Rational habits in residential electricity demand?

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The electricity consumption decision
Are households forward looking?

- Do households consider the future when deciding how much electricity to consume?
- If YES, what are the policy implications?

Example CO$_2$ tax:

- What is the impact of a CO$_2$ tax on energy consumption?
- Direct impact of the tax on today’s consumption
- Impact on today’s consumption through reaction to future tax
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Electricity prices, weather, household income etc.

- These are all in the present. Past? Future?

Past consumption matters

- Appliance stock cannot be replaced immediately
- It takes time to change behavioral patterns

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- Rational agents have expectations of the future
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Overview

What is this paper about?
- Estimating aggregated residential electricity demand in the US
- Panel data set of 48 states and 17 years

What is new?
- Combine rational habits and the partial dynamic adjustment model
- Allow for forward looking agents

How is that relevant?
- Better understand underlying factors of residential electricity demand
- Formulate better policies aiming at, e.g. saving energy
- Calculate more precise price elasticities
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A quick overview of the literature (aggregate data, no info on capital stock)

Static model of electricity demand
Azevedo et al. (2011); Cebula et al. (2012); Eskeland and Mideska (2010)

Dynamic partial adjustment model:
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The rational habits model for electricity demand

Households maximize utility from energy services:

- E.g. Light, hot water, cooling, entertainment
- Energy services are produced from electricity and el. appliances

Household utility at time $t$:

$$U_t = u(e_t, e_{t-1}, c_t; x_t)$$

where $e_t$ is current electricity consumption, $e_{t-1}$ is past electricity consumption, $c_t$ all other consumption goods, and $x_t$ environmental factors.

Lifetime utility function of the household:

$$\sum_{t=1}^{\infty} \delta^{t-2} U_t = \sum_{t=1}^{\infty} \delta^{t-1} u(e_t, e_{t-1}, c_t; x_t)$$

where $\delta = (1 + r)^{-1}$ is the constant rate of time preference and $r$ is the interest rate.
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Today’s consumption as function of past and future consumption

We get the following maximization problem assuming the appliance/habits stock fully depreciates after one period:

$$\sum_{t=1}^{\infty} \delta^{t-1} u(e_t, e_{t-1}, c_t; x_t)$$

s.t.

- $e_0 = E_0$
- $\sum_{t=1}^{\infty} \delta^{t-1}(c_t + P_t e_t) = W^0$

Solution of the FOC leads to the first-difference equation:

$$e_t = \theta e_{t-1} + \delta \theta e_{t+1} + \theta_1 P_t + \theta_2 x_t + \delta \theta_3 x_{t+1}$$
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Empirical model

We modify the first-difference equation to obtain:

\[ e_{it} = \beta_0 + \beta_1 e_{it-1} + \beta_2 e_{t+1} + \beta_3 P_{it} + \beta_4 PG_{it} + \beta_5 Y_{it} \]

\[ + \beta_6 HDD_{it} + \beta_7 CDD_{it} + \beta_8 HS_{it} + \nu_{it} \]

\( e_{it} \): consumption today  
\( P_{it} \): price of electricity  
\( PG_{it} \): price of gas  
\( Y_{it} \): income  
\( HDD_{it}, CDD_{it} \): heating and cooling degree days  
\( HS_{it} \): numbers of detached houses
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Econometric issues

Three potential econometric issues to deal with:
- Heterogeneity bias due to low number of regressors
- Endogeneity of past and future consumption
- Measurement error in the price of electricity

Properties of the dataset:
- Relatively long time dimension (T=17)
- Small number of units (N=48)
- Properties of panel data estimators like GMM hold especially for N large
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Following Becker et al. (1994) and Baltagi et al. (2002), we use the following instruments for the lag and lead of consumption as well as the price of electricity:

- Input prices of coal and gas for the electricity sector
- Two-period lags and leads of the price of electricity
- One-period lag and lead of heating degree days
## Estimation results 2SLSFE specification

<table>
<thead>
<tr>
<th>Instrumented:</th>
<th>$e_{t-1}$, $e_{t+1}$</th>
<th>$e_{t-1}$, $e_{t+1}$, $P_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>$e_{t-1}$</td>
<td>0.432*** (4.90)</td>
<td>0.422*** (4.70)</td>
</tr>
<tr>
<td>$e_{t+1}$</td>
<td>0.221** (2.85)</td>
<td>0.206** (2.80)</td>
</tr>
<tr>
<td>$P_t$</td>
<td>-6787.8*** (-4.19)</td>
<td>-8196.7** (-2.60)</td>
</tr>
<tr>
<td>$PG_t$</td>
<td>-1243.3 (-0.12)</td>
<td>-121.5 (-0.01)</td>
</tr>
<tr>
<td>$Y_t$</td>
<td>0.0309** (2.87)</td>
<td>0.0325** (3.02)</td>
</tr>
<tr>
<td>$HS_t$</td>
<td>-562.0** (-3.11)</td>
<td>-588.6** (-3.29)</td>
</tr>
<tr>
<td>$HDD_t$</td>
<td>0.185*** (10.16)</td>
<td>0.182*** (9.21)</td>
</tr>
<tr>
<td>$CDD_t$</td>
<td>0.641*** (16.84)</td>
<td>0.635*** (16.76)</td>
</tr>
<tr>
<td>$N$</td>
<td>611</td>
<td>611</td>
</tr>
</tbody>
</table>

| Underidentification test | 41.495 [0.0000] | 42.007 [0.0000] |
| Weak identification test | 7.096           | 6.164            |
| 5% critical value        | 3.78            | NA               |
| Hansen J statistic       | 9.848 [0.1312]  | 10.210 [0.1161]  |
Short and long run elasticities

All elasticities are negative and shown in absolute values.

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<th>Long run</th>
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Short run: residential electricity demand inelastic
Immediate adjustment appliances stock and behavioural habits is costly

Long run: residential electricity demand more elastic
Agents have more time to adapt habits and replace equipment
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Conclusions

Understanding demand:
- Knowing the factors influencing demand is crucial for policy makers
- Especially true for policies targeting energy savings
- DPA models may lead to biased estimates of policy impact

Future consumption impacts current consumption:
- We found evidence for forward looking behavior
- Effects of long-term policies today may depend on anticipated effect on future consumption
- Effect reinforced by anticipating the effect on future consumption
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<td>0.476*** (14.97)</td>
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<td>$e_{t+1}$</td>
<td>0.309*** (10.84)</td>
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<td>$P_t$</td>
<td>-5602.4*** (-3.80)</td>
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<td>$PG_t$</td>
<td>-10921.8 (-1.08)</td>
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<td>$Y_t$</td>
<td>0.0114 (1.36)</td>
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<td>$HS_t$</td>
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<td>$HDD_t$</td>
<td>0.181*** (9.72)</td>
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<td>$CDD_t$</td>
<td>0.724*** (14.18)</td>
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<td>Constant</td>
<td>182.5 (0.51)</td>
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$N$ 719
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where \( \rho \) is the depreciation rate of the appliance stock.

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Stock of habits

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- Stock of appliances ↔ Stock of behavioural habits
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