Incorporating Homeowners’ Preferences for Heat Technology Adoption in the UKTM with Heterogeneous Households

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Outline

• Introduction
• Research Procedure
• Discrete Choice Model
• Clustering Analysis
• UKTM
• Residential Heating in UKTM
• New User Defined Constraints
• Preliminary Results
• Conclusions and Future Works
Introduction

- 2008 UK Climate Change Act: 80% reduction by 2050
- Residential heating should be decarbonised dramatically by adopting low-carbon heat technologies
- CCC (2016): 2.3 million heat pumps by 2030; 31 million by 2050
  – Require radical behavioural adjustment
- Homeowners’ preferences of heat technology choice
  – Not yet reflected in energy modelling well!

Source: ECUK, 2016
Research Procedure

- **UK nation wide survey**
- **Choice experiments**
  - K-means algorithm

1. **Identify key factors with DCM**
2. **Group factors with Clustering Analysis**
3. **Create heterogeneous household (HH) types**
4. **Estimate preferences for each HH**
5. **Update structure of residential heat sector in the UKTM**

- **GHG emissions**
- **Heat technology penetrations**
- **Energy consumption**

**UC** for socio-demographic profile in the UK and for heat tech preferences.
Discrete Choice Model (1/2)

• Nationwide survey in 2015
  – 1,007 respondents
  – 721 completed choice experiment
  – 442 homeowners

• Multinomial logit model (MNL)

• Considered factors (wider range)

<table>
<thead>
<tr>
<th>Category</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-demography</td>
<td>Gender, age, household income, education level, work status</td>
</tr>
<tr>
<td>Economy</td>
<td>Upfront cost*, annual cost* (operation &amp; maintenance cost), responsibility of bill payment</td>
</tr>
<tr>
<td>Environment</td>
<td>Carbon emission*</td>
</tr>
<tr>
<td>Technology</td>
<td>Lifetime*, operation hassle*, existing heat technology</td>
</tr>
<tr>
<td>Dwelling</td>
<td>Type, age, bedroom number, family size, region, length of stay</td>
</tr>
<tr>
<td>Eco-knowledge</td>
<td>Awareness of eco-technologies (PV, CFL, electric storage heater, heat pump, wood pellet boiler and etc.)</td>
</tr>
</tbody>
</table>
Discrete Choice Model (2/2)

- Significant factors
  - Region, Dwelling type, Bedroom number, Age, Income, Existing heat tech, Awareness of eco-tech
  - Consistent with previous findings (DECC, 2013)

<table>
<thead>
<tr>
<th></th>
<th>GAS</th>
<th>ELC</th>
<th>HP</th>
<th>SOLID</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing Tech</strong></td>
<td>Gas heater+ Oil boiler+</td>
<td>Elc Storage + Elc other -</td>
<td>Heat pump+ Oil boiler+</td>
<td>Elc other + Open fireplace+</td>
</tr>
<tr>
<td><strong>Cost/Tech Attribute</strong></td>
<td>Upfront Cost(&gt;Gas) - Hassle -</td>
<td>Cost/gas cost -</td>
<td>Upfront cost(&gt;gas) -</td>
<td></td>
</tr>
<tr>
<td><strong>Socio-demographic</strong></td>
<td>Age(&lt;60)+</td>
<td>Age+</td>
<td>Income(&lt;15k)-</td>
<td>Age(35-44)+ Income(&gt;80k)+ Income(30k~80k)+</td>
</tr>
<tr>
<td><strong>Region</strong></td>
<td>East Mid + North East +</td>
<td>London + Scotland +</td>
<td>East Midland+</td>
<td>Scotland+ York&amp;Humber+</td>
</tr>
<tr>
<td><strong>Dwelling</strong></td>
<td></td>
<td>Detached + Semidetached+ Flat -</td>
<td>Bedroom no+</td>
<td>Bedroom no+</td>
</tr>
<tr>
<td><strong>Awareness</strong></td>
<td>Insulation+ CFL – Elc Storage -</td>
<td>Smart meter – Heat pump -</td>
<td>Insulation+ Heat pump+ PV+</td>
<td>PV+ Wood pellet boiler+</td>
</tr>
</tbody>
</table>
Clustering Analysis (1/2)

• Reduce total number of households
  – Easily reach thousands types

• Determine how to group attributes of factors

• Clusters for
  – Existing technology, awareness, region, bedroom number

• K-means++ algorithm
  – partition $n$ observations into $k$ clusters in which each observation belongs to the cluster with the nearest mean
  – **Multiple runs** to find better results

$$\min \sum_{i=1}^{k} \sum_{x \in S_i} \|x - \mu_i\|^2$$
Clustering Analysis (2/2)

Clusters

<table>
<thead>
<tr>
<th>Existing Technology</th>
<th>Awareness</th>
<th>Region</th>
<th>Bedroom no</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Central, Elc Heater, Open fireplace</td>
<td>PV, Heat Pump</td>
<td>London, Scotland</td>
<td>1~3</td>
</tr>
<tr>
<td>Gas heater, Solid boiler, Solid Stove</td>
<td>Wood Pellet Boiler</td>
<td>North East</td>
<td>4</td>
</tr>
<tr>
<td>Oil central, Heat pump</td>
<td>CFL</td>
<td>East Midlands</td>
<td>5</td>
</tr>
<tr>
<td>Elc storage</td>
<td>Other techs</td>
<td>Rest regions</td>
<td></td>
</tr>
<tr>
<td>None</td>
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Existing Technology

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<tr>
<td>Rest regions</td>
<td>0%</td>
<td>0%</td>
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<td>80%</td>
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Bedroom No

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<tbody>
<tr>
<td>1~3</td>
<td>80%</td>
<td>20%</td>
<td>0%</td>
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<td>4</td>
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<td>5</td>
<td>0%</td>
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Heterogeneous Households

Constraints to ensure socio-demographic profile close to real (Surrey + English Housing Surveys)

Preferences (survey data)

Chosen Tech

- Gas Centrail
- Elec Storage
- Heat Pump
- Solid fuel boiler

Households

- CurTech_KHP_Lon_R1
- CurTech_KHP_Lon_R5
- CurTech_KHP_Scot_R1
- CurTech_KHP_Scot_R5
- CurTech_KPV_Lon_R1
- CurTech_KPV_Lon_R5
- CurTech_KPV_Scot_R1
- CurTech_KPV_Scot_R5
- CurTech_Lon_R1
- CurTech_Lon_R5
- CurTech_Scot_R1
- CurTech_Scot_R5
- CurTech_R1
- CurTech_R5

Policy relevant factor

Cost can be attached

Current tech

- Know_HP
- Know_PV

Gas, Elc, Heat Pump, or Solid fuel
UKTM-The UK TIMES Model

- Developed by UCL Energy Institute under wholeSEM project
- Whole Energy System
- Technology-rich
- Minimum cost
- Adopted by UK government for policy making

- Potentials & costs for domestic resources and traded products
- Mainly informed by global model TIAM

- Divided in existing & new houses
- Space heat, hot water, other ser.
- Technology data based on various UK-focused studies

- Generation, storage and trans-mission grid & interconnectors
- Data aligned with DDM

- Divided in low- and high consumption buildings
- Structure similar to residential

- Covers refining, bioenergy processing, landfills, hydrogen production, CCS infrastructure

- 8 subsectors, 4 modelled in a process-oriented manner
- Demand projections aligned with DECC Energy model

- Differentiated in 9 modes
- Demands calibrated to NTM
- Technology data sourced from Dodds and McDowall (2014).

- Differentiated in demand for transport, heat and electricity
- Land use and agricultural emission taken into account
Residential Heating in UKTM

- **UKTM** Includes wide range of heating technology to fulfill *water heating and space heating demands*
- **Heat technology (~100):** gas central heater, electric heater, heat pump, solid fuel heater, micro-CHP, hybrid heater, district heat network
- **Delivery technology:** pipe radiator, underfloor, standalone
New Structure in the UKTM

- **Duplicate** heating technology, district heat and conservation measures for each household type

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**Fuel Supplies**
- Gas
  - Household 1 district heat tech 1
  - Household 1 district heat tech 2
  - Household 2 district heat tech 1
  - Household 2 district heat tech 2

- Electricity
  - GAS_Household 1 GAS Heat tech (gas)
  - ELC_Household 1 GAS Heat tech (elc)
  - HP_Household 1 GAS Heat tech (elc)
  - SOLID_Household 1 GAS Heat tech (gas)

- Solid fuel
  - GAS_Household 1 HP Heat tech (hp)
  - ELC_Household 1 HP Heat tech (hp)
  - HP_Household 1 HP Heat tech (hp)
  - SOLID_Household 1 HP Heat tech (hp)
  - Household 1 converv tech 1
  - Household 1 converv tech 2
  - Household 2 converv tech 1
  - Household 2 converv tech 2

**Space heating demand**
- Radiator-Heat
- Radiator-Water
- Standalone delivery-Heat
- Standalone delivery-Water
- Underground-Heat
- Underground-Water

**Water heating demand**
- Conservation measure

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New Structure in the UKTM
New User Defined Constraints

- **t0**
  - GR1G
  - ER1E
  - HR1H
  - SR1S

- **t1**
  - ER1G
  - GR1G
  - HR1G
  - SR1G

- **t2**
  - GR1E
  - ER1E
  - HR1E
  - SR1E

Heating demand of household R1

UC: total capacity increases
UC: preferences for heat technologies

Reorganise

Time step
Prev tech
Chosen tech
Household type

UC for demographic profile
New User Defined Constraints

- **Demographic profile**
  - Ratio of heating supply for a household type should to total heating supply should equal to the ratio of population of the household type to total population
  \[ R1 \ast = \frac{e}{10} (R1 \ast \ast \ast R2 \ast \ast \ast R3 \ast \ast \ast R4 \ast \ast \ast R5 \ast) \]

- **Increase of heating demand for each household type using a specific heater (UC growth constraint) UC_ACT**
  - Total heating supply for a household type with a switched heating technology from gas boiler in next time-step should larger or equal to heating supply for the household type with gas boiler in previous time-step

- **Preferences for heat tech adoptions (share constraint) (based on statistics of the survey)**
  - Ratio of new capacity of heat pump switched from gas boiler to total new capacity of all types of heaters switched from gas boiler should equal to the household’s preferences for adopting heat pumps
  \[ GR1E_{newcap} = \frac{a}{10} (GR1E + GR1G + GR1H + GR1S)_{newcap} \]

G: gas; E: electric; H: heat pump; S: solid fuel boiler; DH: district heat; CSV: conservation
Update UKTM Structure

- Update UKTM structure by a Ruby program automatically

Considered factors (existing tech, bedroom number)

Create HHs

VT file

SubRES file

Heat techs

Link HHs with heat tech based on fuel type

Survey data file

Create UCs on preferences

Update COM-IN and COM-OUT of HHs

Create Scen file

Update COM-IN of heat techs

Create new VT and SubRES file

Update VT and SubRES files

Put into model directory to update structure

Take existing model files

UKTM

Create HHs

Heat techs
Preliminary Results (1/3)

- **Scenarios**
  - **HH_Pref**: UKTM + heterogeneous households + Preferences + basic tech growth constraints
  - **HH w/o Pref**: UKTM + heterogeneous households + basic tech growth constraints

- **HH_Pref**
  - heat pumps: more in early stage, less in later stage
  - electric heater/biomass: larger in early stage, less in later stage
  - Adopt more conservation measures and district heating

- **HH w/o Pref**
  - Deployment rates are steeper for heat pumps and micro-CHP
Preliminary Results (2/3)

- **Fuel consumption in residential sector**
  - **HH_Pref**
    - More natural gas by 2050
    - Hydrogen kicks in at later stage
    - Use solar/biomass by 2050
  - **HH w/o Pref**
    - Hydrogen kicks in at early stage
    - Electricity consumption is lower at early stage, but becomes higher by 2050
Preliminary Results (3/3)

- Differences of GHGs and Undiscounted total cost between two scenarios
  - HH_Pref emits 11% more GHGs by 2050 (7 millions tons CO2e more from residential sector)
  - HH_Pref costs 76,301 million GBP more
Conclusions and Future Works

• The proposed framework can well represent households’ preferences in TIMES model
• With homeowners’ preferences, the future projection is more realistic
• Future works
  – Scenarios
    • Consider other influential factors, such as awareness of technology and subsidy
  • Sensitivity analysis
    – Investigate how detailed resolution of HHs will influence the outcomes
Thanks for your attention!

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