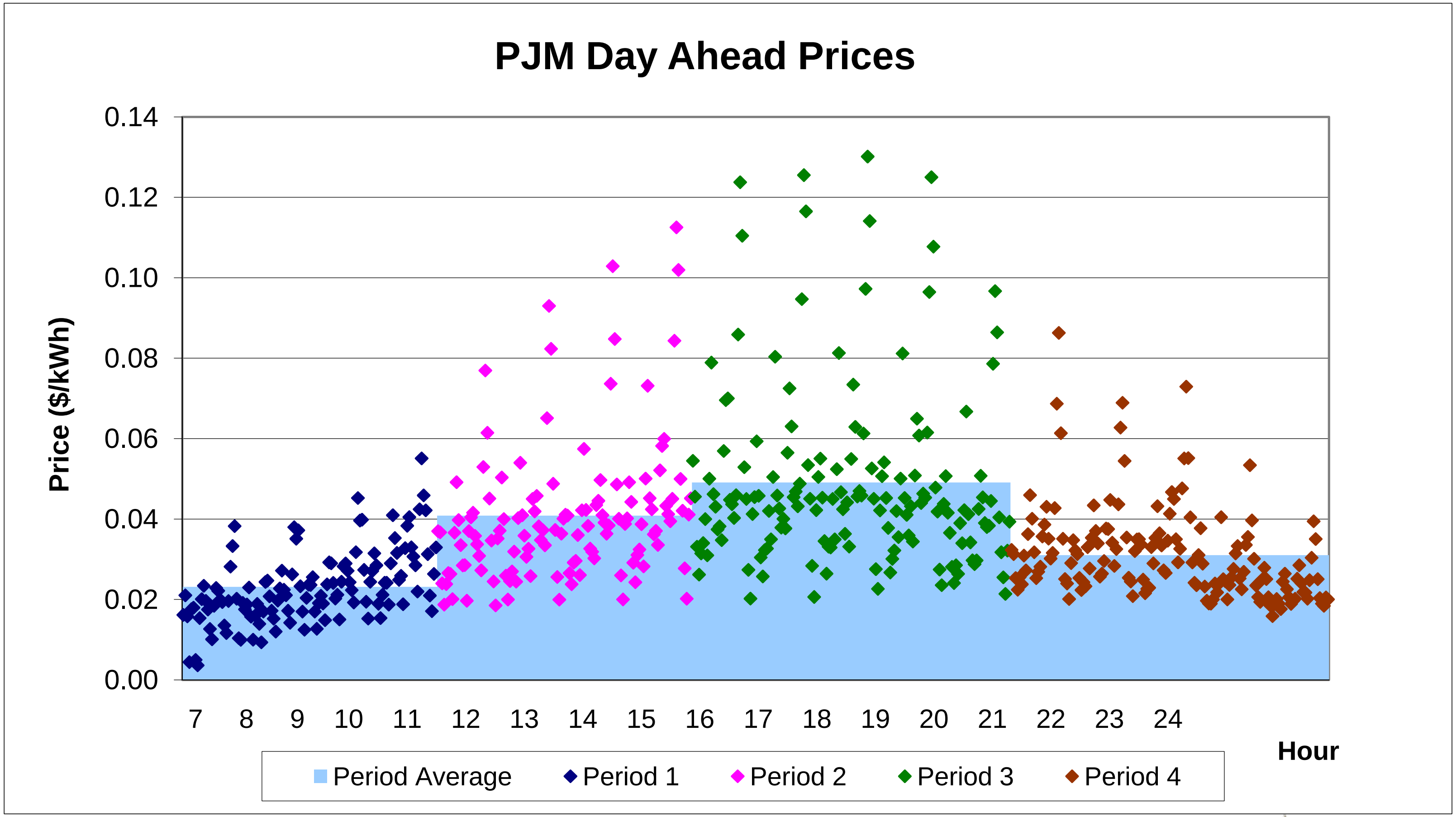
Efficient Pricing -- Comparing TOU with RTP

- Four TOU daytime periods are compared to RTP. TOU leaves quite a bit of potential price response unaccounted for, and CPP or PTR may not make this up.



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Changes in Risk Profiles (Shows Value of RTP)

- The addition of DR changed the risk profile associated with the planning scenarios.
- Results for three DR scenarios are shown below for value at risk (VAR) at 90th percentile (VAR90) and 95th percentile (VAR95).

BEFORE RIGHT SIZING the DR component:

Risk Metrics – Reduction in Net System Costs at Risk ($M)		
	VAR 90	VAR 95
Callable DRR	238	213
Callable DRR with Critical Peak Pricing	924	966
Callable DRR with Real Time Pricing	2,673	2,766

AFTER RIGHT SIZING the DR Component (not in January 2006 IEA report):

Risk Metrics – Reduction in Net System Costs at Risk ($M)		
	VAR 90	VAR 95
Callable DRR	1,071	1,096
Callable DRR with Critical Peak Pricing	1,786	1,828
Callable DRR with Real Time Pricing	3,535	3,628

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Key points

- Using a system of equations to model demand for electricity is the correct approach.
- Single demand curve approaches my under estimate the price responsiveness of demand.
- RTP pricing may be more efficient as it can capture price responsiveness across a wider number of hours.
- Using the demand-side to respond to price due to higher production costs can reduce overall system costs.
- Allowing BOTH demand and supply to respond and work together to reach a market equilibrium is an important industry goal.
- Enhancing the ability of demand to respond to price will lower overall system costs and risks during periods of high prices.

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