The Value of TOU Tariffs in Great Britain: Insights for Decision-makers

Volume II: Technical Appendices

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Appendix A:

Interview Summary

Stakeholder Interview Summary

The following is a summary of key insights from stakeholder interviews that were conducted in the context of this study on TOU tariff value.

The Interviews

1. British Gas
2. Comverge (U.S. domestic DSR aggregator)
3. Electricity Northwest
4. First Utility
5. Northern Power Grid
6. Ofgem
7. UK Power Networks
8. Western Power Distribution

The study has also benefitted from informal conversations on the topic with researchers at Oxford's Environmental Change Institute, EnerNOC, and the Association for Decentralised Energy.

Key Stakeholder Viewpoints

There is a perception that consumers highly value simplicity in tariff design. There is a prevailing view among several interviewees that direct exposure to TOU tariffs is too complex for most consumers. However, aggregators value highly granular prices that reflect the full costs of the system. There is a potential role for aggregators to manage consumer loads against this price volatility to provide savings, while helping customers manage that price risk and uncertainty. Some feel that consumers are not concerned about complexity per se but are concerned about risk of bill increase; a tariff design with a perceived no-lose proposition (e.g., CPR) may be more attractive to consumers and cause them to accept additional complexity in tariff design.

There is risk of cost increase if TOU tariff design is not aligned with system costs. There is a view that TOU tariffs which are designed by suppliers purely to increase market share may provide customers with incentives to shift load in ways that would actually increase system costs. This could be due, in part, to insufficient cost-reflectivity in price signals that are faced by suppliers. There is a need to understand what a "good" and "bad" tariff design looks like from a system perspective.

Timing of the system peak period will be an important consideration in tariff design. There are a number of considerations in this regard: (1) with an increase in EV adoption and rooftop PV adoption, the system peak could shift later in the evening, and (2) distribution and bulk system peaks could either converge or further diverge, depending on future adoption of distributed energy technologies. How to set the peak period will require careful consideration of these factors.

There is some scepticism about the applicability of the findings of field trials. Common concerns include (1) the field trials were conducted on a voluntary basis, so there is self-selection bias, (2) the field trials often included bill protection, so customers were not fully exposed to price signals like they would be in a full-scale offering, and (3) many field trials were conducted in regions with a climate and appliance mix different from that of GB.

There is an opportunity for flexible load to reduce distribution network costs. Assessments of TOU tariff value typically focus primarily on the bulk system (energy and generation capacity) benefits; distribution-level benefits are less proven. However, upcoming initiatives in GB and in the US will demonstrate the extent to which distribution capacity deferral can be achieved through load shifting. A question of additional importance is whether or not domestic consumer response to TOU tariffs is the type of load reduction that the DNOs would be willing to rely upon; one view is that they will be agnostic to the type of resource providing the service (it could be DSR, distributed storage, rooftop PV, etc). A regulatory model like RIIO is considered important to provide DNOs with the incentive to pursue lower-cost demand-side alternatives to distribution network capacity upgrades. One stakeholder noted that the Economy-7 tariff is known to have led to deferral of distribution investment costs, through no data sources could be provided.

There is a "chicken and egg" problem with smart technology. Many argue that granular retail prices won't be effective until consumers have smart appliances. Alternatively, others point out that granular retail prices need to be available to develop the market for smart technologies.

There are barriers to TOU tariff provision/adoption. These include (1) perceived lack of consumer interest, (2) lack of smart meters and half-hourly settlement, (3) lack of smart/automating home technologies, (4) limited financial incentive for suppliers to encourage customers to modify consumption patterns, and (5) price comparison sites that do not currently have the capability to make a fair comparison between flat tariffs and TOU tariffs.

"Behavioural economics" is important to consider in the analysis. There may be ways to present financial savings opportunities to consumers that are more effective than others. For instance, consumers may be interested in a discounted up-front rebate with a year commitment to a new tariff rather than in saving money gradually over the course of a year. Similarly, consumers may value a gift card or "energy rebate" more than (perhaps less transparent) bill savings.

TOU tariffs can be both an opportunity and a risk for domestic DSR aggregators. TOU tariffs are an opportunity if the aggregator is positioned to interface effectively with the customer and help them achieve bill reductions. TOU tariffs are a risk if the aggregator's business model is oriented around interfacing with utilities, and the aggregator is "replaced" by TOU tariffs as a DSR program which they are not involved in providing.

New recruitment methods can improve enrolment. Recent evidence from a field trial trial for fuel poor customers has identified a number of approaches that have been important to enrolling fuel poor customers in new programs. These recruitment keys include non-utility

branding, understanding the culture of the target recruitment customer base, and (with the first two conditions met) in-person interaction.

Operational challenges vary considerably by DNO and even within a DNO's territory. Some DNOs are not experiencing peak-driven capacity upgrade needs and have seen a decline in peak demand on their system. Others have identified a number of locations on their system that will be in need of capacity upgrades in the near term. Some others are experiencing constraints on parts of their system due to output from distribution-connected generators; generators in these areas have faced high interconnection fees or are subject to curtailment. In these instances, local constrains can account for 10% to 30% of major portions of the distribution network. Generally, there is a view that distribution costs are a modest share of the consumer's bill on average but can be very high relative to other costs in specific locations on the system where there are constraints.

There is debate over the role of protections for consumers. Some feel that a policy that "no consumer should be made worse off" is unrealistic, since removing pea-related cross-subsidies embedded in current tariffs means that some customers will see automatic bill savings while others (in the absence of price response) will see an automatic bill increase. Others are of the view that tariffs like a CPR can provide a meaningful incentive to reduce peak demand without increasing bills. All tend to agree that special protections for vulnerable customers are appropriate.

Other Minor Points of Interest

- Suppliers like tariffs that can help them manage against fuel price risk (e.g., seasonal differentiation)
- Advancements in load data disaggregation algorithms could help to enhance attractiveness and understanding of TOU tariffs
- An Oxford spin-off, Mixergy, is developing water heating technology that can provide DSR services
- An underappreciated operational challenge of TOU tariffs is "knife edge" response following a high price event (i.e. rapid increase in demand after prices return to off-peak levels); there is a need to stagger event timing to manage this accordingly
- The FreeTime tariff has had significant uptake and some load response; this type of tariff could be training ground for an eventual TOU rollout

Appendix B:

BAM Description

The Brattle Annual Model

What does it do?

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What does BAM do?

- **BAM determines the short-run marginal price (the energy price) by hour for GB**
  - For this project, we treat flows into/out of GB via interconnectors (currently Ireland/France/Netherlands) as fixed at historic levels
- **To do this, it calculates the *marginal production costs* for all the plant on the system. These take into account:**
  - Fuel costs (commodity costs plus delivery costs)
  - Carbon costs – including impact Carbon Support Mechanism
  - Variable generating costs e.g. water, limestone (for scrubbing CO_2), coal handling and milling costs, system charges etc.,
  - Subsidies (ROCs/FiTs)
  - Efficiency of the plant – varies with age, size, fuel etc.
  - Transmission loss adjustments (currently 0.8% for all plants)

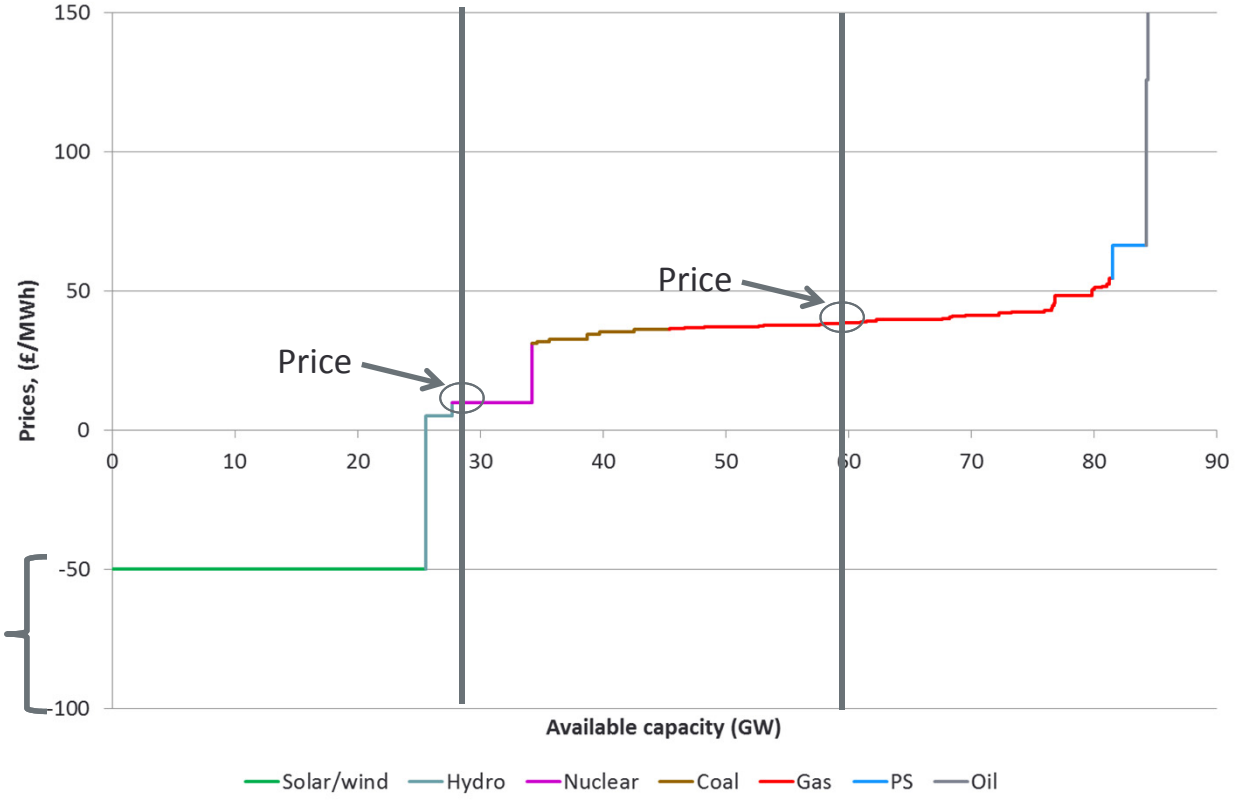
For each hour in a year …

- **BAM calculates the marginal production costs for all the plants**
  - Fuel prices and carbon prices can vary by day or at least by month
- **Plant have to be maintained so their availability can change from month to month**
  - They may also have unplanned outages
- **And the average output of renewables plants can vary by season**
  - It is generally windier in winter but there is less sunshine
- **It then stacks the available capacity of the plant up in order of ascending cost, to form a so-called *merit order***

Finding the short-run marginal price

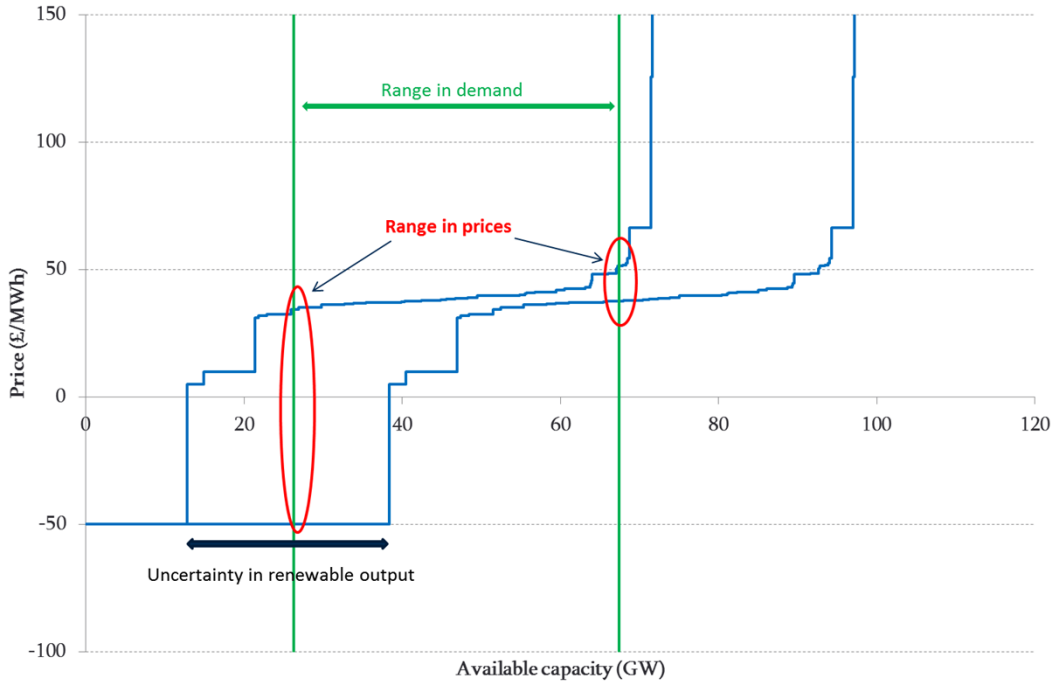
The short-run marginal price is set by the marginal production cost of the last plant required to meet demand:

We assume the marginal production cost of plants receiving a FiT is equal to "–FiT" i.e. will continue running until (price + FiT) =0



Impact of intermittent renewables

The output of wind and solar plants for any given hour is much more uncertain than that of conventional plants



And the effect of the uncertainty on prices can vary significantly

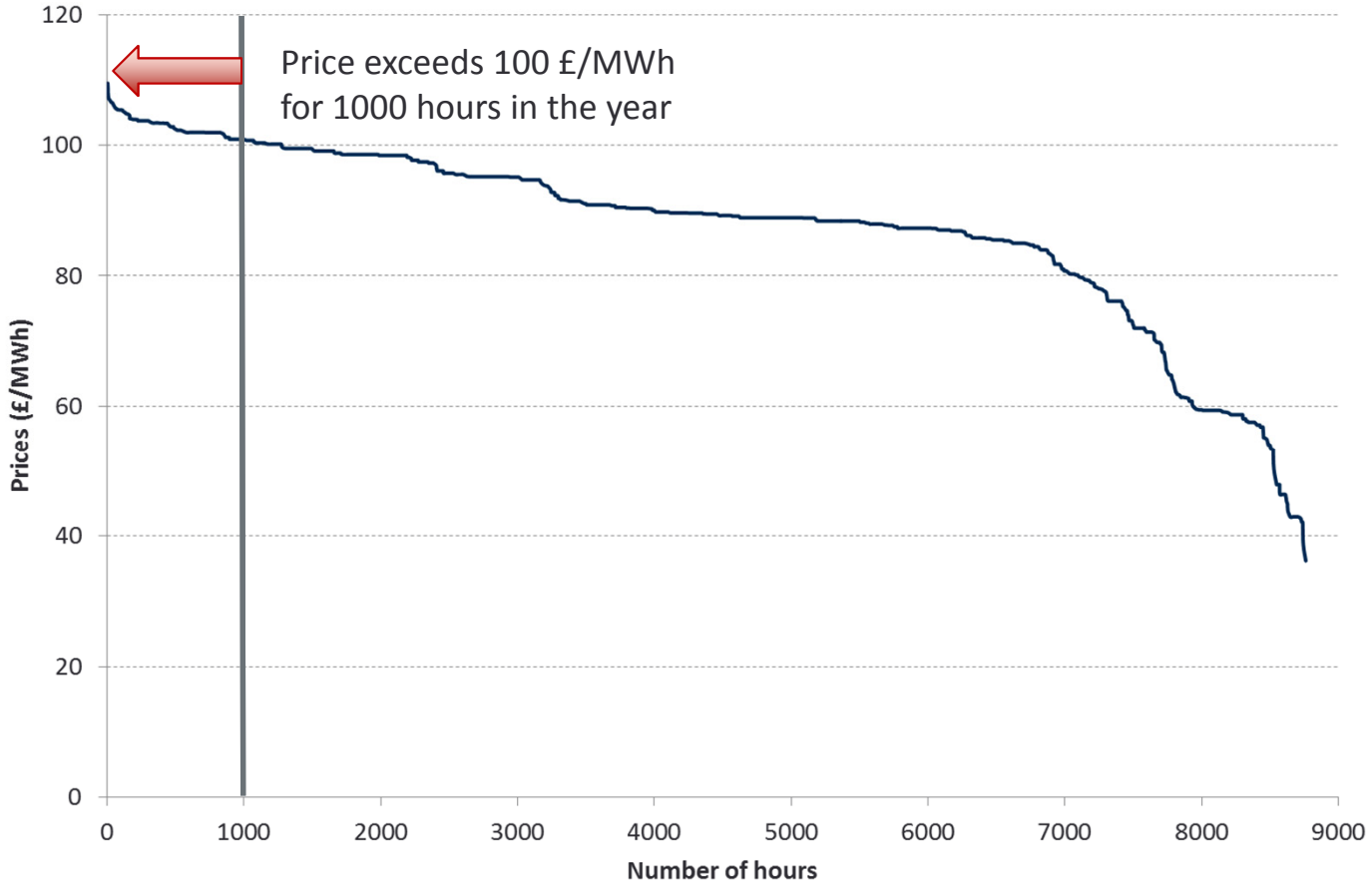
To capture these effects, we carry out multiple runs with different output assumptions and average the results

Over the course of a year

- **BAM seeks to minimize (*optimize*) the costs of meeting demand**
  - Decides the most advantageous maintenance schedule
  - Takes into account any “must run” constraints
    - e.g. CHP plants that have to run to produce heat for industrial processes
- **It calculates a separate price for every hour that is modelled**
  - A year is represented by 4 “characteristic days” for each month, so 48 days are modelled in total
    - Weekday, Saturday, Sunday and day of peak demand in the month
  - Important to capture differences in the profile of demand on different day types

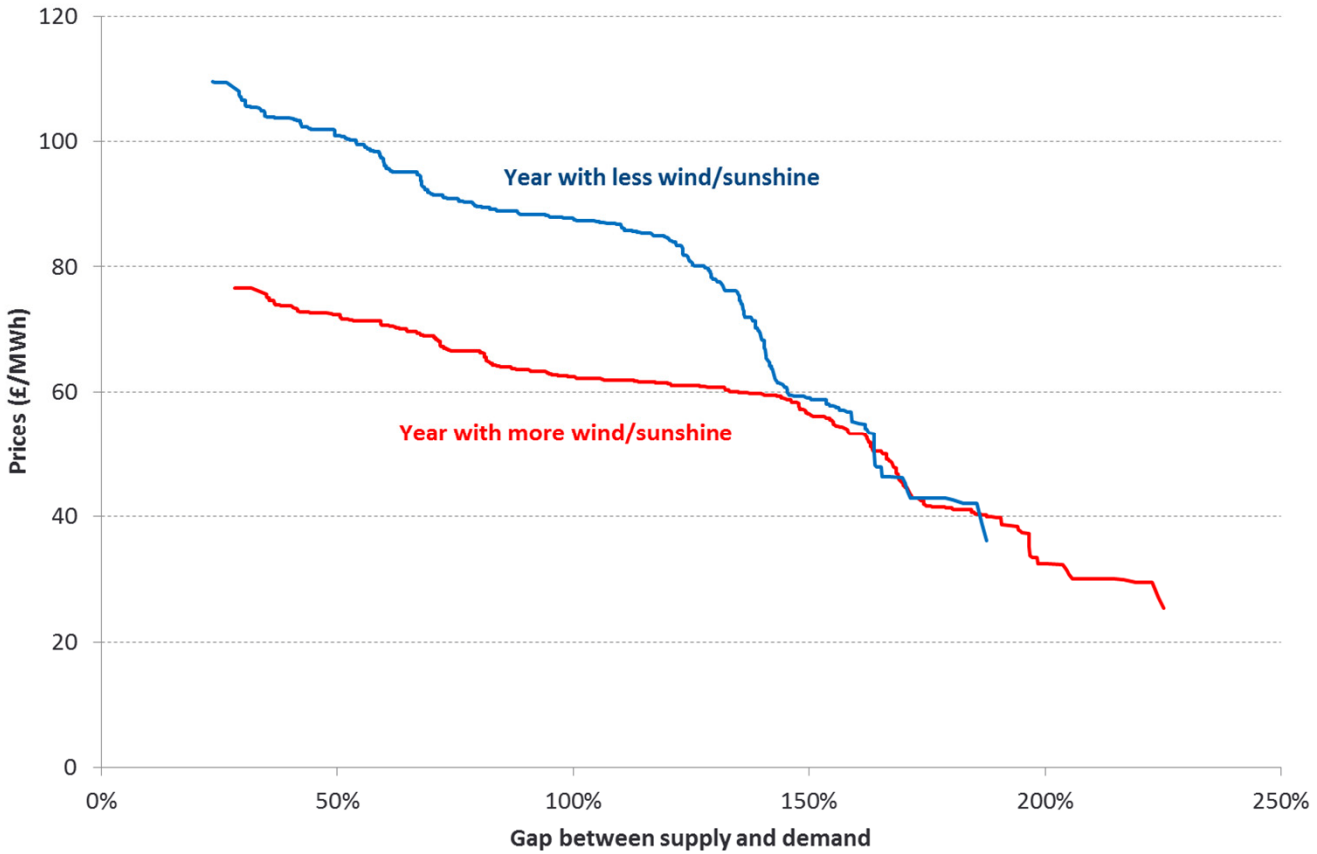
Price duration curve

BAM tells you the number of hours in the year that the price exceeds any given level

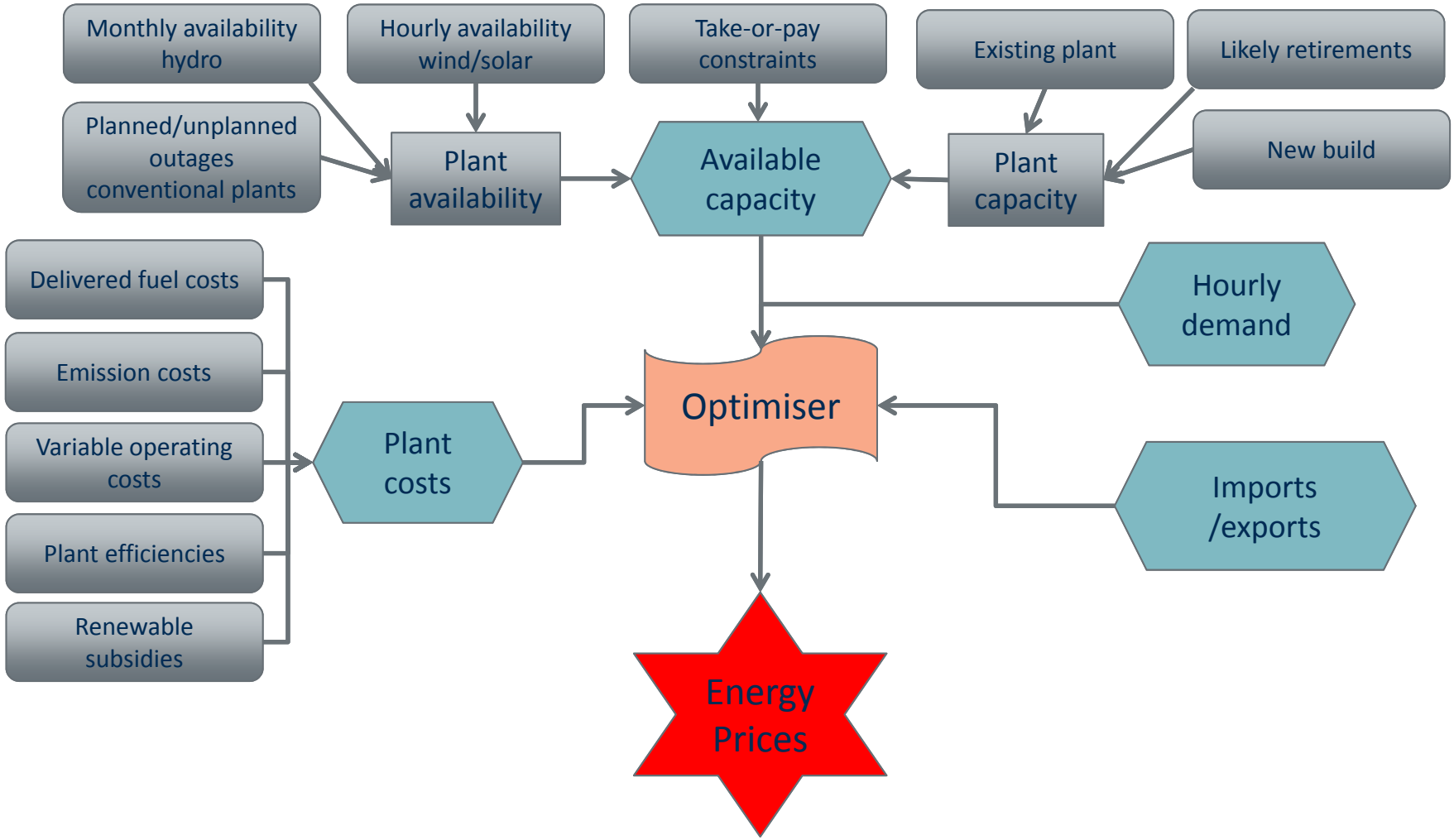


Prices and capacity margin

BAM also reports how the energy price varies as the margin of available capacity over demand varies



Summary of BAM



Appendix C:

PRISM Description

PRISM Model Details

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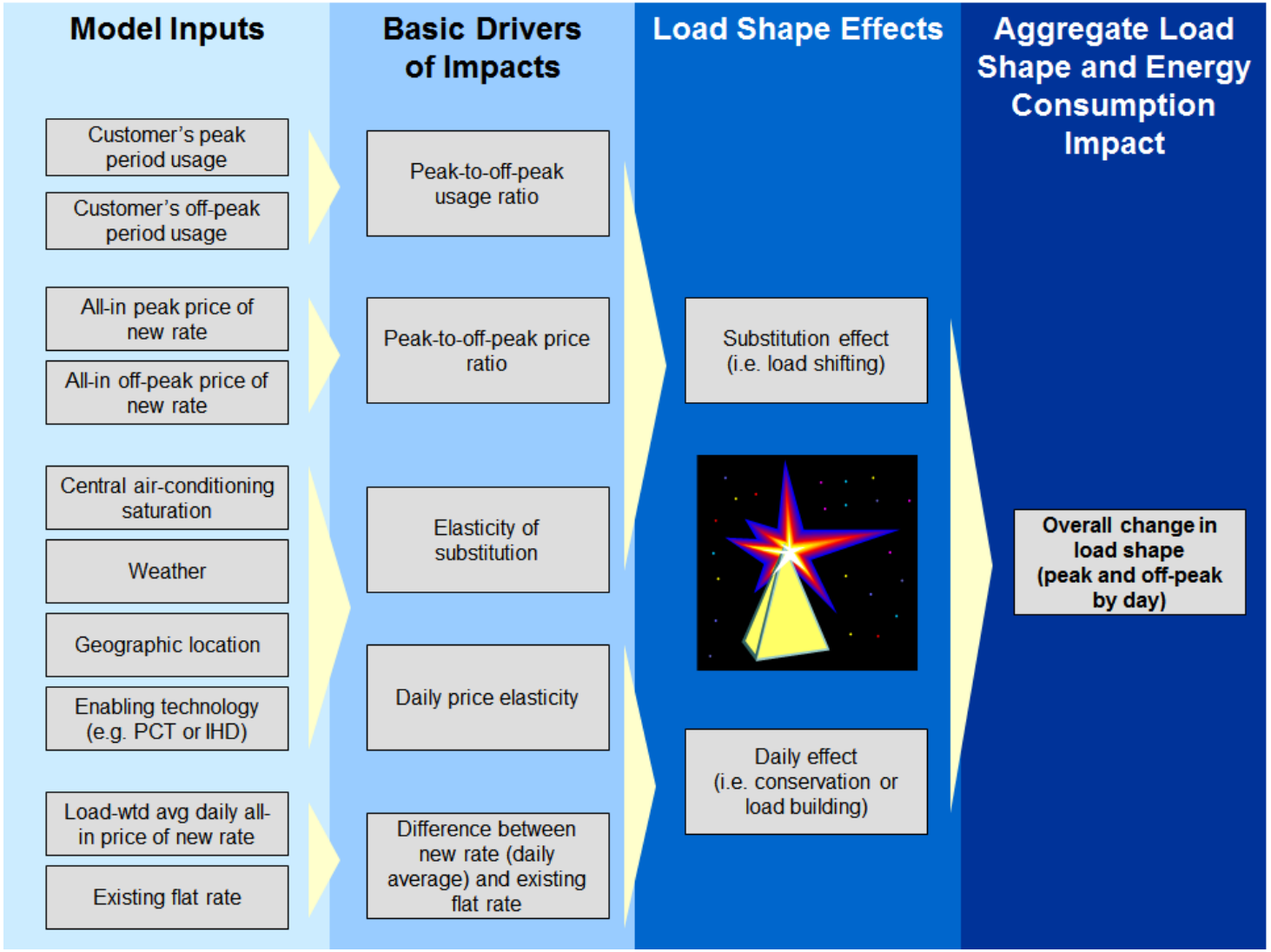
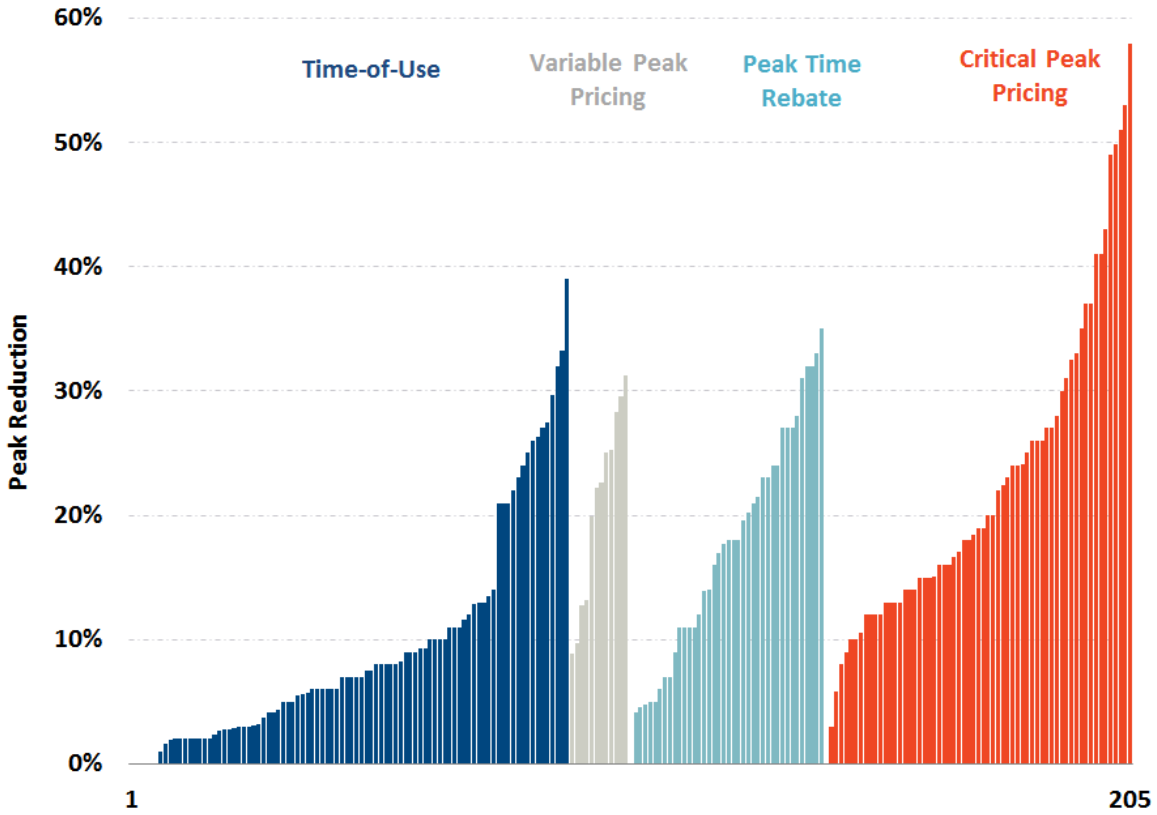
PRISM is a modelling framework for quantifying customer response to changes in tariff design



More than 40 international domestic field trials have quantified customer response to TOU tariffs

Peak Demand Reductions from International Survey of Domestic Time-Varying Rate Pilots

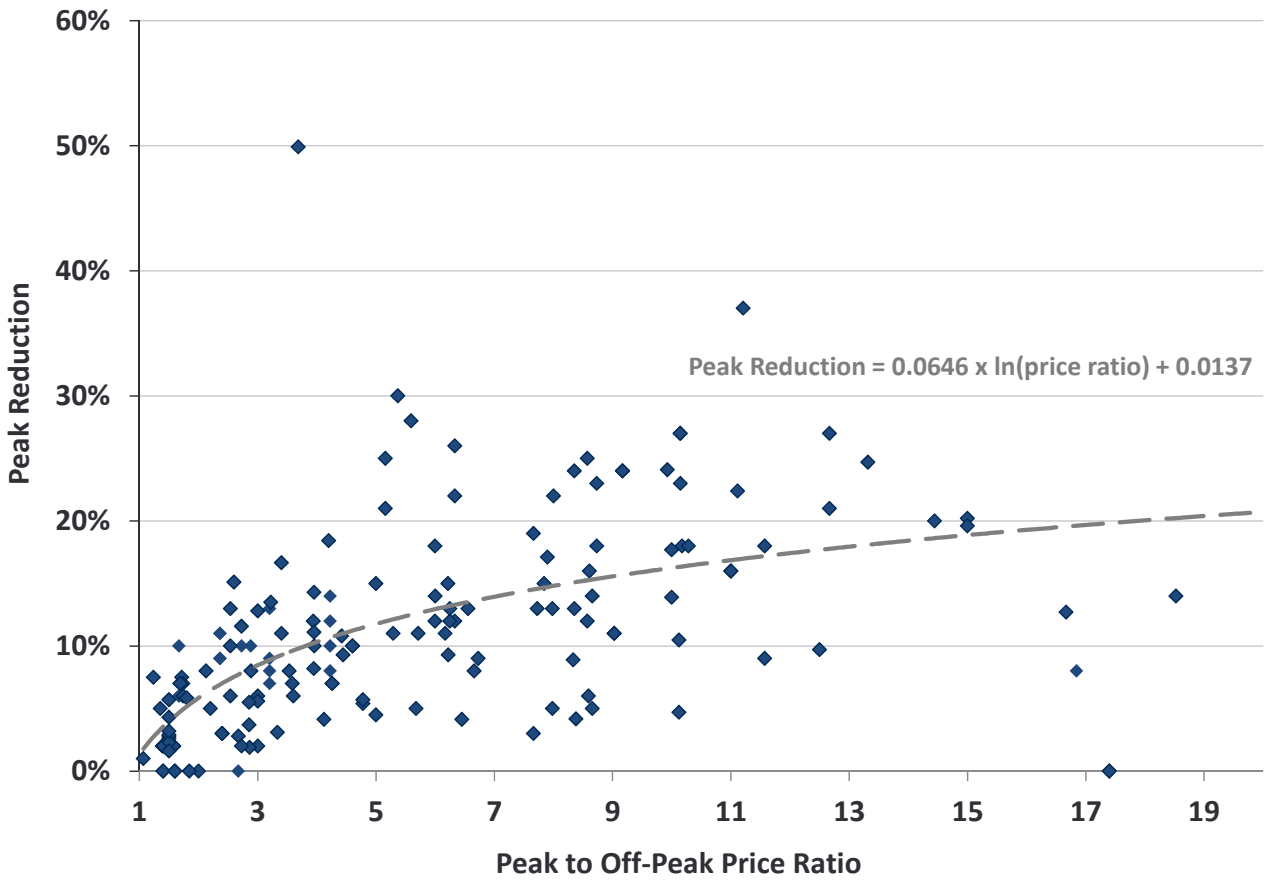


Comments

- An international survey of more than 40 domestic pricing field trials conducted over the past dozen years has found that customers do respond to changes in the tariff design
- Each field trial contains multiple treatments (i.e. rate options), with more than 200 treatments tested across the pilots

The results of the pilots can be organized across two key dimensions – price ratio and peak reduction

The "Arc of Price Responsiveness"



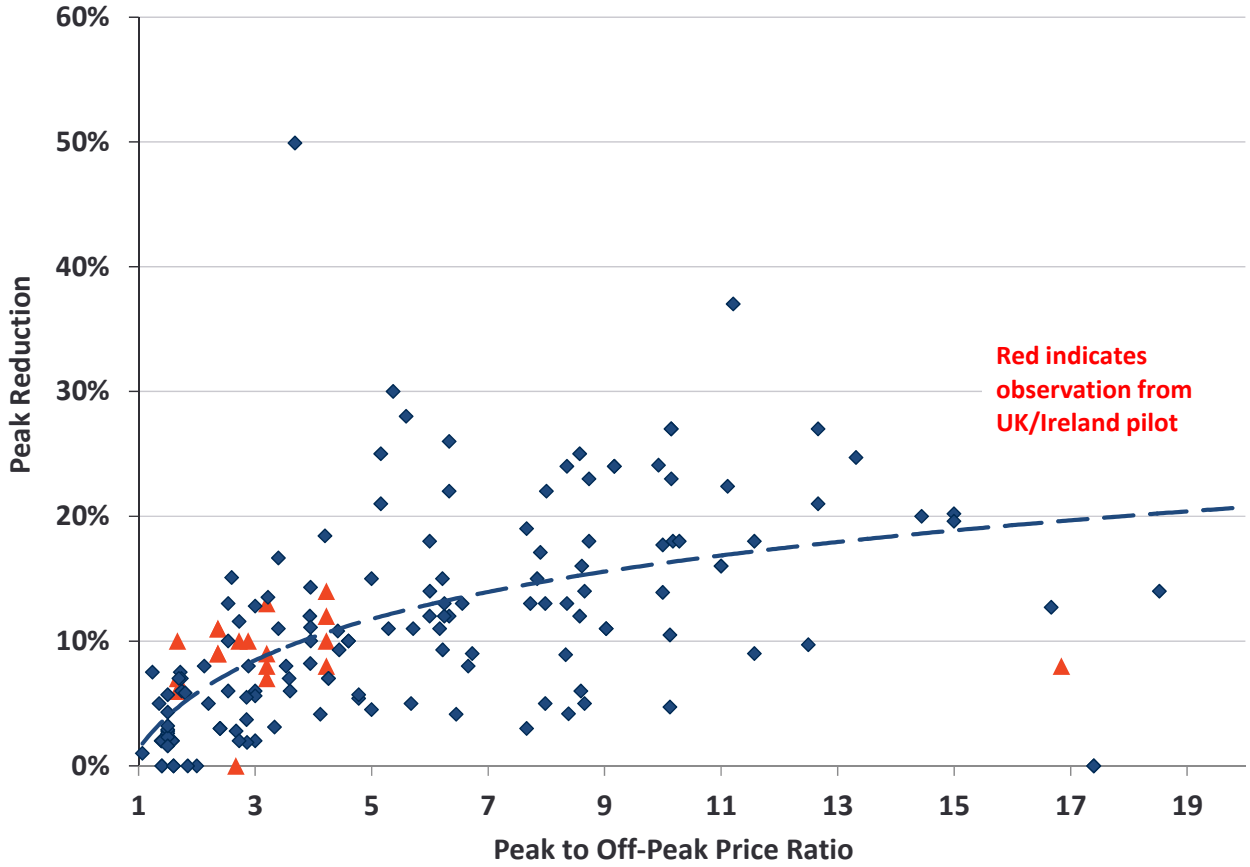
Results shown only for price ratios less than 20-to-1 and for treatments that did not include automating technology such as smart thermostats.

Comments

- Fitting an arc to the data shows that price response increases with a stronger price signal (arc function shown in grey)
- Price response increases at a diminishing rate, as customers run out of practical actions that can reduce peak demand
- Results shown only account for behavioral response and not the potential impacts of automating technology
- The Arc is a way to simplify the PRISM framework and incorporate the findings of many field trials rather than relying on price elasticity estimates from a single field trial

Of the 40+ pilots, four were conducted in the UK and Ireland

The "Arc of Price Responsiveness"



Results shown only for price ratios less than 20-to-1 and for treatments that did not include automating technology such as smart thermostats.

Comments

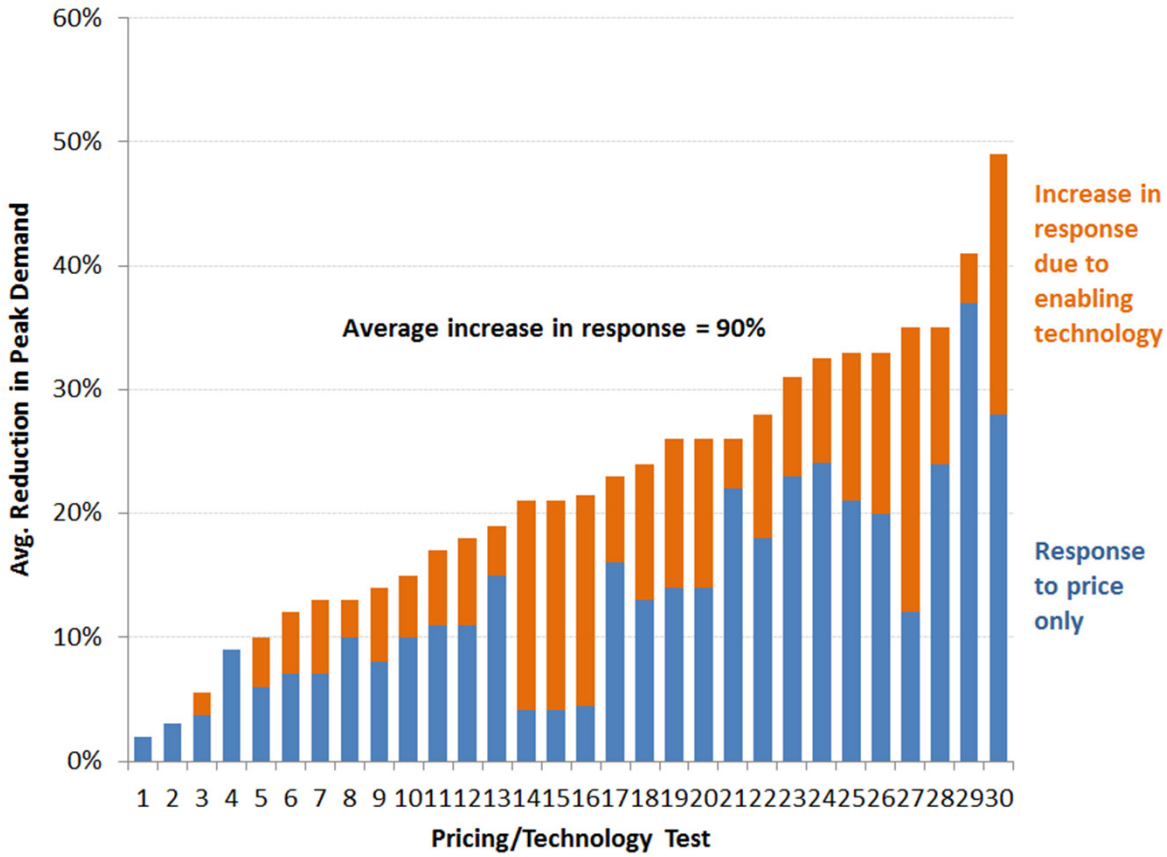
- Price response in GB is generally within the range of observations from the international database of field trials (when expressed as a percentage of peak demand)
- Given that there is no clear difference between the results of UK/Ireland studies and the other pilot studies, we use the arc to capture the relationship between price ratio and price responsiveness in this analysis

Impacts are scaled to account for enabling technology

Comments

- Price responsiveness to TOU tariffs increases significantly when customers are equipped with automating technologies
- Based on the relationship observed in other pilots, we assume a 90% increase in response attributable to technology

Price Response with and without Tech



Per-customer pricing impacts are scaled down in the opt-out deployment scenario

- A TOU field trial by the Sacramento Municipal Utility District (SMUD) found that the average residential participant's peak reduction was smaller under opt-out deployment than under opt-in deployment
- This is likely due to a lower level of awareness/engagement among participants in the opt-out deployment scenario; note that, due to higher enrollment rates in the opt-out deployment scenario, aggregate impacts are still larger
- Per-customer static TOU impacts were 40% lower when offered on an opt-out basis
- Per-customer CPP impacts were roughly 50% lower
- We have accounted for this relationship in our modelling

Appendix D:

Market Scenarios

Market Scenario Summary

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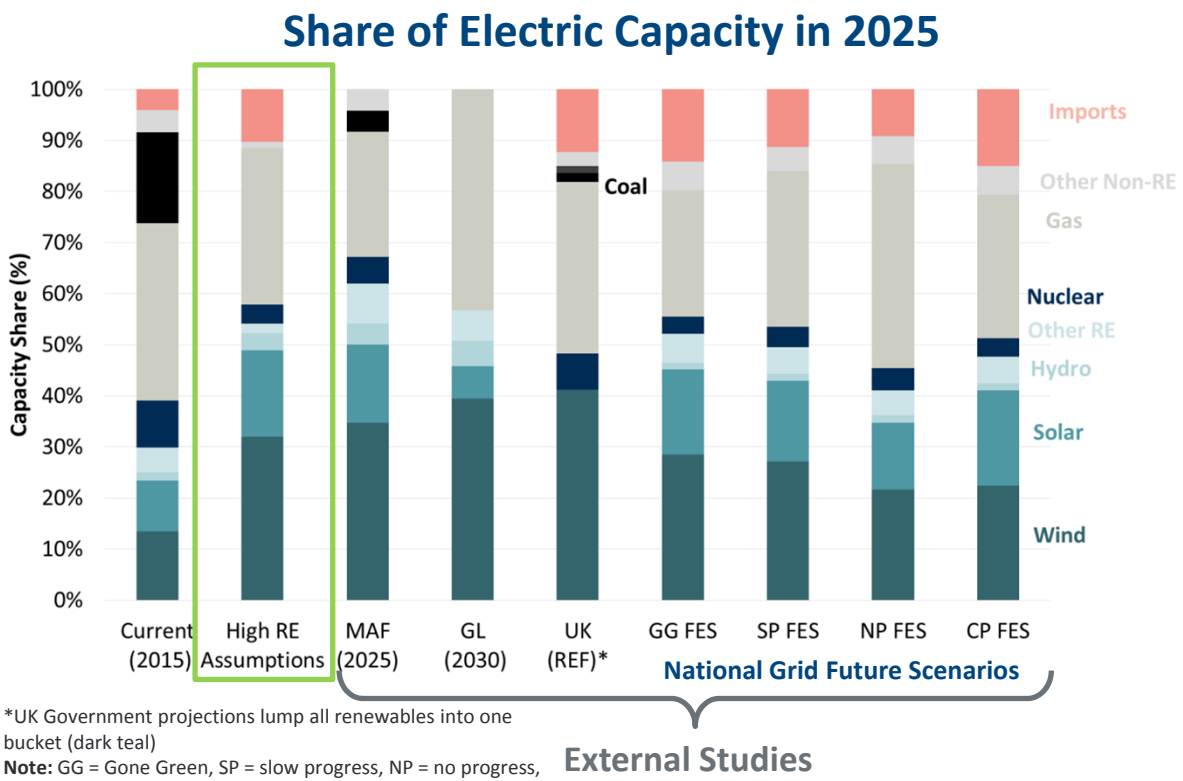
The Market Scenarios

We analyse the value of TOU tariffs under four possible future states of the GB power market in 2030:

Market Scenario	Description
Current Trends	**Market reflects current conditions with modest changes** - Fairly tight reserve margins, but with relatively low capacity prices - Supply mix dominated by nuclear, gas, some wind - Little adoption of smart appliances
High Renewables	**Aggressive investment in renewable generation** - Wind and solar represent 32% and 17% of installed capacity, respectively - Peak-related generation and transmission capacity needs mostly unchanged due to lack of coincidence in wind output and system peak - Some local distribution constraints due to output from embedded gen - Negative wholesale energy prices in some hours
Electrification	**Significant load growth** - Electrification leads to adoption of 8 million EVs and 6 million heat pumps - Accelerated load growth leads to higher capacity prices - Energy prices increase but the price profile flattens to some degree
Electrification with Automation	**Additional demand-side advancements** - Same definition as Electrification case, with the additional assumption that the adoption of smart appliances (smart thermostats, EV charging control) facilitates a greater degree of price response

High Renewables Case: Capacity

- High RE case based on review of projections from the UK Government, National Grid's Future Energy Scenarios (FES), and the ENTSO-E's Mid-Term Adequacy Forecast (MAF)
- 55% of capacity to come from renewable sources, relative to 30% currently



*UK Government projections lump all renewables into one bucket (dark teal)
Note: GG = Gone Green, SP = slow progress, NP = no progress, and CP = consumer power from NG FES

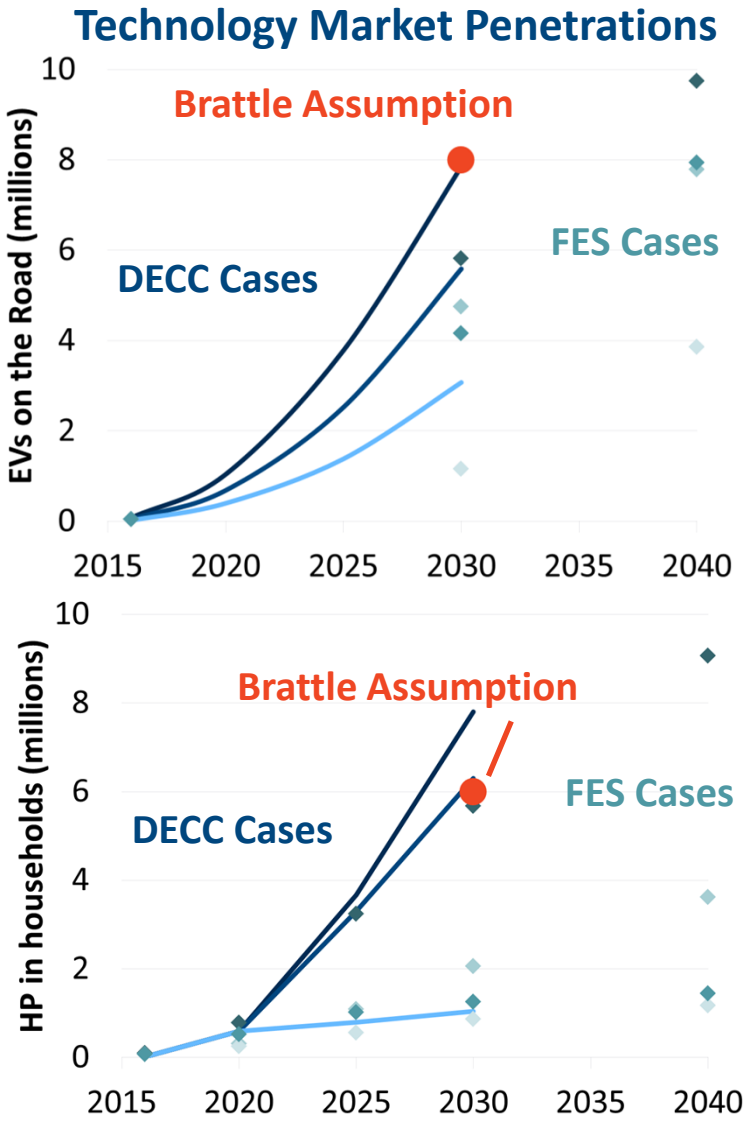
Type	Current (%)	High RE Case (%)	Change (%)
Wind	14%	32%	+18%
Solar	10%	17%	+7%
Hydro	2%	3%	+1%
Other RE	5%	2%	-3%
Nuclear	9%	4%	-5%
Gas	35%	31%	-4%
Coal	18%	0%	-18%
Other Non RE	4%	1%	-3%
Imports	4%	10%	+6%

Other RE includes Biomass and marine energy

Electrification Case: Market Penetration of Electric Vehicles and Heat Pumps

Forecasted market penetration of electric vehicles (EVs) and heat pumps (HPs) based on 10- to 20-year outlook

- Estimate is derived from a review of various GB market forecasts
  - National Grid's FES, Element Energy's Pathway to EVs, and UKPN's Low Carbon London field trial
- Electric Vehicles
  - 8 million on the road
  - 27% market share of all personal vehicles on the road in GB
- Heat Pumps
  - 6 million in households
  - 22% market share based on GB household count



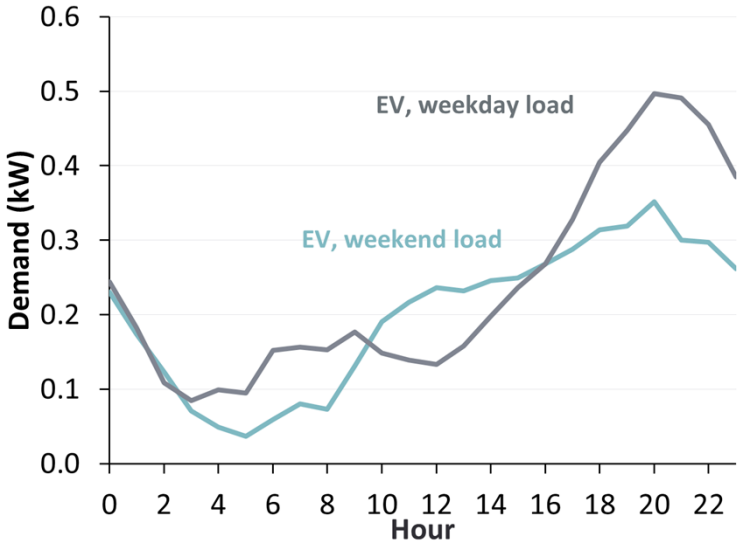
Source: National Grid FES and Department of Energy and Climate Change's Household Electricity Survey Program

Electrification Case: Average EV and HP load profiles in GB

Load profiles are used to represent "average" impact of an individual electric vehicle and heat pump

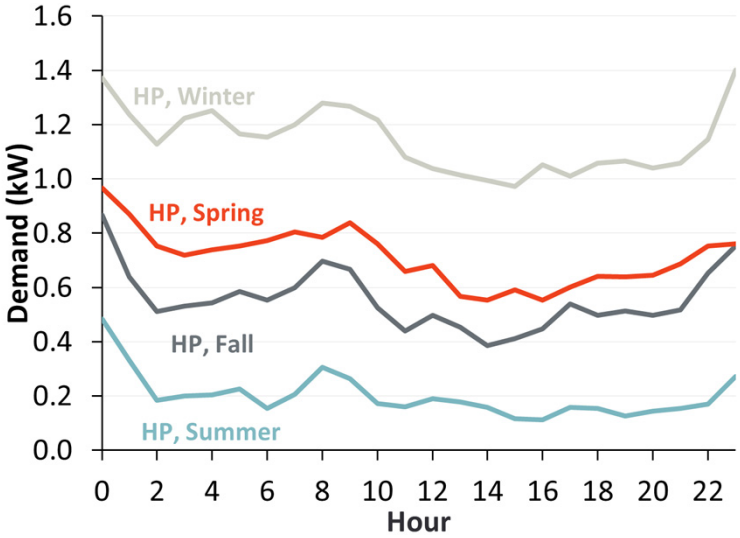
- Low Carbon London trial monitored 72 vehicles over the course of 4 months
- Scaled up average load profile (which includes charging at home and public stations) to reflect GB-wide vehicle miles traveled estimate and 8 million EVs on road

Individual EV Demand



Source: UKPN EV Pilot (2014) scaled to match UK VMTs

Individual HP Demand



Source: CCC Pilot on HP (2011)

- On a per-household basis, HPs consume significantly more electricity than EVs in GB
- Field trial monitored HPs in 10 households
  - Coefficient of Performance of 2.3
  - 5,700 kWh of energy consumption per HP per yr
- Load profile scaled up for 6 million households

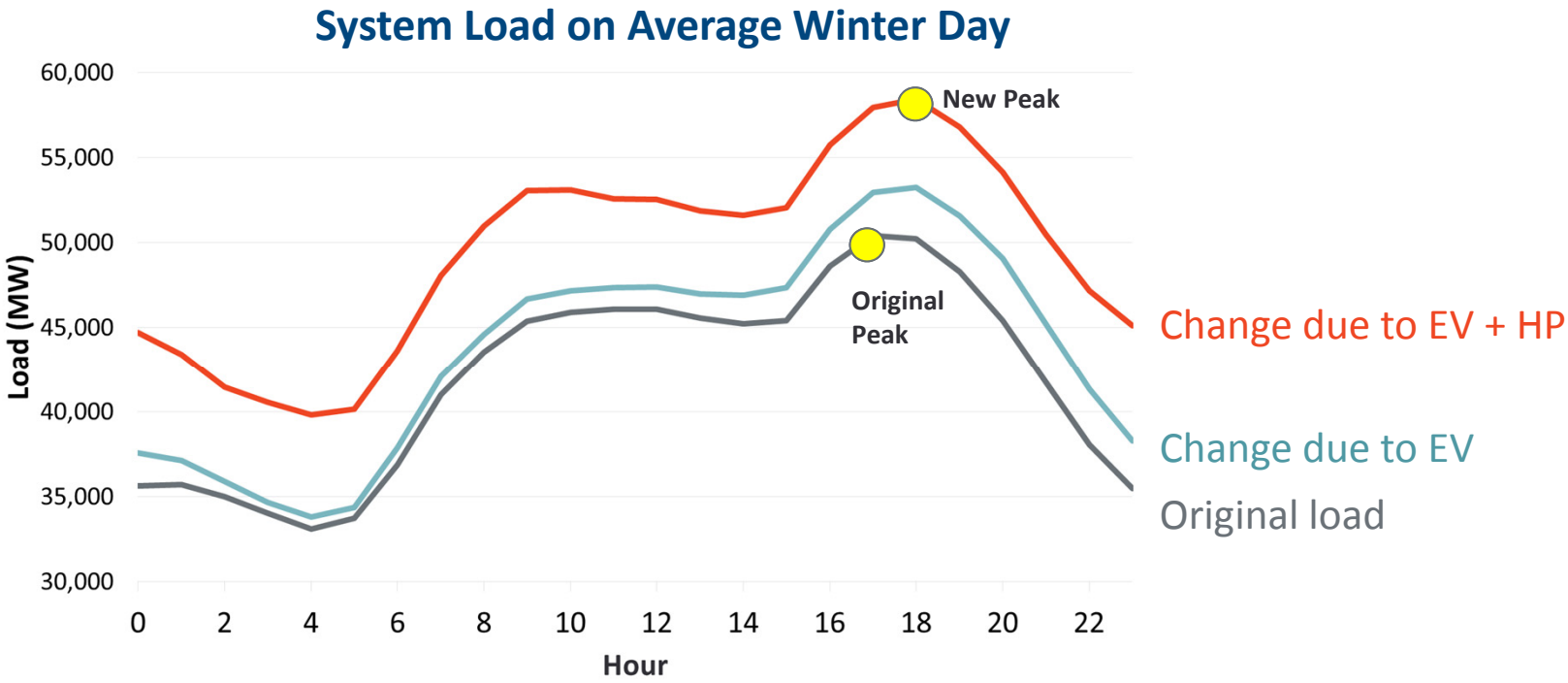
Electrification Case: System Load Impacts

GB system load increases significantly due to electrification assumptions

- 15% increase in total energy (from 337 TWh to 387 TWh)
- 16% increase in peak demand (from 57 GW to 66 MW)

Timing of system peak shifts slightly from 5pm to 6pm

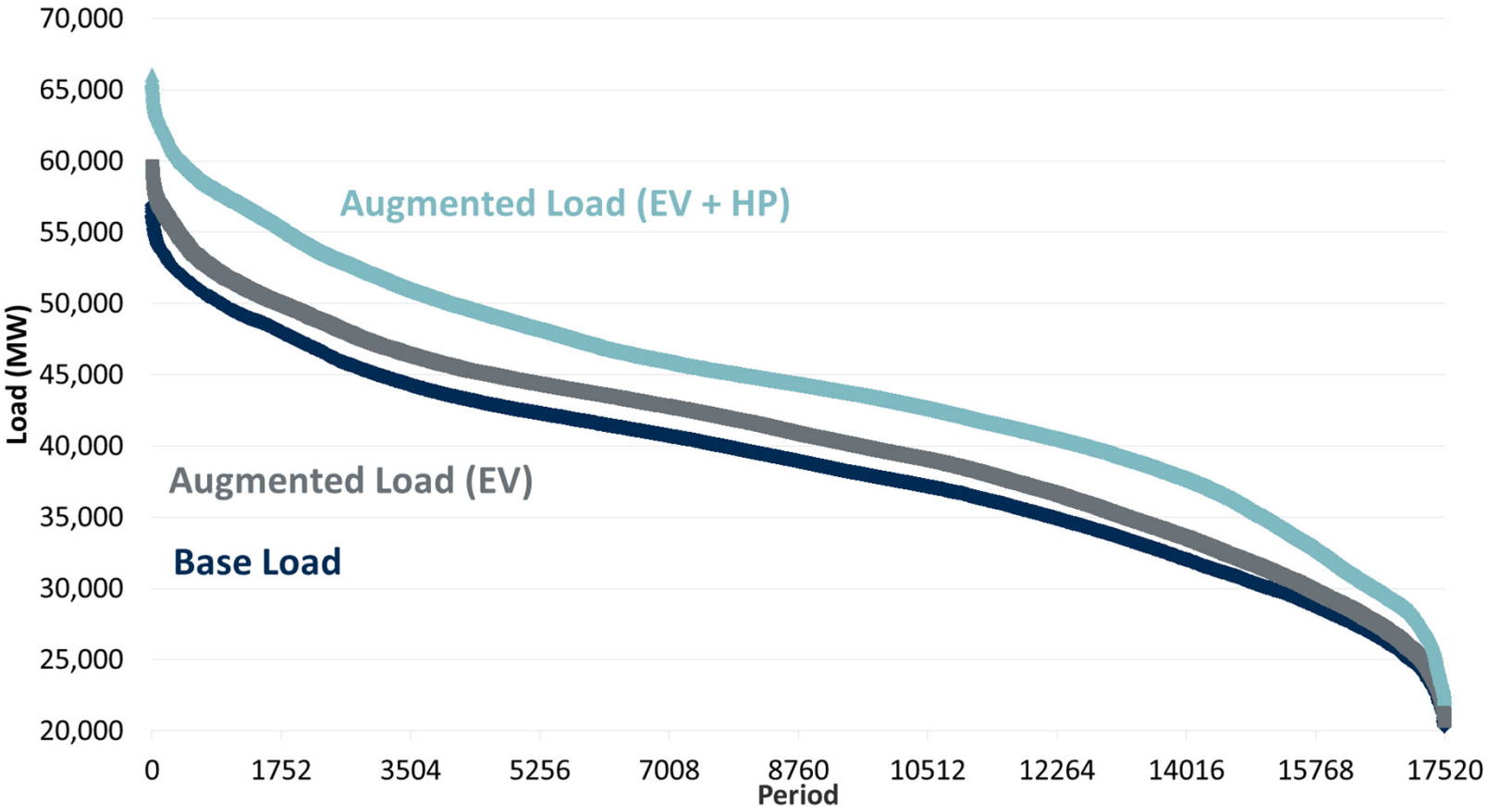
- Impacts on distribution system peak will be more significant; this will be explored through TOU power system value analysis



Source: Base Load Taken from National Grid; Brattle analysis
Notes: Winter defined as November through March

Electrification Case: Aggregate Load Duration Curves

Effect of new tech deployment (Electric Vehicles and Heat Pump)



Source: Base Load Taken from National Grid

Electrification Case with Automating Technologies

We consider two types of automating technologies, which have the potential to increase consumer response to retail electricity price signals

Assumptions are illustrative due to lack of available adoption projections

Smart thermostat assumptions

- 22% of customers will have some form of electric heating
- 50% of those will have a smart thermostat

EV smart charging assumptions

- ~25% have an EV
- 30% of those enrol in and respond to a TOU tariff

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Appendix E:

Literature Review

Customer Acceptance of and Response to Time-Varying Tariffs in Great Britain: A Literature Review

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Ryan Hledik

Prepared for:
Citizens Advice

Organisation

This presentation is organized into four sections:

1. Executive summary
2. Attractiveness and uptake of time-varying tariffs (TVTs)
3. Customer satisfaction with TVTs
4. Customer response to TVTs

Tariff acronyms and definitions

- CAP: capacity pricing (NB this is not a time-varying tariff, and is only included where it appeared alongside time-varying tariffs in trials)
- CPP: critical peak pricing, where customers are exposed to occasional higher electricity prices on an irregular basis (often known as 'critical events'). The high price may be fixed (CPP-F) or variable (CPP-V)
- CPR: critical peak rebate, where customers are paid for reducing electricity consumption during critical events
- RTP: real-time pricing, where electricity prices vary with high frequency, such as on an hourly basis, usually to reflect wholesale prices (sometimes also referred to as hourly pricing [HR])
- Dynamic TOU: dynamic time of use, where electricity prices vary at irregular times, but at a lower frequency to real-time pricing and usually with set price bands
- Static TOU (also here referred to by the shorthand 'static'): static time of use, where electricity prices vary between set bands at set times of the day/week
- TVT: time-varying tariff, the generic term used to describe any tariff where the price of electricity varies in some way over time

Section 1:
Executive Summary

Methodology

The objective of this research was to assess both (1) the customer attractiveness of TVTs and (2) the extent to which customers in GB are likely to respond to the tariffs by changing their electricity consumption patterns.

Our assessment of **customer attractiveness** included a "rapid review" methodology through which we identified more than 4,000 reports/articles/studies on the topic and then systematically reduced this (based on factors like geography and nature of findings) to a list of 27 studies that were specifically relevant to the research questions. We reviewed these studies in detail.

Given the more extensive body of literature on **customer price response**, our assessment of customer response included a "review of reviews" to identify common themes and findings across studies that have summarized the many (i.e., 40+) TVT field trials that have been conducted around the world. We identified 23 such meta-studies. Our review was supplemented with a more detailed analysis of four recent UK/Irish field trials, given their high degree of relevance.

Findings: Customer Acceptance

Across surveys, field trials, and full-scale deployments, the range of observed uptake of domestic TVTs is huge, ranging from 0% to 96%

Possible explanations for this wide range could include:

- Deployment method (opt-in vs opt-out)
- Financial participation incentive (e.g., gift card)
- Tariff type
- Automation (e.g, presence of smart thermostat)
- Bill protection
- "Messaging (e.g., “sign up to save money”)
- Type of customer

The impact of each of these factors on enrolment is summarized on the following two slides

Note: The type of study (i.e., survey versus actual deployment) also influences the observed uptake level, but that factor is not discussed in this summary section since it is not something that energy companies or policymakers can control. It will be considered when developing enrolment assumptions for the power system value assessment.

Findings: Customer Acceptance (cont'd)

Factor	Key takeaways	Strength of findings
Deployment method (opt-in vs opt-out)	Biggest driver of difference across studies. 83% average enrolment with opt-out versus 26% with opt-in.	High
Financial incentive (e.g. gift card)	Statistically significant impact in comparision across studies, with 35% enroling when offered incentive versus 20% enroling when not offered.	High
Tariff type	Static (35% average uptake) is more popular than dynamic, particularly hourly RTP (18%). However, limited data makes it difficult to compare across individual tariff designs like CPP, CPR, etc.	Moderate
Automation	Comparision across studies finds no statistically significant difference. However, individual studies that have looked specifically at this issue have found that automation increases uptake, possibly to a greater extent for dynamic tariffs than static.	Moderate

Findings: Customer Acceptance (cont'd)

(Continued from previous slide)

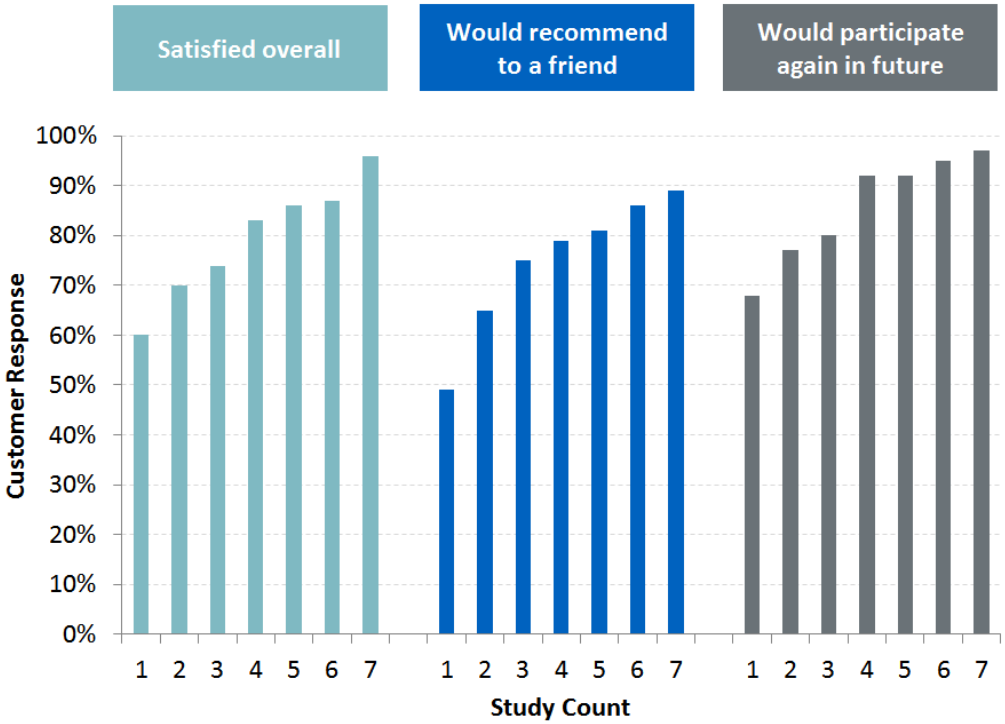
Factor	Key takeaways	Strength of findings
Bill protection	Comparison across studies finds higher uptake with bill protection (35%) than without (27%) though the difference is not statistically significant. Individual studies identified a modest boost due to bill protection.	Moderate
Messaging (e.g., "sign up to save money")	There is limited research on this issue since most studies emphasize financial savings (i.e., hard to find a control for comparison). Results, where available, are largely conflicting through suggest a modest effect from promoting environmental benefits.	Inconclusive
Type of customer	This was not analyzed in any of the reviewed studies.	Inconclusive

Findings: Customer Satisfaction

Comments

- 16 field trials explored satisfaction with TVTs after customers had experience with the tariffs
- Various measures of satisfaction identified largely 70% to 90% of participants as satisfied (see chart)
- One study which included opt-out deployment found that 90% of participants would participate again, suggesting that self-selection bias in opt-in field trials it not likely to be the primary driver of these relatively high satisfaction levels
- Compared to the observed enrolment rates discussed previously, this survey of customer satisfaction suggests that acceptance of TVTs could increase as experience/understanding develops
- See body of presentation for important caveats

Results of Satisfaction Surveys Across TVT Studies

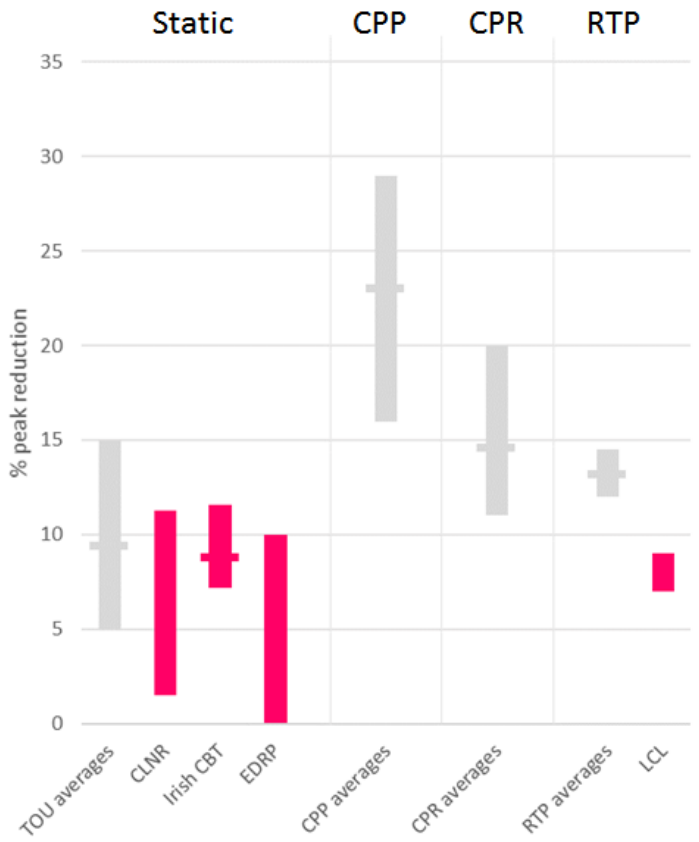


Findings: Customer Response

Comments

- Our survey of field trials and full scale deployments strongly indicates that domestic customers do respond to price
- Price response varies significantly across the field trials and is influenced by factors like price, appliance mix, messaging, and even study design
- As a percentage of peak demand, price responsiveness of GB customers appears to be roughly average or slightly below average compared to field trials elsewhere, mostly North America (see chart)
- No CPP or CPR tariffs have been tested in the UK, though they produce the largest impacts internationally (with CPP impacts being roughly 40-50% higher than CPP on a per-participant basis)
- Automation can roughly double price responsiveness. However, studies with technology treatments are from summer peaking regions mostly with smart thermostats for A/C, significantly limiting applicability to the UK

Peak Impacts from UK/Ireland Trials, Compared to International Trials



Findings: Customer Response (cont'd)

Other relevant findings from the price response review include:

- There has been a limited number of field trials in UK/Ireland and in winter peaking regions broadly; while general themes can be extracted from the research, this is a limiting factor
- Studies suggest that price response from lower income customers tends to be similar to or slightly less than response from the average customer; there is a fair amount of empirical support for the notion that lower income customers can respond to price
- The studies do not identify a clear propensity for vulnerable customers to be worse off under TVTs on average, though this point will be further tested empirically by Brattle using LCL/CLNR data
- When tariffs are offered on an opt-out basis, the average per-participant impact is roughly half of average opt-in impact (however, as discussed previously, enrolment tends to be 3x higher under an opt-out offering)
- A majority of customers were generally found to save money under TVTs, though this conclusion is impacted by issues such as the provision of bill protection; bill impacts are also something that will be explored further by Brattle through bill simulations

Next steps

- Convert these findings into (1) participation rate and (2) price response assumptions which will be used as inputs to the power system value assessment
- Conduct surveys to further differentiate acceptance between tariff design types, socio-demographic groups, etc.
- Simulate bill impacts under each tariff design to be considered in this study to understand the impact on vulnerable customer bills

Section 2:
Assessment of attractiveness and uptake of time-varying tariffs

Aim

The key aim of this task was to assess the attractiveness of, and uptake to, different time-varying tariff (TVT) designs and features.

Rapid review

- "Assessment of what is already known…using systematic review methods to search and critically appraise existing research" (Grant and Booth, 2009)

- Compared to a systematic review, a rapid review places constraints on the scope of the search strategy due to time pressures

- Due to systematic approach, the rapid review maximises the change that all relevant evidence has been captured

Rapid review method

The review was conducted following the review protocol:

1. List of 5 key TVT attractiveness publications identified
2. Reference lists of these key documents were reviewed and saved for review if the titles suggested they would be in scope
3. Using a 'snowballing' approach, reference lists that passed screening were assessed for inclusion
4. The 5 key documents were used to create a list of keywords for the search (keywords in appendix)
5. The following bibliographic databases were used for conducting the search:
    1. Scopus
    2. Web of Science (all databases)
    3. ScienceDirect
6. The website of 11 key organisations (e.g. Ofgem, BEIS) were also searched using the keywords
7. Potential sources were saved in Mendeley (reference manager)
8. Two reviewers screened the documents using the inclusion criteria (see Appendix); initially parallel reviewing was conducted until high levels of agreement were reached with screening performed by one reviewer thereafter
9. Screening and extraction was completed in EPPI-Reviewer (extraction was only completed on documents that passed the screening criteria)
10. Included documents were also reviewed to check that no important studies were omitted; 4 studies were added on this basis

This review

- 4117 unique documents identified and screened.
- The results presented in this section of the slide deck summarise data extracted from 27 studies covering 66 individual measures of uptake to a TVT.
- Additional exclusions: studies that did not provide a measure of uptake that could be converted into a proportion were excluded (this involved excluding 3 studies)
  - Buryk et al. (2015) – measured willingness to pay
  - Dutschke and Paetz (2013) – measured on a Likert scale, insufficient information to create proportion
  - Schwartz et al. (2015) – measured on a Likert scale, insufficient information to create proportion

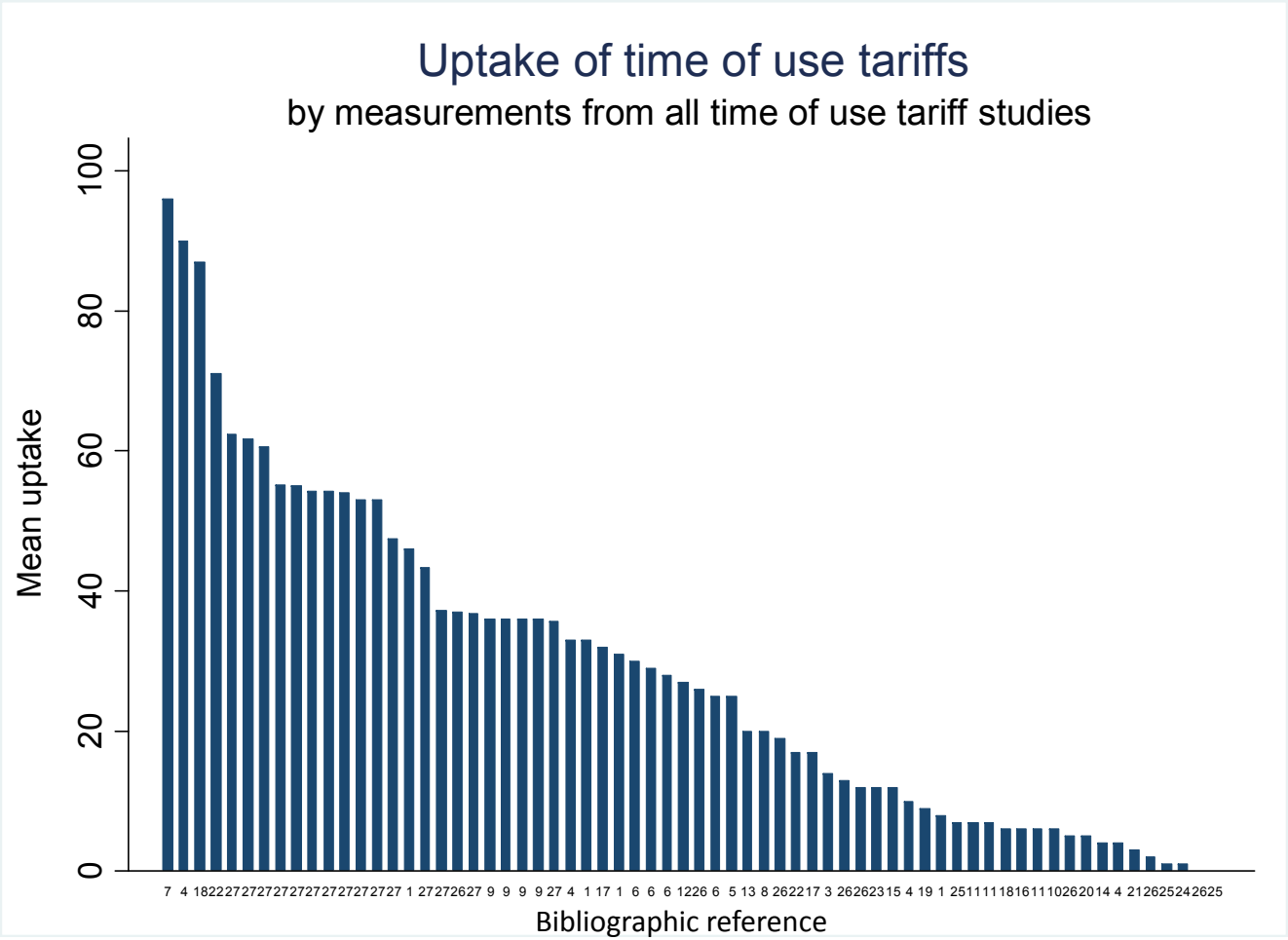
Attractiveness evidence base

There are three broad types of evidence base on consumer attractiveness of time-varying tariffs which have strengths and weaknesses:

Evidence type	Strength	Weakness
1. Sign up rates to commercial offerings	High external validity, high internal validity (based on actual sign up rates)	Hard to obtain (commercially sensitive) No evidence on what might make the tariff more acceptable UK – sign up rates to legacy tariffs are unlikely to reflect underlying preferences towards tariffs
2. Recruitment rates into industry/supplier trials	High internal validity (based on actual sign up rates)	Low external validity (due to inclusion criteria, expensive recruitment campaigns)
3. Stated preferences towards tariffs obtained from surveys	Can be run on nationally representative samples (to increase external validity) Easy to obtain and test methods of what might make tariffs more acceptable	Low internal validity (based on what people say they like/will sign up to)

Attractiveness – overall

Large variation in attractiveness of TVTs: enrolment rates of 0-96% with a mean enrolment rate of 29% and standard deviation almost as large (24%). Median is 27%.



N=66 measures of uptake.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

What might explain this variation?

- Measurement method
- Tariff type
- Region
- Framing (opt-in vs opt-out, money vs environment)
- Bill protection
- Additional financial incentives e.g. payment for participation in trial
- Presence of automation technology
- Recruitment method

Modelling predictors of variation in uptake

A multiple regression analysis was run to estimate the impact of each preceding factor on uptake.

Multiple regression was identified as the best method because it was clear that the relationships between uptake and some variables (e.g. country) were likely to be mediated by other factors (e.g. when looking just at the raw data, Australian enrolment is higher than US enrolment, however the majority of the evidence on US enrolment is based on uptake of commercial products and enrolment rates for commercial products are substantially lower than hypothetical enrolment rates obtained from surveys).

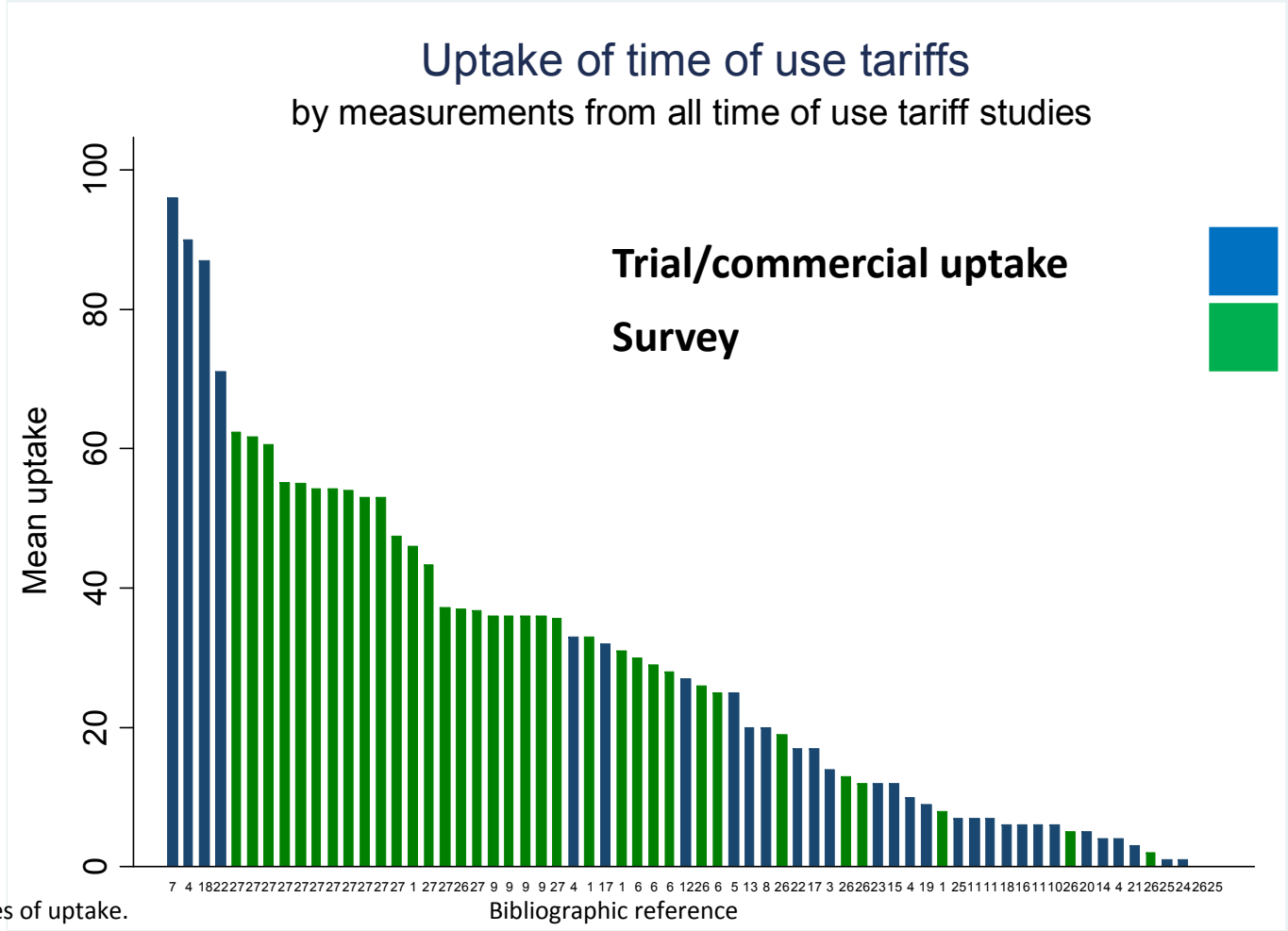
This also enables us to identify the most important factors, whilst holding all other factors constant, which is important in identifying what summary measure is the most appropriate for use in the final model.

Moreover, in many cases, multiple uptake measures were obtained from the same study. It is highly likely that uptake measures from the same study will be inter-correlated because the measures will be obtained from the same samples, with the same recruitment methods etc. The regression analysis includes fixed effects for each study, to attempt to control for clustering in uptake measures within studies, which could otherwise bias estimates and lead to incorrect statistical inferences.

For brevity, the coefficients obtained from this analysis are not presented in this slide deck but are available in a table in MS Word format.

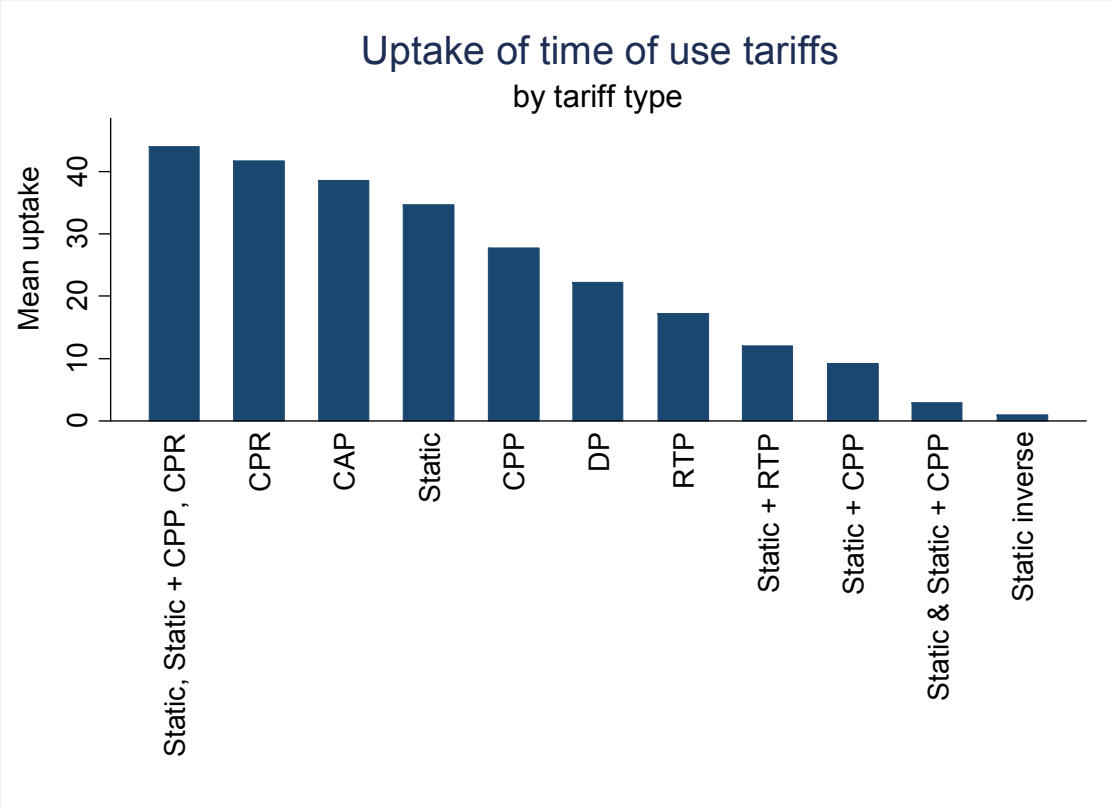
Attractiveness by measurement method

There are large variations in uptake depending on how uptake is measured.



N=66 measures of uptake.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value) and direct load control/automation only studies.

Attractiveness by tariff type - across studies



Tariff type	Count
Static + (Static + CPP) + CPR	2
CPR	5
Capacity pricing	3
Static	22
CPP	10
DP	5
RTP	10
Static + RTP	1
Static + CPP	4
Static + (Static + CPP)	1
Static inverse	1

Please note that categories with a combination of tariffs (e.g. Static + RTP) reflect cases where reports did not distinguish between uptake to different tariffs and cases in which one design (e.g. CPP) was overlayed over a static tariff. We recommend that uptake for these tariffs is not given any strong weighting. We would be happy to discuss removing such tariffs from bar charts for the final report (but include them here for transparency).

N=66 measures of uptake.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Attractiveness by tariff type - across studies (cont'd)

- Real time pricing tariffs are substantially and statistically significantly less popular amongst consumers than static TOU tariffs ($p<0.01$)
  - Mean static: 35%
  - Mean RTP: 17%
- Dynamic tariffs are marginally less popular amongst consumers than static TOU tariffs ($p<0.10$)
  - Mean dynamic: 22%
- Critical peak rebates are statistically significantly more popular amongst consumers than real time pricing tariffs ($p<0.05$)
  - Mean CPR: 53%
- Capacity pricing is less popular than static time of use ($p<0.001$) and marginally less than dynamic time of use ($p<0.10$):
  - Mean dynamic: 22%
  - Mean capacity pricing: 39%
- The differences in uptake between the other tariffs are not statistically significant, however we do not interpret this to mean that people are indifferent between static time of use and other tariff designs because it is also possible that there are genuine differences which, due to sample size, we cannot detect. For example, the evidence on CPP and CPR is mostly drawn from a single Australian survey study which obtained relatively high estimates of uptake.

Attractiveness by region

Attractiveness is higher in Australia than anywhere else – and higher in the UK than in the US. However, this is likely to be because all of the Australian evidence and the majority of the evidence from the UK is survey based, which elicits much higher average uptake levels than measures based on trial recruitment or commercial offerings, which the US literature is predominantly based on.

Country	Mean (%)	Lower 95% confidence interval	Upper 95% confidence interval	N
Australia	51	46	56	15
UK	30	22	37	15
US	25	10	35	25
Norway	25	-	-	1
France	19	-165	2	2
Netherlands	14	4	25	8

N=66 measures of uptake. * Evidence drawn from a single study.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Attractiveness by opt-in vs opt-out

Opt-out enrolment results in much higher enrolment rates than opt-in – opt-out has only been tested in three studies and all were in the US.

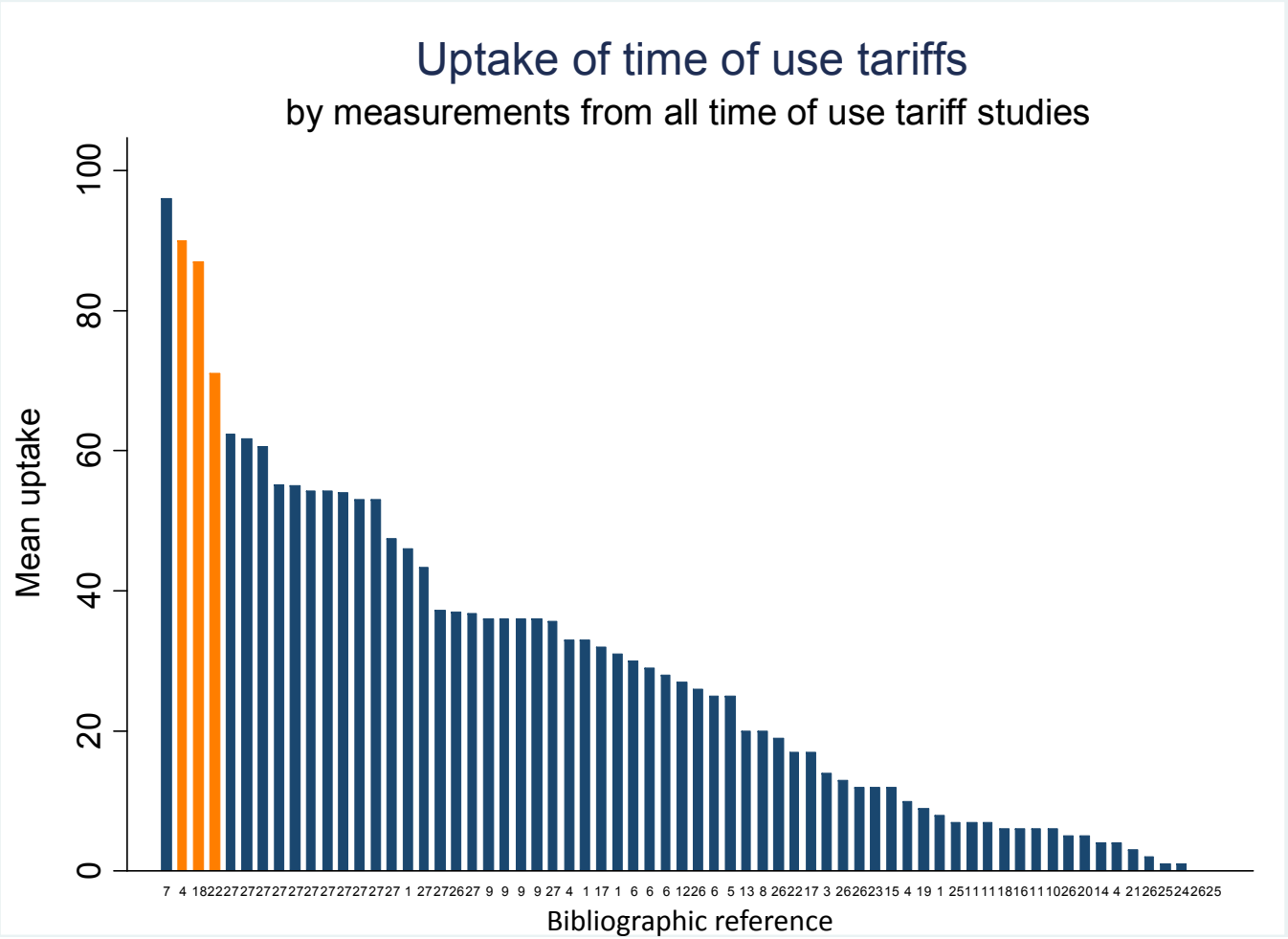
The difference is statistically significant even after controlling for all other variables.

	Mean uptake (%)	Lower 95% confidence interval	Upper 95% confidence interval	N
Opt-out*	83	57	108	3
Opt-in	26	21	32	62

N=66 measures of uptake. * Evidence drawn from three studies.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Attractiveness by opt-in vs opt-out cont'd

Aside from one study (7), opt-in enrolment rates never exceed 50% whereas opt-out enrolment ranges from 70%-90%.



N=66 measures of uptake.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Attractiveness by opt-in vs opt-out (cont'd)

The paper with the highest enrolment rate (an opt-in study) states that "the high sign-up rate is directly attributed to an intense marketing effort consisting of: (1) an initial mailing to introduce the CCC™ program; (2) follow- up phone calls and door drop-offs to arrange an in-person meeting; and (3) subsequent workshops to answer questions." [13, p. 899].

However, a number of other trials used similar recruitment methods and did not achieve these high enrolment rates so it is hard to explain why this programme was so successful.

Another possibility is that this trial recruited almost exclusively amongst central air conditioning customers, who may be able to make higher savings on the tariff than consumers without these high consuming electrical loads.

N=66 measures of uptake.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Attractiveness by message frame

The majority of uptake measurements are taken from studies which have attempted to motivate people to sign up to a TVT to save money. Some measurements (2) have been taken from studies which aim to motivate people to sign up by emphasising the environmental benefits of TVTs. However the difference in uptake are not statistically significant.

	Mean uptake (%)	Lower 95% confidence interval	Upper 95% confidence interval	Count
Money	36	36	36	2
Money & environment*	30	22	37	48
Unknown	26	14	38	16

N=66 measures of uptake. * Evidence drawn from a single study.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Bill protection

Bill protection, in which participants are offered a refund if they pay more on the time varying tariff than their existing tariff, has been used but very rarely (just 12 measures are taken from a study using bill protection).

The difference in uptake is not statistically significant, even after controlling for all other variables.

	Mean uptake (%)	Lower 95% confidence interval	Upper 95% confidence interval	Count
Bill protection offered	35	16	53	12
No bill protection	27	21	33	49
Unknown	35	-9	78	5

N=66 measures of uptake.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Additional financial incentive

Some industry trials provide participants with financial payments for participating e.g. £100 M&S voucher in the case of the CLNR trial.

Uptake is higher when financial incentives are provided compared to no financial incentive provided (excluding the 4 unknown categories) and this difference is statistically significant, even after controlling for all other variables.

	Mean uptake (%)	Lower 95% confidence interval	Upper 95% confidence interval	Count
Financial incentive offered	35	28	41	35
No financial incentive offered	20	10	30	27
Unknown*	37	-28	102	4

N=32 measures of uptake (confined to studies that were non survey based)
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Automation

Some industry trials and tariffs were accompanied by automation devices – usually smart thermostats which control space heating and cooling.

However, the difference in uptake is not statistically significant, regardless of the inclusion or exclusion of control variables.

	Mean uptake (%)	Lower 95% confidence interval	Upper 95% confidence interval	Count
Automation present	31	16	46	15
No automation	32	25	39	33
Unknown	18	4	31	7

N=66 measures of uptake.
This excludes stated preference surveys where it was not possible to compute a proportion who agree to sign up (e.g. willingness to pay surveys where the outcome measure is a monetary value), notably the BEIS 2016 study, and direct load control/automation only studies.

Within study comparisons

Cross-study evidence on the role of automation, message framing and the impact of many tariff designs on uptake was inconclusive.

To guide our interpretation of the non statistically significant results, we compare results from studies which explicitly sought to test the impact of these factors (e.g. tariff design and automation) on uptake.

Attractiveness by tariff type and automation – within studies

- Five surveys (Dutschke et al., 2013; Stenner et al., 2015; Buryk et al., 2015; Fell et al., 2016; BEIS, 2016) explicitly tested the impact of tariff design on uptake

- Three of these test the impact of automation on uptake (Dutschke et al., 2013; Stenner et al., 2015; Fell et al., 2016)

- These are studies in which participants were randomly assigned to one of a variation of tariffs, meaning that uptake rates to the tariff can be interpreted as reflecting consumer attraction to those specific types of tariffs. By comparison, although many tariff trials included multiple tariffs, because participants were often required to sign up to the trial without knowing which tariff they had or would be assigned to (and, regardless, reports do not break down uptake by tariff type), these studies do not on their own lend themselves to any interpretation of the impact of tariff design or automation on uptake.

- Note that Buryk et al (2015) and Dutschke et al (2013) were two of the studies excluded from the meta analysis because it was not possible to transform their outcome measure into a proportion measure of uptake

- These studies are described on the next slide

Attractiveness by tariff type and automation – within studies (cont'd)

- Dutschke et al (2013) compared willingness to switch to three different tariff designs with and without automation*:
  - Static time of use
  - Dynamic time of use
  - Real time pricing

- Stenner et al. (2015) compared willingness to switch to five different time-varying tariffs with a flat rate tariff used as the baseline against which each time-varying tariff was compared, with and without automation*:
  - Flat rate tariff
  - Static time of use
  - Critical peak pricing
  - Peak time rebate
  - Real-time pricing
  - Capacity pricing

- Buryk et al (2015) compared willingness to switch to two different time-varying tariffs in which the baseline was a flat rate tariff (no automation was present):
  - Static and dynamic time of use (results are not disaggregated)
  - Critical peak pricing

* Studies do not report interaction effects between the offer of automation and tariff type.

Attractiveness by tariff type and automation – within studies (cont'd)

- Fell et al. (2016) compared willingness to switch to two different time-varying tariffs with and without automation and direct load control, in which automation of home heating is performed by the customers' supplier:
  - Static time of use
  - Dynamic time of use
  - Direct load control of home heating

- BEIS (2016) compared willingness to switch to four different tariffs:
  - Static time of use
  - Dynamic time of use
  - Critical peak pricing
  - Direct load control of home heating

Tariff type within study results

- Both studies that included a flat rate tariff as the baseline found that the time-varying tariffs of any type were statistically significantly less attractive to consumers than a flat-rate tariff (Dutschke et al, 2013; Buryk et al, 2014)

- Studies find some evidence that real time pricing and dynamic tariffs are less popular amongst consumers than static TOU tariffs
  - There is mixed evidence on static and dynamic tariffs, with Dutschke et al. (2013) finding static to be significantly more acceptable, while Fell et al. (2015) did not find a significant difference (although other measures showed that people saw it as significantly more difficult to use and gave a lower expectation of control with regard to energy use).
  - Studies in which the flat rate tariff was the baseline (Stenner et al, 2015) found that the real-time pricing tariff was twice as unpopular than the static TOU tariff, when both tariffs were compared to the flat-rate tariff
  - However, the only study to report interaction effects between automation and tariff type (Fell et al, 2016) finds that the offer of automation combined with a dynamic tariff significantly increases intention to switch (this is not observed for the static tariff)
  - Buryk et al (2015) do not disaggregate the results on the static tariff from the dynamic tariff so this study cannot be used to judge the relative uptake of dynamic tariffs compared to otheres

- Three studies included Critical Peak Pricing (Buryk et al., 2015; Stenner et al, 2015; BEIS, 2016) but find conflicting results
  - Buryk et al (2015) results suggest that CPP is less popular than static time of use, when compared to a flat rate tariff and BEIS (2016) results similarly suggest that CPP is less popular than static time of use
  - Stenner et al (2015) results suggest that CPP is no more or less popular than static time of use, when compared to a flat rate tariff

Automation within study results

- All studies testing the impact of automation find that automation increases uptake to time-varying tariffs (Dutschke et al, 2013; Stenner et al, 2015; Fell et al, 2016):
  - Dutschke et al (2013) finds that automation increases uptake by just over half a Likert scale point (7 point scale)
  - Stenner et al (2015) finds that automation increases uptake by 4.5% (1-100 scale)

- Only one study reports interaction effects between automation and tariff type (Fell et al, 2016), finding that automation increases uptake to dynamic tariffs but not static TOU tariffs

- Two studies compare uptake to direct load control amongst a nationally representative GB sample run in 2015 and 2016, in which a third party controls home heating, to the other time-varying tariffs but obtain conflicting results:
  - Fell et al (2016) finds that direct load control is statistically significantly more popular than any other tariff tested (static time of use [with and without automation] and dynamic time of use [with and without automation]
  - BEIS et al (2016) finds that direct load control was one of the least popular tariffs and that a static TOU tariff is the most popular (compared to dynamic time of use, direct load control and critical peak pricing) – although the poplarity of direct load control did not differ from critical peak pricing

Other inconclusive within study results

- The only study (Stenner et al, 2015) to explicitly test whether bill protection would increase uptake to time-varying tariffs found that bill protection increase willingness to switch by 10% (more than automation, which increased uptake by 5%)

- The only three studies testing the impact of environmental messaging on uptake to time-varying tariffs found conflicting results:
  - Schwartz et al (2015) found that telling people about the environmental benefits of a RTP tariff increased willingness to switch to a RTP tariff relative to telling people about the potential energy bill savings BUT that when the environmental message was combined with a financial message, there was no effect (the authors interpret this as evidence that appealing to self-interested motivations crowds out people's altruistic motivations)
  - However, Buryk et al (2015) found that telling people about the environmental benefits as well as the financial benefits increased willingness to switch to time-varying tariffs
  - Consistent with Schwartz, Nicolson et al (2017) found that telling people about the environmental and financial benefits of a static TOU tariff made no difference to willingness to enrol relative to just mentioning the potential financial savings (this study did not test an environmental only message)

Attractiveness summary – overall

- Based on evidence from 66 measures of median enrolment to TVTs across 27 studies average enrolment is 28%

- However the range in enrolment measures is huge: the standard deviation around the mean is 24% and uptake measures range from 0%-96%

- Most of the variation in enrolment rates is likely to be explained by two factors:
  - Differences in the way that enrolment is measured: surveys provide higher estimates than trial recruitment and enrolment in commercially available tariffs (and survey evidence predominates)
  - Opt-in versus opt-out enrolment: the high enrolment rates are obtained from opt-out enrolment (with one exception); opt-out enrolment achieves a median enrolment rate of 83% whereas opt-in achieves a median of 26%

Attractiveness summary – tariff design

- The evidence suggests that RTP pricing tariffs and dynamic tariffs are less popular than static TOU tariffs – this finding is highly robust
- Lack of evidence on non static tariffs
  - 30% of measures are based on measures of attractiveness of static tariffs
  - There is a particular dearth of evidence on CPR tariffs (5 measures, 3 studies), capacity pricing (3 measures, 1 study) and inverse static TOU (1 study
  - We recommend that uptake for tariffs for which the evidence is inconclusive be modelled based on the mean uptake for each tariff (as this is the best available evidence) or ideally, the upper and lower 95% confidence levels

Attractiveness summary – cross-country

- Although uptake varies across regions, we advise not interpreting this as evidence that attractiveness of TVTs varies across regions due to differences in the way attractiveness has been measured across regions (industry trials, commercial sign ups, surveys)
- In particular, although attractiveness is higher in the UK than in the US this is likely to be because the majority of the evidence from the UK is survey based, which elicits higher average uptake levels than measures based on trial recruitment or commercial offerings, which the US literature is predominantly based on
- We recommend that the full evidence base is used to judge the likely attractiveness of TVTs in GB rather than just considering GB based measures because the US has a much wider variety of evidence types (e.g. surveys, commercial uptake, trial recruitment) than GB and a much higher number of measures
- A large proportion of studies from the US are from states with an average external temperature of 11°C and below (similar to the UK)

Attractiveness summary – increasing uptake

- There is relatively little evidence on what might increase uptake to TVTs; of 35 studies just 8 tested alternative ways of incentivising uptake other than opt-in enrolment combined with a "switch to save money" message
- The evidence that does exist focuses on just two methods of increasing uptake:
  - Opt-in vs opt-out enrolment (3 studies)
  - Money versus environmental marketing (2 studies)
- Although bill protection and upfront financial incentives have been used in some trials, the differences in uptake in the meta-analysis using the data available are not statistically significant (possibly due to a lack of studies including these as factors)
- However, when the impact of bill protection and automation on uptake has been tested systematically in randomised trials, the evidence suggests that both increase uptake

Attractiveness summary – increase uptake (cont'd)

- Based on the evidence, we suggest that the following are likely to increase uptake to time-varying tariffs
  - Opt-out rather than opt-in enrolment (strongly boost uptake)
  - Upfront financial payments (moderately boost uptake)
- If opt-out does present consumer welfare concerns, ways of increasing opt-in enrolment will be required
- Bill protection and automation are promising avenues for future research into methods of increasing opt-in uptake to time varying tariffs
- Message framing is also a significantly underexploited and cheap method of increasing opt-in uptake to time-varying tariffs – it has been highly successful in other domains, including education and health, but has rarely been applied to time-varying tariffs

Summary statistics for modelling uptake

Averages

- Overall median: 27%
- Opt-in median: 26%
- Opt-out median: 83%
- Static mean: 35%
- RTP mean: 17%
- All other tariff types: use the upper and lower 95% confidence levels OR use the mean uptake

Range based on lowest and highest observed 95% confidence intervals around mean uptake

- Opt-in: 1%-43%*
- Opt-out: 57%-~100%**

* 1% is the smallest observed lower 95% confidence interval [pertaining to commercial uptake] and 43% is the highest observed upper 95% confidence interval [pertaining to survey uptake]

** 57% is the lowest observed 95% confidence interval [pertaining to non survey methods] and 100% is the highest estimated interval. No surveys used opt-out enrolment.

Research needs

- More research is required to measure consumer attractiveness of non static TOUs, especially Critical Peak Pricing and Critical Peak Rebates (if these are judged as being valuable for the energy system)
- Evidence suggests that money is just one driver of decision making; more research is required to establish methods of increasing uptake to TVTs that do not just rely on telling people that switching will save them money. Median uptake is 17% and the majority of studies include 'money marketing' but the UK Government relies on 30% signing up to a static TOU by 2030. Promising areas for future research include:
  - Bill protection
  - More/less automation
  - Tailored marketing (e.g. at consumers with flexible electrical appliances)
  - Prize draws
  - Electricity pre-payment
  - Upfront cash payments
  - Presenting savings in terms of points (e.g. Nectar points) rather than money
- More GB research that measures demand based on revealed rather than stated preferences – this research needs to be designed to measure recruitment rates as an aim in itself (rather than this being a bi-product of running responsiveness studies) on average and amongst sub-groups
- More research is required into the impact of opt-out enrolment on outcomes other than uptake (e.g. customer satisfaction and energy consumption)

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Appendix 1 – keywords used in rapid review

Table 1: Concepts and search terms to be used in conducting the search, with example search string for use in Scopus. Syntax will be adapted for use in other databases.

	Time of use	Uptake
Concept	Time of use tariffs	Uptake
	Time-varying tariffs	Consumer
	Off peak tariffs	Acceptability/acceptance
	Dynamic pricing	Switching
	Cost-reflective tariffs	Preferences
	Critical peak pricing/rebates	
	Peak-time rebates	
	Real-time pricing	
Search term	"time of use"	uptake
	"time-of-use"	consumer*
	"time-varying"	accept*
	"off peak"	switch*
	dynamic W/2 pric* OR tariff*	preference*
	"cost-reflective"	
	"critical peak"	
	"peak-time"/peaktime	
	"real-time pric*"/realtime	
Scopus example	TITLE-ABS-KEY("time of use" OR "time-of-use" OR "time-varying" OR "off peak" OR (dynamic W/2 pric* OR tariff*) OR "cost-reflective" OR "critical peak" OR "peak-time" OR peaktime OR "real-time pric*" OR "realtime pric*") AND TITLE-ABS-KEY(uptake OR consumer* OR accept* OR switch* OR preference*) AND ALL(tariff OR pric*) AND ALL (energy OR electr*)	

Appendix 2 – inclusion criteria in rapid review

Table 2: Inclusion and exclusion criteria for attractiveness review screening.

Include if source	Exclude if source
Is in English	Is not in English
Reports findings from empirical research or evaluation.	Does not report empirical results (e.g. includes only modelled uptake).
Includes quantitative findings that can help to inform estimation of tariff uptake rates.	Reports only qualitative findings.
Reports research designed to enable estimation of the degree of consumers' expressed or demonstrated willingness to sign up (hypothetically or in reality) to at least one TVT design, and the reasons associated with this.	Does not report research including a time-varying tariff (for example, focused only on direct load control or other non-price-based demand response product).
Reports work conducted in an OECD country.	Reports work conducted in a non-OECD country.
Is focused on the domestic sector.	Is focused on the non-domestic sector.

Section 3:
Satisfaction Assessment

Aims

This task aimed to assess participant satisfaction levels during previous TVT trials and identify reasons for satisfaction (or lack of it).

Approach

- No additional search conducted but information extracted from identified files in reviews and studies known to us
- 19 documents reviewed
- Challenges in interpretation:
  - Often low response rate
  - Various measures of satisfaction
  - Often responses not split up for tariff type
  - Generally measured only amongst those who did not drop out

Satisfaction

- Between 60% - 96% of participants satisfied with program#

60% TOU-CPP [11]*	**70% TOU-CPP [2]**	**74% CPP, CPR, HR [10]**	**83% TOU-CPP [1]**	**86% CPP [7]**	**87% TOU, CPP [6]**	**96% TOU, TOU-CPP [5]**

- Same tariff design (TOU-CPP) had highest and lowest satisfaction across studies
  - Due to effect of smart control system? (present in [5])

- *Number in brackets indicates respective study, see reference slide 37
- # Satisfaction amongst dropouts 20% [11]

Satisfaction – other measures

- Participants were moderately satisfied or satisfied
  - 5.1 (out of 6) [8]
  - 7.6 (out of 10 =extremely satisfied) [12]
  - 7.7 to 8.3 (out of 10= very satisfied) [16]
  - 4 (out of 5 = very positive experience) [19]
  - 3.7 (out of 5 = extremely satisfied))[3]
- 91% endorsed the tariff [14]
- 'high' satisfaction, not detailed [15]
- 97% of the respondents support program [17]

Satisfaction – within-study-difference between tariffs

- Inconclusive results
  - CPP, CPP-LC, and CPR groups report higher satisfaction than those in the control group [19]
  - CPP most satisfying rate, followed by PTR and TOU [8]
  - 89% of TOU and 89% of CPP-F consider rates as fair, compared to 82% for CPP-V [4]
  - Control group as satisfied as CPP and CPR with TOU with / without IHD [3]

Recommend to others (general)

- Between 49% - 89% of participants would recommend program to others / friends

49% CPP, tech [13]	**65% TOU [18]**	**75% TOU-CPP [11]**	**79% TOU-CPP [12]**	**81% TOU, CPP, CPR [19]**	**86% TOU-CPP [2]**	**89% CPP, CPR, HR [10]**

- Same tariff structure with lowest and highest rating

Participate again

- Between 69% - 97% of participants would participate in similar program / participate again / sign up to similar tariff

68% TOU, CPP [6]	**77% dTOU [14]**	**80% TOU, CPP-V, CPP-F [4]**	**92% CPP, CPR, TOU [8]**	**92% CPP, tech [13]**	**95% TOU, RT [9]**	**97% TOU [17]**

- 90% [1] and 74% [3] of participants chose to participate in a second year

Opt-in vs. opt-in

- The vast majority of studies reviewed were opt-in
- One study had both opt-in and opt-out group [13]
  - Response rate to survey almost double in opt-in group (financial incentive) than opt-out group, 85% vs. 46%
  - But actual responses not reported split up depending on recruitment method (over 90% would consider continuing in the program)

Dropout

- 10% (variations of TOU-CPP) [1]
- 15% (TOU-CPP) [11]
- 16% (4-tiered TOU) [17]
- 21% (TOU) and 30% (flat rate with CPP) [6]
- 26% (TOU-CPP) [2]
- 43% (TOU, CPP, CPR) [19]
- Not always clear why participants drop out
  - Dissatisfaction vs. e.g. moving away, not qualifying anymore

Other findings

- Saving money most important motivator / reason for satisfaction [3, 6, 10, 11]
- Not saving money was most important reason for dissatisfaction / drop-out [2, 3, 6, 11]
- Unpredictability of peak events led to some dissatisfaction [2]
- Equipment wasn't changed much once set up [2]/ technology not used much [7]

Summary satisfaction

- Generally positive evaluation
- Majority would refer program to friends
- Same tariffs evaluated very differently
  - Likely to reflect trial (not tariff) effects
- No tariff clearly better / worse
- Money saving / non-saving important for satisfaction

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Section 4:
Assessment of Consumer Response to Time-Varying Tariffs

Aims

The key aims of this review were to:

- Identify magnitude of peak load reduction associated with different types of TVT
- Identify role of types/sizes of load, and of automation
- Identify associations between response/savings and socio-demographic factors.
- Indicate the likely relevance of the results of international trials to the UK context.

Approach

We undertook a ‘review of reviews’ combined with a review of recent UK/Irish TVT trials. The approach is set out in the review protocol included separately.

- 23 sources identified after screening, with more detailed extraction from 10 reviews plus 4 recent UK/Irish trials
- Drawn from ‘attractiveness’ search and additional identified material.
- Information extracted where applicable on peak reduction, overall reduction and bill savings, role of technology and automation, and possible distributional impacts.

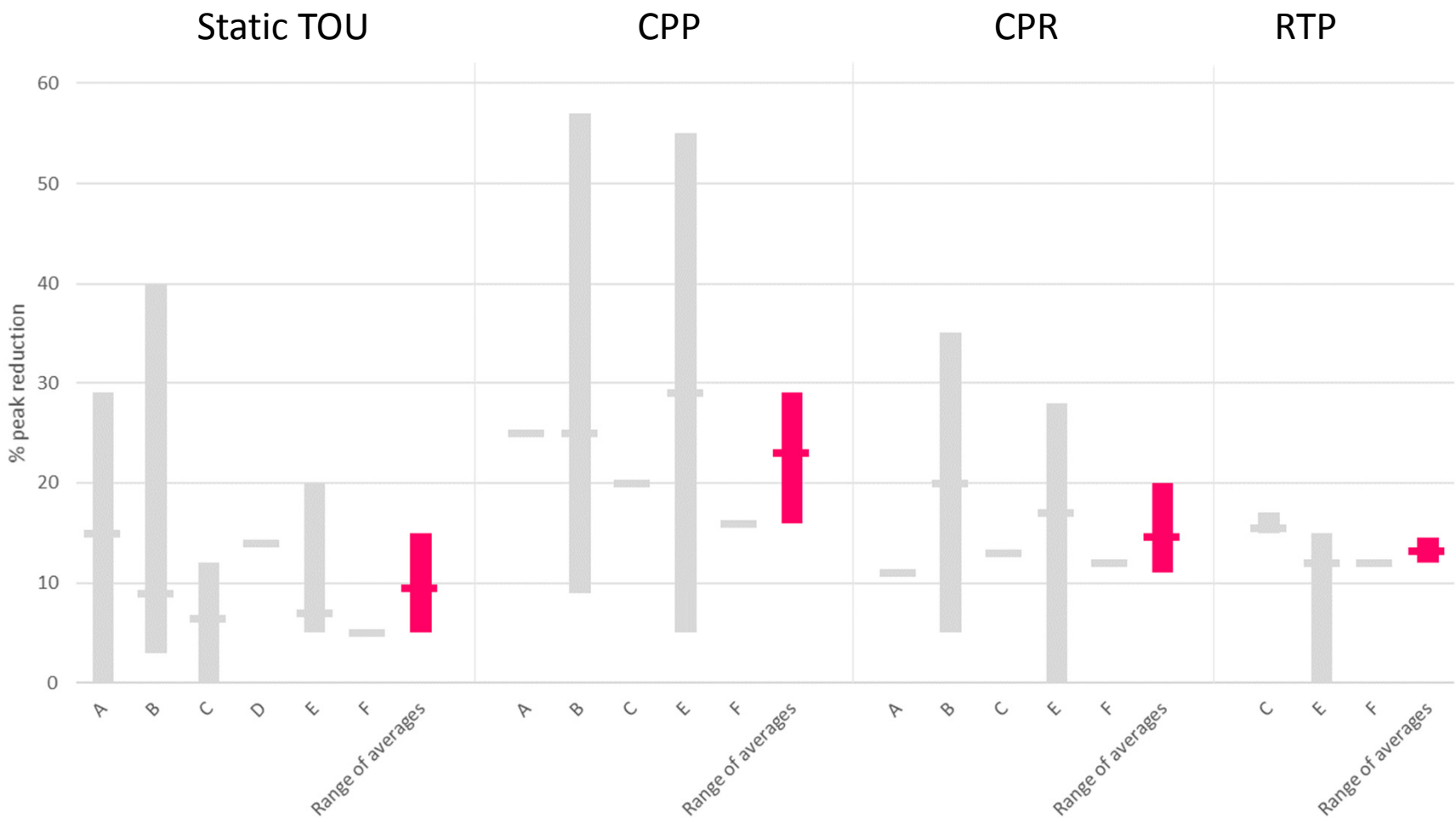
Peak reduction

TVTs can aim to affect electricity use patterns to a number of ends, but the most common target is peak reduction. Most of the reviews examined here include a measure of peak reduction for the studies or programmes they include represented as a percentage compared to absence of a TVT.

- Figure 1 presents a headline summary of peak reductions by review, broken down by tariff type.
- Where possible a range is included showing the maximum and minimum effects observed, and in each case an average is given. Note that where possible a median has been used (reducing the impact of outliers), but a mean (or unspecified 'average') is included where this figure was not available.
- An additional bar has been included for each tariff type indicating the range of the reported averages, and the mean of those averages.

Caveats

- It is important to note that some (indeed many) studies are likely to have been captured in more than one review. However, the extent of this overlap is hard to quantify since the reviews do not always report in detail which studies they have included, or which results are extracted from which studies. The effect of any double-counting would be to push average findings towards those from the most commonly represented studies. The findings should be viewed with this caveat in mind, and for this reason we prefer to keep to indicative ranges and relative comparisons.
- It is also the case that these results make no distinctions based on peak to off-peak price ratios, peak times and durations, number of tariff tiers of critical peak events, location, number of studies, sample size, technology use, etc. They are therefore presented for indicative overview purposes only. For consideration of some of these questions see sections ??? to ???.



A	US DoE 2016
B	Faruqui and Sergici 2013
C	Frontier Economics and Sustainability First 2012
D	Gyamfi, Krumdieck, and Urmee 2013
E	Newsham and Bowker 2010
F	Stromback et al. 2011

Figure 1: Range and average peak reductions of included reviews by tariff design

Key observations

- There is a large degree of variability in responsiveness even within classes of tariff design, and overlap in the ranges of reductions achieved by the different tariff designs.
- CPP tariffs have tended to elicit the strongest peak reductions (on event days), concentrated around 16-29%. This tariff type also has the highest observed variability and includes the very highest peak reductions.
- Followed by CPR, clustering around 11-20%, and static TOU at 7-15% (NB TVT applies day in, day out).
- There is relatively little data for RTP tariffs, but observed peak reductions here have tended to be around 15%.

Peak reduction in UK/Irish trials

The Customer-Led Network Revolution, Energy Demand Reduction Project and Irish Customer Behaviour Trials all tested the effect of static TOU. Peak reductions were at the mid to lower end of the ranges represented in the reviews:

- CLNR: reduction in electricity consumption in peak hours of 1.5-11.3%
- Irish CBT: peak reduction average 8.8%, range of 7.2-11.6% with higher reduction for higher price ratio
- EDRP: Inconclusive, one trial showed shifting of electricity use from peak to off-peak periods of up to 10%

The Low Carbon London trial tested a dynamic tariff which sits between real-time pricing and CPP in that it had fixed price tiers which varied unpredictably, with occasional high price periods.

- Peak reductions of 7-9% where observed on average across all high price periods (with an increase in consumption of 11-14% at low price periods)

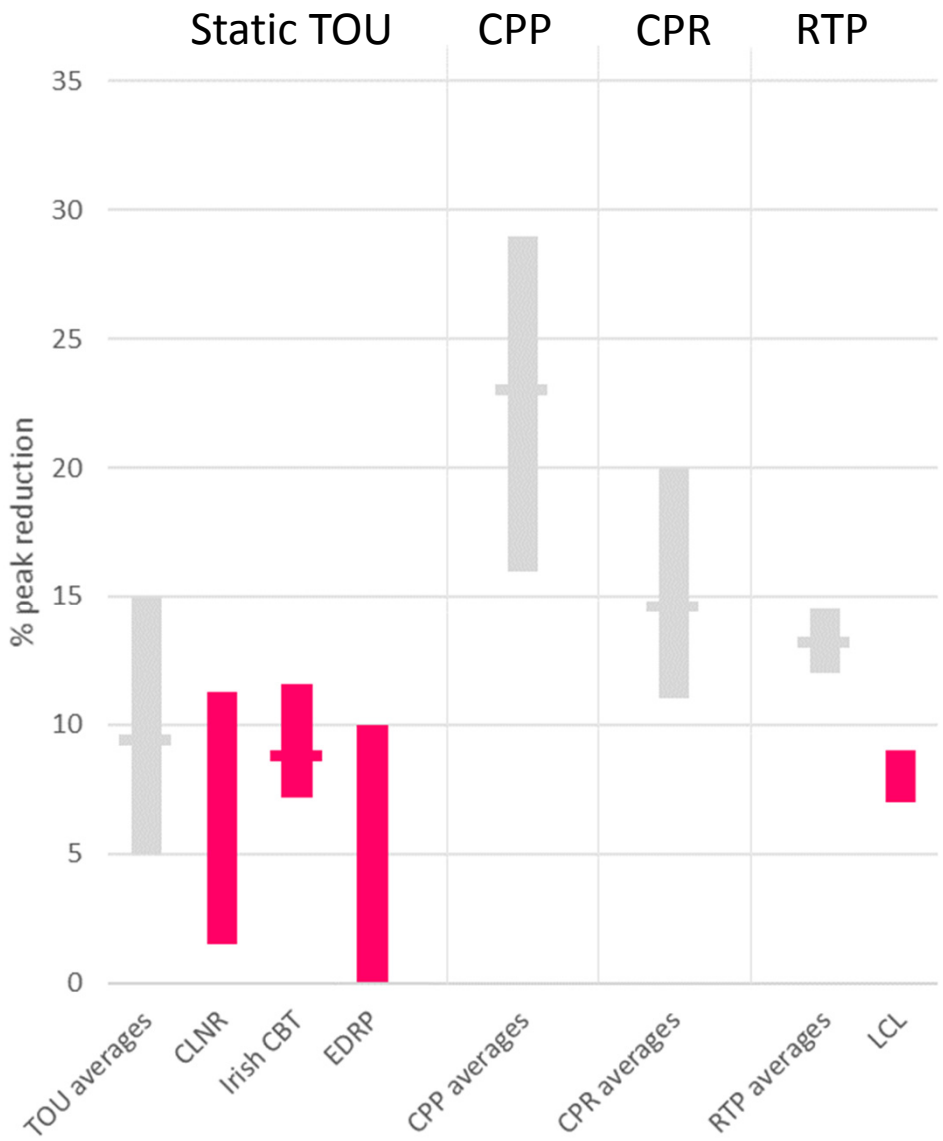


Figure 2: UK/Irish trial peak reductions compared to reviewed averages.

Presence of large loads

The reviews are consistent in showing that the magnitude of response tends to be larger when customers have large loads such as air conditioning, electric heating and other major appliances. For example, modelling by Brattle (presented in Faruqui and Sergici 2013) suggests that while customers with major appliances in hot climates may be able to reduce by 15% at a 3:1 peak to off-peak price ratio for static TOU and up to 40% for higher ratios, the reduction for customers in cool climates with no major appliances is unlikely to exceed 10% at any ratio.

This latter figure is broadly in line with the results of recent UK/Irish trials, representing a cooler climate with limited penetration of large electrical loads (~10% of UK homes have electricity as primary source of space heating [Owen, Pooley, and Ward, 2012]). The extent of electric heating in the trials themselves is mixed (low for CLNR and Irish CBT, higher for LCL), but in no case was automated response to price changes offered.

Electric vehicle (EV) charging

No studies were identified which review findings on response of EV drivers to TVT pricing. However, a there is empirical evidence from a number of individual studies.

- 'The EV Project' (Schey et al. 2012) compared charging behaviour in two regions of the US, one with access to TVT rates (San Francisco, n=1044), the other without (Nashville, n=289). In the non-TVT region charging demand peaked at 20.00 on weekdays, while in the TVT region demand spikes at midnight (the beginning of the off-peak period) and spikes at 01.00.
- In another study under 'The EV Project' (Biviji et al. 2014), Portland Gas and Electric TVT customers did only a fifth of their charging outside of off-peak hours, while flat-rate customers, did 16% more charging in peak than off-peak. Again, a large spike was seen in charging for TVT customers at the beginning of the off peak period.
- [continues]

Electric vehicle (EV) charging (cont.)

- In a trial by San Diego G&E (Cook et al. 2014), EV users on TVTs (n=430) did 78-85% of their charging during super off peak periods. It was estimated that the majority of drivers used timers to coincide charging with off-peak periods.
- In a smaller trial in Texas (Zarnikau et al. 2015), EV owners (n=34) increased night-time charging from 32 to 55% during during months when a TVT was in operation.

In summary, there is emerging empirical evidence that EV owners' charge their vehicles differently in response to TVT pricing. The range of reported responses is large, but several studies have shown the majority of charging taking place in off peak hours.

Role of automation

The presence of technology which could automate response to TVT pricing consistently increased peak reduction.

- The US DoE trials focused on the use of programmable communicating thermostats (notably, all for air conditioning). Response to static tariffs was increased from an average of 10 to an average of 21% (at price ratios of 2:1-4:1), while CPP and CPR responses also increased (from av. 20% to av. 35% and from av. 5% to av. 25% respectively). Automation also had modest reliability benefits.
- Similar order of effect in other reviews – see chart next slide showing means ranges, and/or ranges as reported. Where no averages but only ranges were reported, the mid-points of those ranges have been marked and included in calculating the range and average of averages.
- None of the recent UK/Irish trials tested automation of appliances in response to price signals.

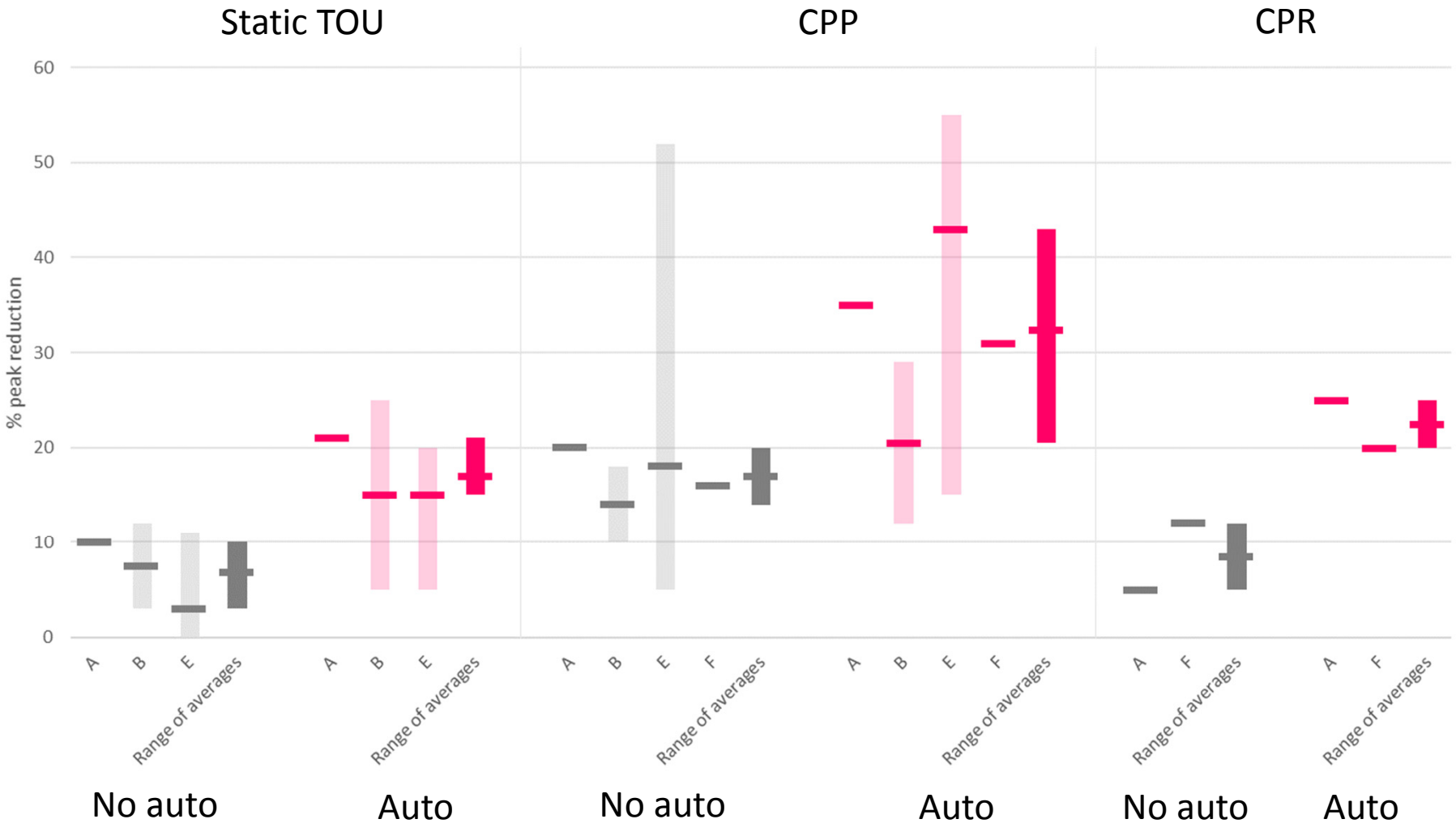


Figure 3: Association between enabling technology and peak reduction.

A	US DoE 2016
B	Faruqui and Sergici 2013
E	Newsham and Bowker 2010
F	Stromback et al. 2011

Considerations for UK context so far

Mapping these results to the UK context is not straightforward.

- CPP/CPR are most often used to combat high heating loads in summer
- Most of the effects shown in the results reflect automaton of air conditioning systems.
- Growth in major appliances in UK likely to be in heat pumps (for heating) or electric vehicles, with different load patterns and storage capabilities.
- There is limited evidence from large-scale trials of the effectiveness of automating these technologies to respond to regular or event-based price changes. However, what evidence there is does suggest that automation has an important role to play here too (for example a study by SDG&E found EV owners used timers to set their EVs to charge at off-peak times).

Saving money

Few reviews reported on financial savings, and extent of savings is clearly dependent on specific aspects of tariff design. The review by Frontier Economics and Sustainability First found that people tended to save money on TVTs, and suggested this is mainly because such tariffs are often designed to be revenue neutral and, when people do respond, it tends to be to make savings. Identified savings varied substantially for the limited number of trials reported (see p33):

- Proportion of customers saving tended to be above 70%
- Actual savings ranged from 3-18% on average for TVT, 2-5% for CPP/CPR, and up to 39% for RTP.

Trial results on this can other metrics can be skewed as bill protection is often offered, meaning customers face no actual penalty if they do not alter their behaviour.

Saving money – UK/Irish trials

Reported savings for the UK/Irish trials were as follows:

- LCL: Over 75% saved compared to flat rate, mean saving £21, 4.3% (info on average loss unavailable), maximum loss £40
- CLNR: 40% of participants would have lost money (without bill protection), median loss £18.40 (info on average saving unavailable), maximum loss £190.78.
- Irish CBT: Range of measures used, but on average participants saved (average 0.67-25.47 Euros depending on measure).

Socio-demographic differences in response

There is mixed evidence on the existence of associations between various socio-economic variables and response to TVT pricing.

Previous Brattle review and modelling based on data from US trials has suggested peak reduction tends to be slightly lower for low-income than average customers, but that the majority of such customers will benefit financially even without load shifting as their demand tends to be flatter (Faruqui et al. 2010). We are not aware of evidence of this flatter profile being the case in the UK (although there is evidence of lower overall and peak demand in low-income groups, e.g. from LCL).

The review of pilots by VaasaETT (2011) found that 'social factors such as age, income, education, household size, load profile and environmental factors such as house type, house size, house age etc. ... do not have an impact on pilot results' (p35). However, they note that such factors are rarely captured by studies.

The review by Frontier Economics and Sustainability First (2012) found no studies specifically collected information on vulnerable groups as defined by the Government's Fuel Poverty Strategy (people with a long-term illness, families with children, disabled people and the elderly).

Socio-demographic differences in response (cont.)

The UK/Irish trials found as follows:

- CLNR: No significant difference between Mosaic categories either in peak reduction or likelihood of saving/losing money overall.
- Irish CBT: Higher socio-economic groups achieved greater overall electricity reductions (AB>C1>C2,D,E) – they also tended to consume more originally. Less pattern for peak reduction (NB statistical analysis not included) – higher reduction associated with more education and having children in the home. Less change for people on Free Electricity Allowance (likely to be vulnerable) but they are partly insulated against price. Fuel poor people were shown to be able to reduce electricity consumption at peak (6.8-10.7%).

Socio-demographic differences in response (cont.)

- EDRP: Inconclusive, more shifting observed in smaller households.
- LCL: No significant differences in response between ACORN groups. Greater response in larger households (cannot extrapolate beyond 3 occupants) – so opposite to EDRP. This trend remains but is less pronounced for participants they classified as in 'adversity'. Also, higher consumers (usually more affluent) benefitted more from low-price periods.
- NB The Energywise trial, which is currently underway and is being coordinated by UKPN, should provide evidence specifically focused on fuel poor customers' response to TVT pricing.

Socio-demographic differences in response (cont.)

Taken together, findings on the potential impact of TVT pricing on low income and vulnerable groups present a mixed picture. There clearly exists the opportunity for people to end up spending more on such tariffs, but there is no strong evidence that certain groups systematically lose more than others.

Clear evidence has been found, however, that households with large loads and the ability to automate their response to price changes can have a significant impact on peak reductions, and therefore potentially ability to save money. While it is not assured that low income or vulnerable groups are less likely to have such loads (for example, heat pumps are often installed in social housing), loads such as electric cars may be expected to be preferentially purchased by higher income groups due to their high cost. This in turn could be expected to result in stronger distributional impacts of TVT pricing.

Other issues

- Trial duration: The VaasaETT review found a slight decrease in peak reduction in longer static TOU trials, while the opposite was the case for CPP/CPR trials.
- Trial size: VaasaETT also broke down pilots by sample size. There was substantial variability, but no indication that larger trials saw smaller peak reductions.
- Opt-in/out: The majority of TVT trials are opt-in (like TVTs in real life). The US DoE CBS trials showed that opt-in customers tended to be more responsive than opt-out customers (11% peak reduction after two years, vs 6%).

Summary

- Reviews show high variability of peak reductions within and between tariff designs, but CPP tends to provoke highest reductions, followed by CPR and static TOU (RTP similar, less evidence).
- UK/Irish trials are at the mid to lower end of the range (usually up to 10% peak reduction) – consistent with low penetration of major appliances such as air conditioning and lack of automated response (which has been shown to significantly increase response, although predominantly in the case of air conditioning).
- People tend of save money on TVTs compared to control flat rate tariffs, but savings (and the proportion who save) variable and large losses are possible. No strong evidence for consistent associations with socio-demographic factors.

References **NB Excludes some reviewed documents which will provide context in the final report.**

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Appendix F:

Market Research Detail

Results of a survey measuring uptake to time-varying tariffs under a range of design and marketing conditions

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Organization

This presentation is organized into three sections:

1. Executive summary
2. Introduction to research and sample
3. Experiment results

Tariff acronyms

- CPP: critical peak pricing, where customers are exposed to occasional higher electricity prices on an irregular basis (often known as 'critical events'). The high price may be fixed (CPP-F) or variable (CPP-V)
- CPR: critical peak rebate, where customers are paid for reducing electricity consumption during critical events
- RTP: real-time pricing, where electricity prices vary with high frequency, such as on an hourly basis, usually to reflect wholesale prices (sometimes also referred to as hourly pricing [HR])
- Static TOU (also here referred to by the shorthand 'static'): static time of use where electricity prices vary between set bands at set times of the day/week
- TVT: time-varying tariff, the generic term used to describe any tariff where the price of electricity varies in some way over time

Section 1:
Executive Summary

The research

- There is currently mixed evidence on potential for uptake to some TVT designs, and little or none for others. Little is also known about what might prompt consumers to sign up to such tariffs.
- We conducted an online survey on a representative sample of 2959 energy bill payers in Great Britain.
- Experimental design allowed testing of the effect on uptake of various TVT designs and marketing approaches, specifically:
  - Tariffs: static TOU, inverted TOU, CPP, CPR and RTP
  - Marketing: bill protection, labelling, EV tailoring, load disaggregation
  - Critical peak rebate mode: direct payment, bill credit, free units, lottery, offered by current supplier vs unknown company
  - Automation: 1 vs 3 ^{o}C temperature range, override vs no override, choice of thermostat vs no choice
  - We also tested the effect of offering TVTs on trust in suppliers, and potential role of government or consumers organizations in this.

Key findings

Tariff design

- Average of 26% would switch to TVTs.
- Inverted TOU significantly more popular than all other designs (not comparable with previous results as not previously tested).
- RTP significantly more popular than static TOU (small effect) – at odds with previous findings, although this design of RTP has not been tested in UK before.
- No significant differences between static TOU, CPP and CPR – consistent with previous findings.
- Possible lower uptake in those aged 65+ (compared to 18-34), and amongst social housing tenants (compared to owner-occupiers).
- Greater perceived ease of understanding of tariff and greater perceived ability to save money increase uptake significantly.

Key findings (cont.)

Tariff marketing

- Bill protection, quality assurance labelling and the offer of providing load disaggregation had no effect on average uptake of three-tier static TOU.
- Bill protection closes the gap in uptake between the flat rate tariff and the TOU tariff amongst loss-averse bill payers (~95% of all bill payers)
- EV tailoring significantly decreased overall uptake, but significantly increased it amongst EV owners (who offer – and stand to gain – most value).

Critical peak rebate

- £20 bill credit and 100 free units offers were as popular as a bank transfer, even though the value to consumers of free units is only around £12-14 and the cost to suppliers even less.
- People were as likely to sign up when the CPR came from an unknown third party company as from their own supplier.

Key findings (cont.)

Automated/direct load control

- So long as people can override DLC of a smart thermostat, the potential temperature range (i.e. 1 or 3 ^{o}C up/down) does not make a significant difference to uptake.
- However, offering DLC with no override is significantly less popular. Even so, 29% of people would sign up to the maximum 3 ^{o}C (up/down) range with no override.

Trust

- Just stating that suppliers plan to offer more TVTs slightly (but significantly) reduces trust in suppliers.
- Saying this is encouraged by government reduces trust in suppliers even further
- Saying it is encouraged by consumer groups mitigates the reduction in trust (i.e. trust is the same as when TVTs are not mentioned).

Section 2:

Introduction to research and sample

Overall rationale

As demonstrated by the review conducted as part of this project, there is currently mixed evidence on potential for uptake to some TVT designs, and little or none for others. Little is also known about what might prompt consumers to sign up to such tariffs.

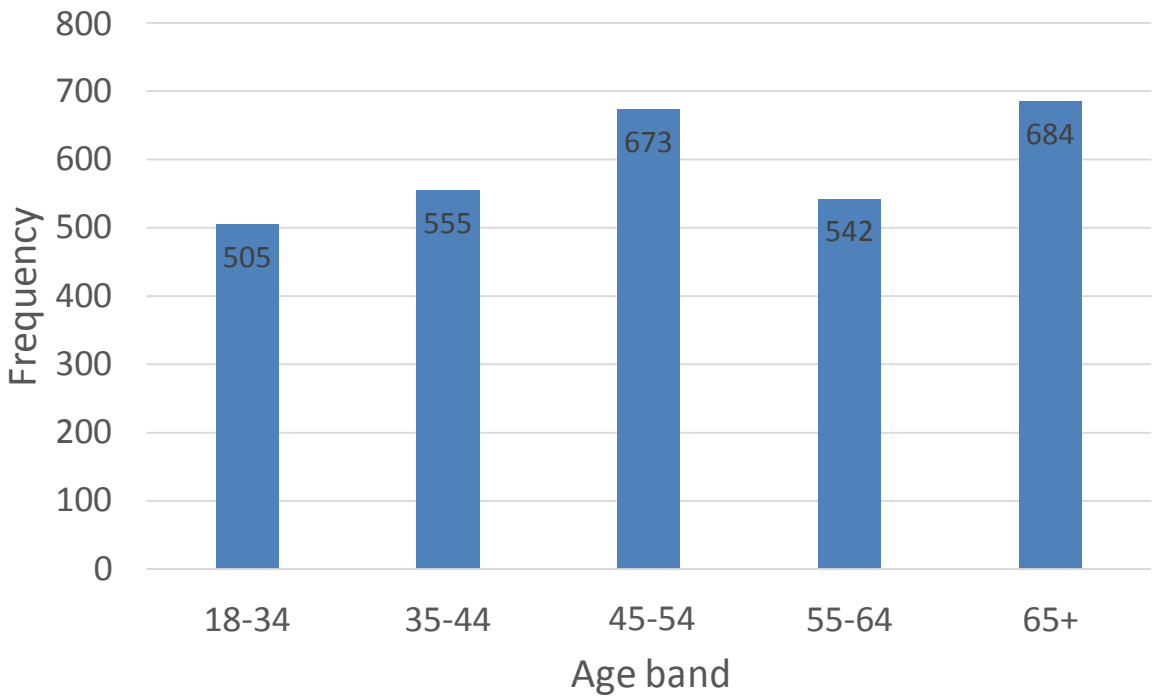
The aim of this survey was to provide additional evidence on these points, improving our understanding of the factors driving attractiveness and uptake of TVTs and the potential implications of this for consumers and networks.

Survey outline

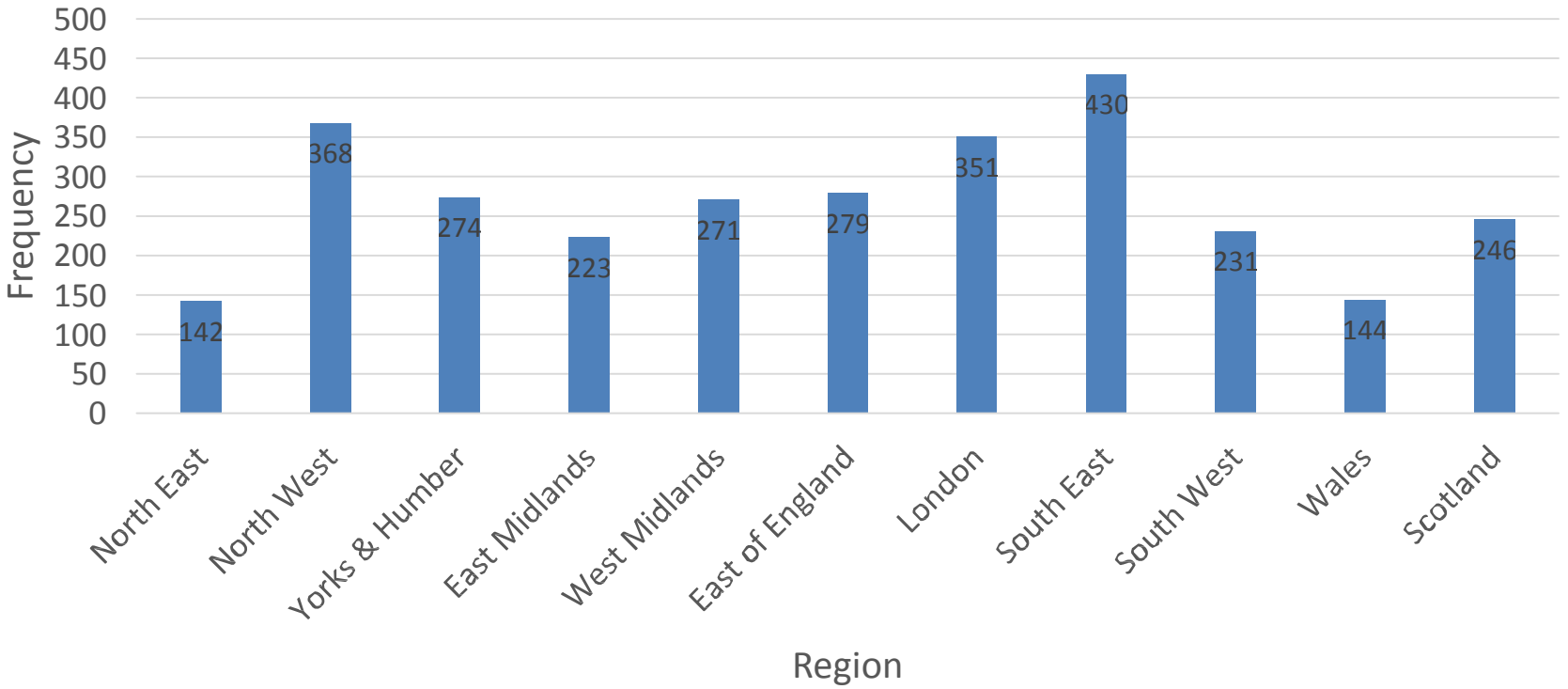
- Conducted with survey company Opinium.
- Last week of March 2017.
- N = 2959 online respondents, representative of energy bill payers in Great Britain.
- Five experiments conducted testing a variety of tariff designs and marketing conditions.
- Also collected a range of other demographic, household and energy-related data.
- Subsequent sections set out aims, approach, findings and implications of each experiment.

The sample- Age and gender

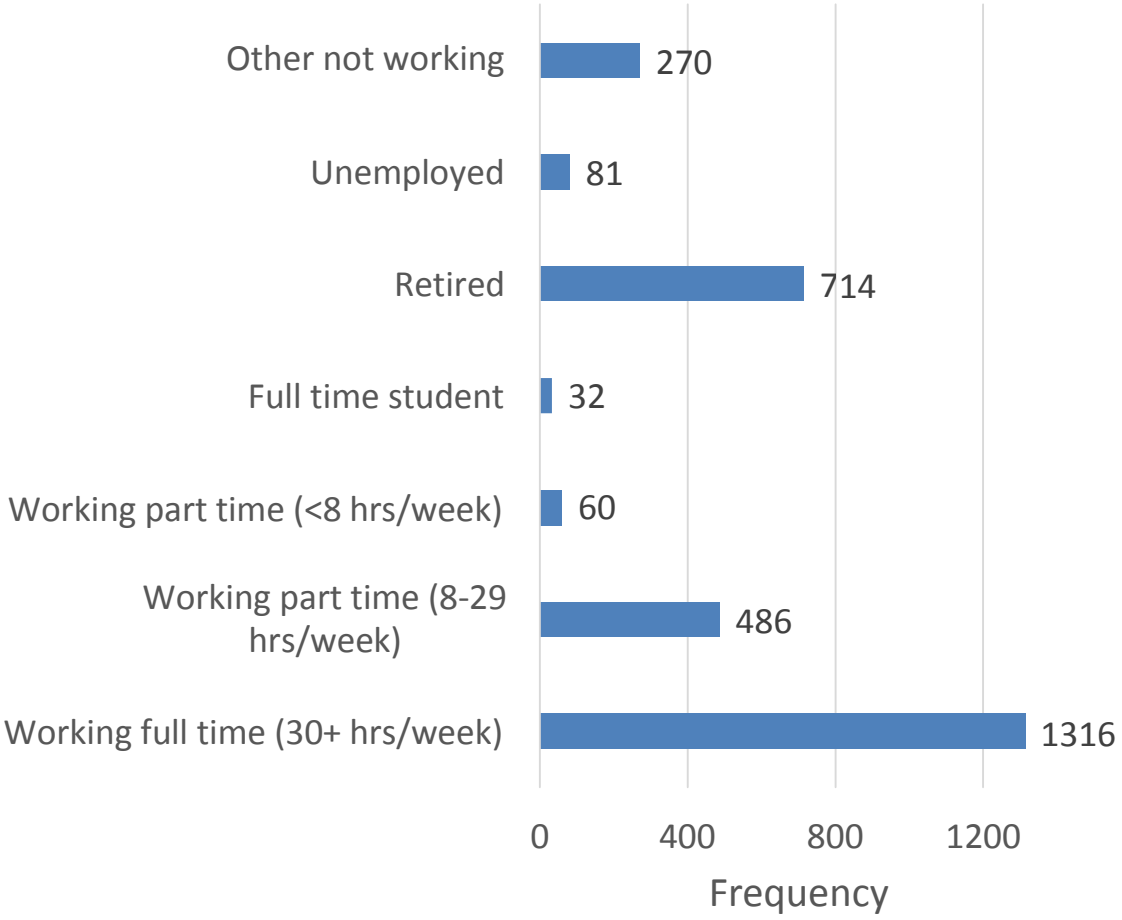
- 46.4% male respondents, 53.6% female



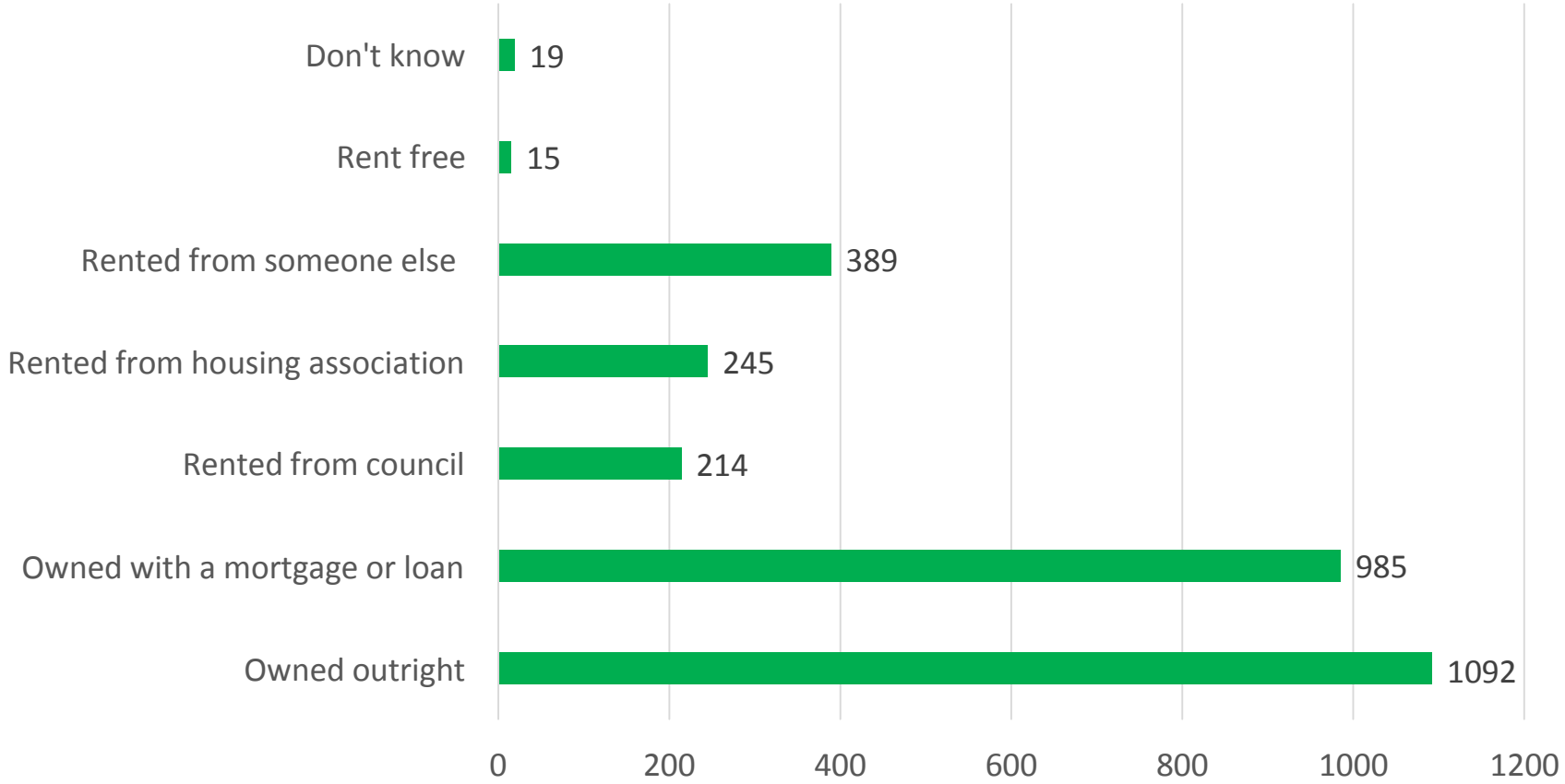
The sample - Region



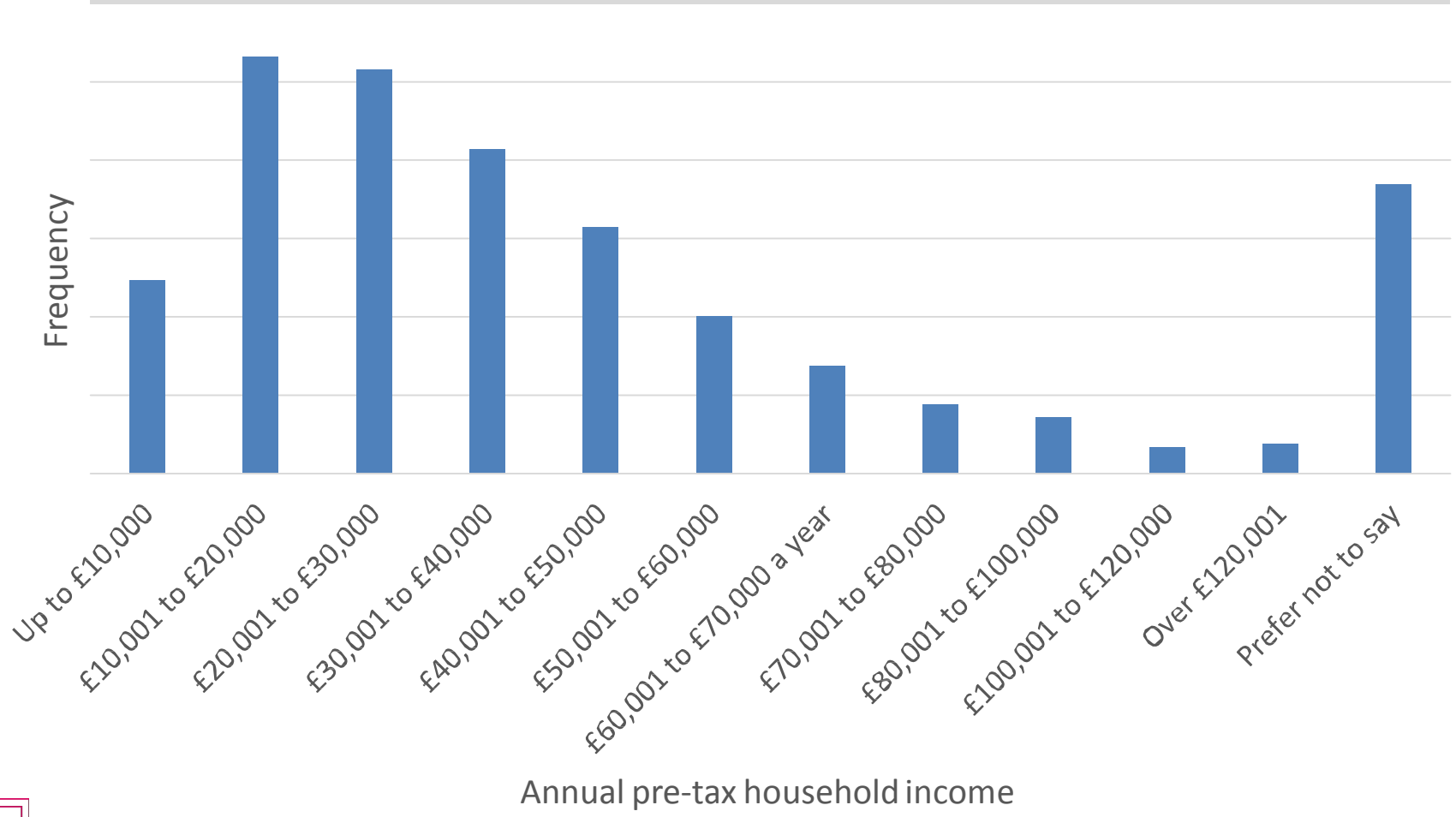
The sample - Employment status



The sample - Tenure



The sample - Annual pre-tax household income



Note on analysis

- Regression tables show regression coefficients (B), standard error (SE) and odds ratios (OR).
- Imagine an experiment with control and intervention groups, and a binary outcome (e.g. yes/no). If the odds ratio is 3 for the intervention, that means that for every 1 ‘yes’ outcome in the control group, there are 3 ‘yes’ outcomes in the intervention group.
- Regression analysis with more than one dependent and independent variable involves running multiple comparisons. This increases the chances of making a ‘false discovery’, where the p value wrongly suggests a variable is associated with a significant difference in the population.
- To correct for this we used the Benjamini-Hochberg approach. Where variables fell out of significance following Benjamini-Hochberg we have indicated this using the ^ symbol.

Section 3:
Experiment results

Design experiment: Aims

- Aim:
  - To test relative attractiveness of five different TVT design
  - To identify factors that impact on uptake
- Rationale:
  - Evidence on the attractiveness of various TVT design is limited, in particular in GB context.
  - Evidence limited on whether some population segments likely to miss out on TVT offerings.

Design experiment: Method

- Participants randomly allocated to see one of five TVT tariffs.
- All participants also shown attractive flat-rate tariff.
- Answer options:
  - Switch to TimeSaver (TVT).
  - Switch to SteadySaver (flat rate tariff).
  - Stay on current tariff.

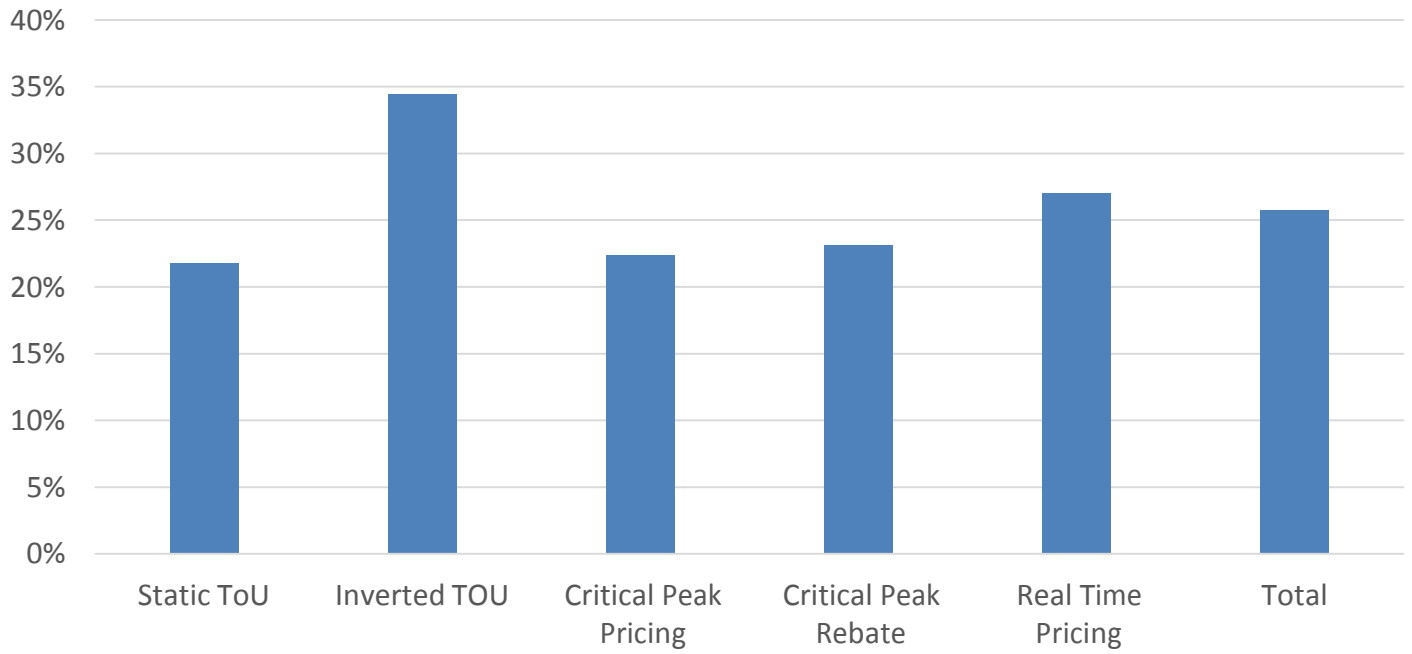
} Combine into "not switching to TVT" in analysis

Design experiment - Method

Participants randomly assigned to one of five conditions:

1. Static ToU
   - Off-peak rate: 6p per unit, applies 8pm-4pm on weekdays and all weekend
   - Peak rate: 18p per unit, applies 4-8pm on weekdays
2. Inverted ToU
   - Daytime rate: 5p per unit, applies 10 am to 4 pm on all summer days (April – September)
   - Standard rate: 15p per unit, applies 4 pm to 10 am on summer days and all hours of non-summer days
3. Critical Peak Pricing
   - Normal rate 10p per unit
   - Announced on up to 18 weekdays a year with a unit rate of 60p between 4-8 pm
   - Notification the day before by choice of text, phone or email
4. Critical Peak Rebate
   - Normal rate 12p per unit
   - Announced on up to 18 weekdays a year with a £1 bill credit given if electricity use between 4-8pm kept to below the average used over the previous three days at this time
   - Notification the day before by choice of text, phone or email
5. Real Time Pricing
   - Most of the time the hourly price lower than the the SteadySaver tariff rate, and last year the average rate was 10p per unit of electricity
   - Prices usually low during the spring, summer and autumn. Higher prices most likely during the winter on cold weekday evenings
   - Each evening, prices for the following day available online and by phone
   - Day-ahead alerts (by text, phone or email) to inform about upcoming high prices

Design experiment: Impact of tariff design, switching rates



Design Experiment: Impact of tariff design, regression analysis

	B	SE	OR
Tariff (Ref = Static TOU)			
Inverted TOU	0.632***	0.132	1.88
Critical Peak Pricing	0.034	0.140	1.03
Critical Peak Rebate	0.075	0.140	1.08
Realtime Pricing	0.285** ^	0.136	1.33
Constant	-1.277***	0.100	0.28
Observations	2,959		
Log Likelihood	-1,671.433		
Akaike Inf. Crit.	3,352.866		

Note: *p < .05 **p< .01 ***p<0.01

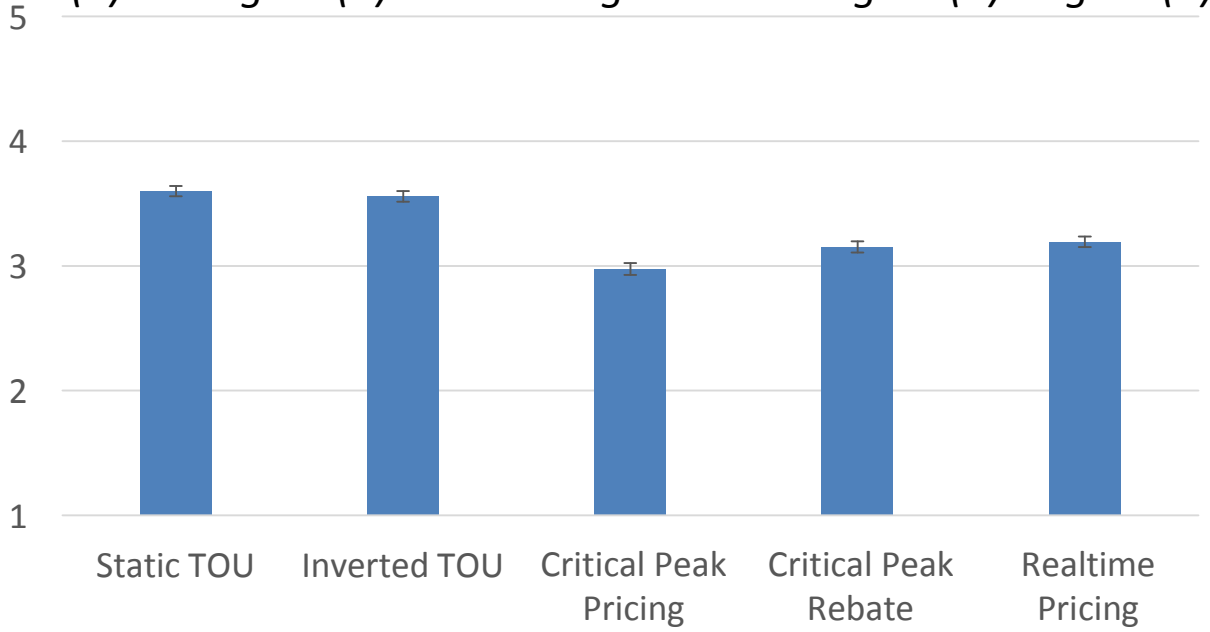
Perceived ease of understanding

Item phrasing:

This tariff is easy to understand

Answer options:

strongly disagree (1) - disagree (2) - neither agree nor disagree (3) - agree (4) - strongly agree (5)



One-way ANOVA:

$F(4, 2958) = 38.02$, $p < .001$.

Posthoc pairwise comparison ease of understanding

	Static TOU	Inverted TOU	Critical Peak Pricing	Critical Peak Rebate	Realtime Pricing
Static TOU	-	ns	*	*	*
Inverted TOU	ns	-	*	*	*
Critical Peak Pricing	*	*	-	*	*
Critical Peak Rebate	*	*	*	-	*
Realtime Pricing	*	*	*	*	-

Both inverted and static TOU significantly easier to use than Critical Peak Pricing, Critical Peak Rebate, Realtime pricing. Critical Peak Pricing most difficult to ease.

Hochberg correction for multiple comparisons.
* $p < .05$

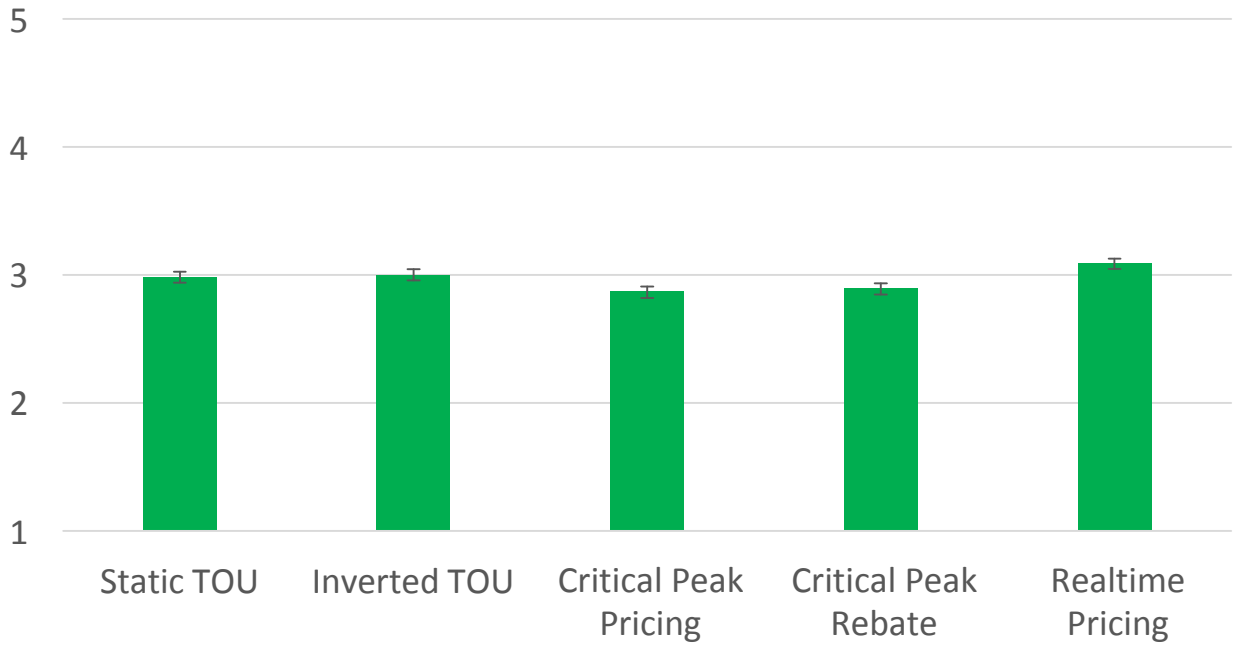
Save money

Item phrasing:

I am confident I would save money on this tariff.

Answer options:

strongly disagree (1) - disagree (2) - neither agree nor disagree (3) - agree (4) - strongly agree (5)



One-way ANOVA:

$F(4, 2958) = 4.451$, $p = .001$.

Save money

	Static TOU	Inverted TOU	Critical Peak Pricing	Critical Peak Rebate	Realtime Pricing
Static TOU	-	ns	ns	ns	ns
Inverted TOU	ns	-	ns	ns	ns
Critical Peak Pricing	ns	ns	-	ns	*
Critical Peak Rebate	ns	ns	ns	-	*
Realtime Pricing	ns	ns	*	*	-

Significantly higher for realtime pricing than CPR and CPP.

Hochberg correction for multiple comparisons.
* $p < .05$

Adding household characteristics

- Increased switching
  - On prepayment
  - Owning appliance with timer
  - Socially renting
- Decreased switching
  - Being 65+
  - Not disclosing income
- No effect of
  - Household size
  - Electric heating (night storage or other
  - Being already on TOU
  - Children under 15 in the house
  - Full-time employment
  - Gender
  - Being in during week daytime
  - Being in during week evening

	B	SE	OR
Tariff (Ref = StaticTOU)			
Inverted TOU	0.630***	0.134	1.88
Critical Peak Pricing	0.054	0.142	1.06
Critical Peak Rebate	0.054	0.141	1.06
Realtime Pricing	0.282**^	0.138	1.33
*On prepayment (*Ref= No)			
Yes, on prepayment	0.311**^	0.157	1.36
Own appliance with timer (Ref = no)			
Yes, appliance with timer	0.154*	0.089	1.17
Tenure (Ref = owner occupied)			
Socially rented	-0.380***^	0.145	0.68
Other	-0.188	0.137	0.83
Age (Ref = 18-34 years)			
35-44	-0.244*^	0.143	0.78
45-54	-0.220	0.141	0.80
55-64	-0.304*^	0.159	0.74
65+	-0.375**^	0.172	0.69
Income (Ref= £20,001-30,000)			
Up to £10,000 a year	-0.149	0.195	0.86
£10,001 to £20,000 a year	-0.019	0.149	0.98
£30,001 to £40,000 a year	0.003	0.154	1.00
£40,001 to £50,000 a year	0.178	0.166	1.20
£50,001 to £60,000 a year	0.015	0.195	1.02
£60,001 to £70,000 a year	-0.061	0.226	0.94
£70,001 to £80,000 a year	0.143	0.261	1.15
£80,001 to £100,000 a year	0.281	0.279	1.32
£100,001 to £120,000 a year	-0.014	0.412	0.99
Over £120,001 a year	0.428	0.362	1.53
Prefer not to say	-0.288*	0.168	0.75
Constant	-1.139***	0.266	0.32
Observations	2,959		
Log Likelihood	-1,646.499		
Akaike Inf. Crit.	3,370.998		

Note: *p< .05 **p< 0.1 ***p<0.01

Adding psychological characteristics

- Increased switching
  - Socially renting
  - Perceived ease of use
  - Perceived opportunity to save money
- Decreased switching
  - Being 65+
  - More than £120,000 income
  - Accepting gamble with zero loss/ gain
- No effect of
  - Household size
  - Electric heating (night storage or other
  - Being already on TOU
  - Children under 15 in the house
  - Full-time employment
  - Gender
  - Being in during week daytime
  - Being in during week evening
  - Loss aversion
  - Time preference
  - Being on prepayment meter
  - Having appliance with timer

	B	SE	OR
Tariff (Ref = StaticTOU)			
Inverted TOU	0.842***	0.156	2.32
Critical Peak Pricing	0.386*^	0.167	1.47
Critical Peak Rebate	0.334*^	0.163	1.40
Realtime Pricing	0.416**^	0.159	1.52
Tenure (Ref = owner occupied)			
Socially rented	-0.410*^	0.165	0.66
Other	-0.242	0.157	0.79
Age (Ref = 18-34 years)			
35-44	-0.061	0.165	0.94
45-54	-0.085	0.164	0.92
55-64	-0.134	0.186	0.87
65+	-0.434*^	0.201	0.65
Income (Ref= £20,001-30,000)			
Up to £10,000 a year	-0.053	0.221	0.95
£10,001 to £20,000 a year	-0.075	0.172	0.93
£30,001 to £40,000 a year	0.045	0.176	1.05
£40,001 to £50,000 a year	0.236	0.190	1.27
£50,001 to £60,000 a year	-0.100	0.226	0.90
£60,001 to £70,000 a year	-0.010	0.258	0.99
£70,001 to £80,000 a year	0.162	0.308	1.18
£80,001 to £100,000 a year	0.452	0.330	1.57
£100,001 to £120,000 a year	0.017	0.460	1.02
Over £120,001 a year	1.206***	0.428	3.34
Prefer not to say	-0.189	0.190	0.83
Ease of understanding of tariff	0.266***	0.057	1.30
Saving money on tariff	1.148***	0.065	3.15
Accepting gamble 5 (Ref = No)			
Yes, accepting gamble 5	-0.765***	0.222	0.47
Constant	-5.886***	0.434	0.00
Observations	2,959		
Log Likelihood	-1,301.011		
Akaike Inf. Crit.	2,700.023		

Note: *p<0.05 **p<.01 ***p<0.001

Exp 1: Household vs. psychological characteristics

- Knowing household characteristics: Targeting households
- Knowing psychological characteristics: Understanding switching behaviour better
- Being on prepayment meter and owning an appliance with timer not significant anymore once controlling for psychological variables – however, important variables to identify those liking to switch
  - Hence important finding

Exp 1: Conclusion

- Some predictors only marginally significant once controlling for multiple comparisons
  - Age, tenure
- Robust finding that InvertedTOU preferred to static TOU, followed by RTP
- Robust finding that perceived ease of use of tariff and perceived opportunity to save money significant predictors
  - Important to design and market tariffs in such a way emphasizing those aspects

Marketing experiment: Aims

- Aim:
  - To test impact of different ways of communicating TVT tariffs on uptake
- Rationale:
  - Evidence on how consumers may respond to different types of marketing methods is limited.
  - International evidence suggests that **bill protection** could increase uptake whilst protecting consumers .
  - A number of energy suppliers have experimented with so-called 'Electric Vehicle' tariffs but it is not known what impact this has on uptake of electric vehicle owners and consumers who don't own electric vehicles (these are very common in the US).
  - Anecdotal evidence suggests that consumers want disaggregated energy feedback but this has never been tested in the context of TVT tariffs.

Marketing experiment: Method

- Participants randomly allocated to see the same static time of use tariff that is marketed in one of five different ways.
- One group was also shown an attractive flat-rate tariff, with no accompanying marketing message.
- Answer options:
  - Switch to tariff
  - Stay on current tariff.

Marketing experiment - Method

Flat rate tariff

- 12p per unit

Static Time of Use tariff

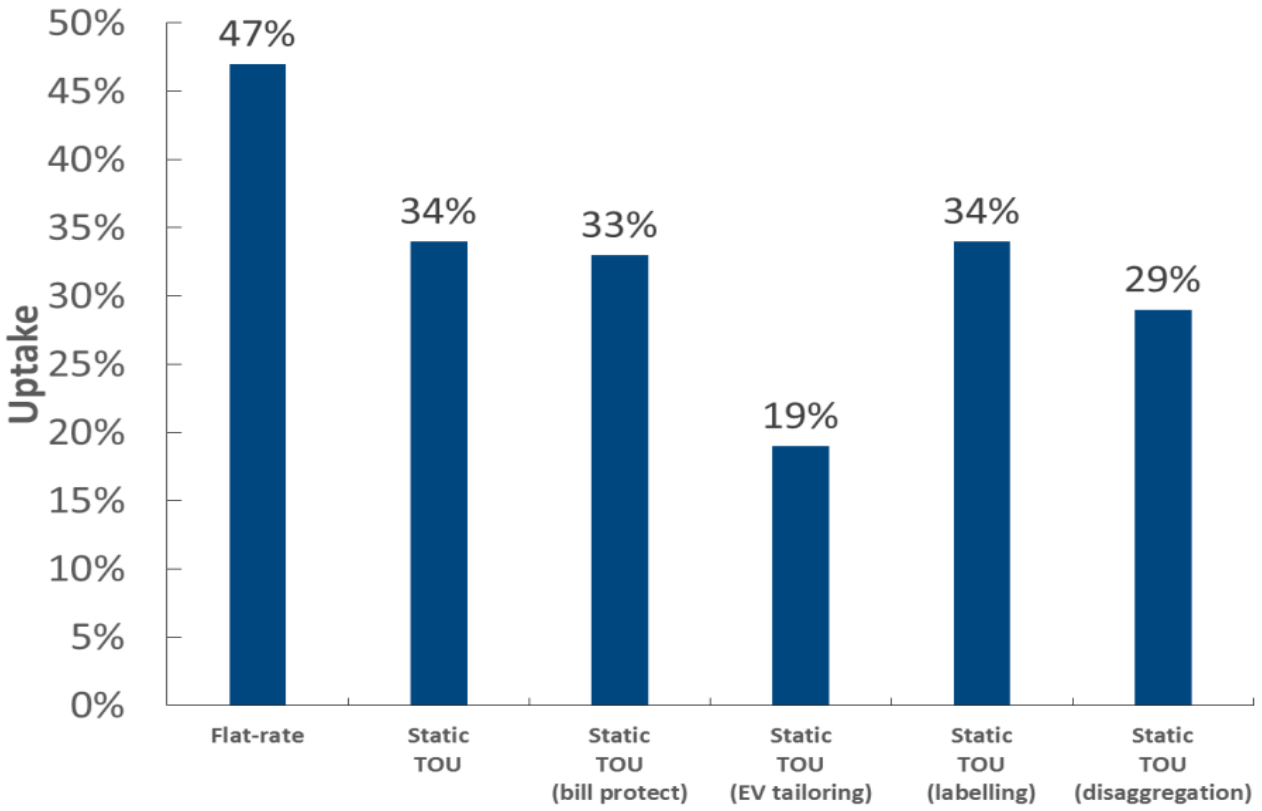
- Super Off-peak rate: 6p per unit, applies 11pm-6am on weekdays and all weekend
- Off-peak rate: 12p per unit, applies 6am-4pm and 8pm-11pm on weekdays and all weekend
- Peak rate: 24p per unit, applies 4-8pm on weekdays

Marketing experiment - Method

Participants were randomly assigned to one of six conditions:

Tariff condition	Marketing message
1. Flat rate tariff (control group 1)	None
2. TOU tariff (control group 2)	None
3. TOU tariff + bill protection	"This tariff comes with a six month bill protection guarantee. We will automatically refund you if you spend more on this tariff than your old one - so you can't lose out."
4. TOU tariff + tailored towards EV owners	"This tariff is particularly suited to people with electric vehicles, who use more electricity than the average household (that mostly just use electricity for lighting and kitchen appliances) and could therefore save more money by charging their vehicle during the cheap off-peak or super off-peak times." The tariff was also called the "Electric Vehicle tariff".
5. TOU tariff + GB regulator endorsement	"This is a *GoodGrid Approved* tariff as certified by the GB energy regulator. Approved trials have shown that most people who sign up save money, and that it helps the electricity grid to run more efficiently."
6. TOU tariff + disaggregated feedback	"When you sign up to this tariff you will also get access to a service showing your household electricity use broken down by appliance (e.g. washing machine, oven, etc.). This will show you exactly how much electricity your washing machine (for example) is using in a day or week, and what times you have used it. This makes it easier to decide what to use when to save money."

Marketing experiment: Impact of tariff marketing, switching rates



Marketing Experiment: Impact of tariff marketing, regression analysis

Table 1: Average treatment effect of marketing on uptake to TVT tariff

	Control = flat rate tariff, no marketing						Control = TOU tariff, no marketing					
	B	SE	OR	B	SE	OR	B	SE	OR	B	SE	OR
Flat							0.595***	0.131	1.813***	0.634***	0.135	1.886***
TOU	-0.595***	0.131	0.552***	-0.634***	0.135	0.530***						
TOU + bill	-0.633***	0.133	0.531***	-0.622***	0.138	0.537***	-0.038	0.135	0.963	0.012	0.140	1.013
TOU+ tailored	-1.402***	0.146	0.246***	-1.443***	0.148	0.236***	-0.807***	0.148	0.446***	-0.809***	0.151	0.445***
TOU+ labelling	-0.574***	0.132	0.563***	-0.552***	0.135	0.576***	0.021	0.134	1.021	0.083	0.137	1.086
TOU+ disaggregation	-0.833***	0.135	0.435***	-0.855***	0.138	0.425***	-0.238	0.137	0.788	-0.221	0.140	0.802
Knowledge test score	-0.221***	0.065	0.802***	-0.109	0.067	0.897	-0.221***	0.065	0.802***	-0.109	0.067	0.897
_cons	-0.076	0.091		0.021	0.199		-0.671***	0.094		-0.613**	0.200	
Controls				X	X	X				X	X	X
XN	2959			2959			2959			2959		
pseudo R^2	0.029			0.059			0.029			0.059		
AIC	3649.464			3579.665			3649.464			3579.665		

Coefficient in first column, Standard errors in second column, Odds ratios in third column. Shaded columns show results controlling for demographic/household variables.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Marketing Experiment: Impact of bill protection on loss averse bill payers

Table 2: Effect of bill protection on uptake to TVT tariff amongst loss-averse bill payers

	Control = Flat tariff, no marketing			Control = TOU tariff, no marketing		
	B	SE	OR	B	SE	OR
Bill protection Slightly loss averse	-0.132	0.416	0.877	-0.401	0.412	0.670
Moderately loss averse	0.365	0.448	1.440	-0.099	0.431	0.906
Very loss averse	0.253	0.349	1.287	-1.316***	0.353	0.268***
Highly loss averse	0.190	0.343	1.210	-0.867**^	0.335	0.420**^
Bill protection*Slig. loss averse	-0.696*^	0.323	0.499*^	-1.385***	0.332	0.250***
Bill protection*Mod. loss averse	-0.679	0.657	0.507	-0.216	0.645	0.806
Bill protection*V. loss averse	-0.290	0.500	0.748	1.278*^	0.503	3.590*^
Bill protection*High. loss averse	-0.996*^	0.504	0.369*^	0.061	0.499	1.063
Constant	-0.387	0.473	0.679	0.302	0.479	1.353
Observations	0.041	0.286		0.310	0.281	
Pseudo R^2	985			989		
AIC	0.051			0.040		
	1280.839			1232.506		

Coefficient in first column, Standard errors in second column, Odds ratios in third column

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Marketing Experiment: Impact of tailoring on EV owners and non EV owners

Table 3: Effect of tailoring TVT tariffs to EV owners on uptake to TVT tariffs amongst EV owners and non EV owners

	Control = flat rate tariff, no marketing						Control = TOU tariff, no marketing					
	EV owners vs everyone else			Non EV owners vs everyone else			EV owners vs everyone else			Non EV owners vs everyone else		
	B	SE	OR	B	SE	OR	B	SE	OR	B	SE	OR
Tailored	-1.575***	0.160	0.207***	0.041	0.523	1.042	-0.904***	0.140	0.405***	0.163	0.395	1.176
EV	1.102*^	0.455	3.010*^				1.913***	0.237	6.772***			
noEV				-0.848*	0.398	0.428*				-1.401***	0.188	0.246***
Tailored * EV	1.686**	0.627	5.399**				0.875†	0.492	2.400			
Tailored * No EV				-1.637**	0.548	0.195**				-1.084**	0.420	0.338**
Constant	-0.157	0.092		0.693	0.387		-0.828***	0.050		0.571**	0.181	
Observations	986			986			2463			2463		
Pseudo R^2	0.119			0.116			0.055			0.048		
AIC	1111.653			1115.710			2846.442			2867.953		

Coefficient in first column, Standard errors in second column, Odds ratios in third column

† $p < 0.10$ * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Marketing Experiment: Conclusion

- Robust finding that flat tariff preferred to any TOU tariff regardless of marketing message
  - However, bill protection closes the gap in uptake between the flat rate tariff and the TOU tariff amongst loss-averse bill payers (in other words, whilst bill protection doesn't make the TOU tariff more appealing than the flat rate tariff, it at least means that loss-averse consumers are no longer less willing to switch to the TOU tariff than the attractive flat rate tariff)
  - Also, calling a TOU tariff an 'Electric Vehicle' tariff has a very strong positive impact on intention to switch to the TOU tariff amongst EV owners when compared to the flat-rate tariff or the same TOU tariff that isn't called an Electric Vehicle tariff
    - Calling a TOU tariff an 'Electric Vehicle' tariff also detracts non electric vehicle owners from wanting to switch (which may or may not be a good thing depending on how likely they are to save money on the tariff concerned)
- A TOU tariff with bill protection is no more appealing than a TOU tariff without any bill protection – this may seem to be at odds with the finding above but it's not (it just means that bill protection provides do additional value to a person choosing between two identical TOU tariffs but for loss-averse consumers choosing between a TOU tariff and a flat rate tariff, bill protection would make them indifferent between the TOU option and the flat rate option whereas without bill protection the TOU option would definitely be less appealing than the flat rate option)
- Loss-aversion is associated with a much lower willingness to switch from current tariff to another attractive flat-rate tariff, suggesting that it could be holding customers back from saving money on their energy bills
- The most loss-averse group of consumers (~30% of bill payers) were also much less willing to switch to the TOU tariff compared to non loss averse consumers (~5% of bill payers)
- The success of the tailored message on EV owners suggests that a one-size fits all approach to marketing TOU tariffs is unlikely to work; more research is needed to find out what works for different consumer groups
  - Ideally this research needs to be undertaken in a real-world context where consumers really can switch to the tariff – it is possible that 'hypothetical bias' means that the results found here would not translate into real world setting (e.g. would bill protection have a bigger impact if people were actually faced with the decision to switch?)
  - Ofgem is planning to conduct trials in this area, so uptake to TOU tariffs could be a potential avenue for research

CPR experiment: Aims

- Aim:
  - Test effect of mode of rebate on uptake
  - Test effect of identity of firm offering CPR on uptake
- Rationale:
  - Customers may not be able to recognize poor value when rebates described in certain terms.
  - If unknown companies can obtain similar uptake to the customer's supplier, this opens up the market to more competition.

CPR experiment: Method

- Participants randomly allocated to see one of five CPR offers, and asked if they would sign up (response: Yes/No) (see example next slide).
- The rewards for reducing usage at specified times were:
  - £20 payment to bank account
  - £20 bill credit [same value to customer as direct payment, better value to supplier depending on payment method]
  - 100 free electricity units after the winter [worth approx. £12 to customer, even cheaper to supplier as wholesale costs lower outside winter]
  - Entry into lottery to win one of five £1000 prizes [worth average £5 to customer if 1000 people participate – although most get nothing]
- All the above offers were framed as coming from the customer's current supplier; a final offer was framed as coming from Purple Power, a [fictional] energy management company.

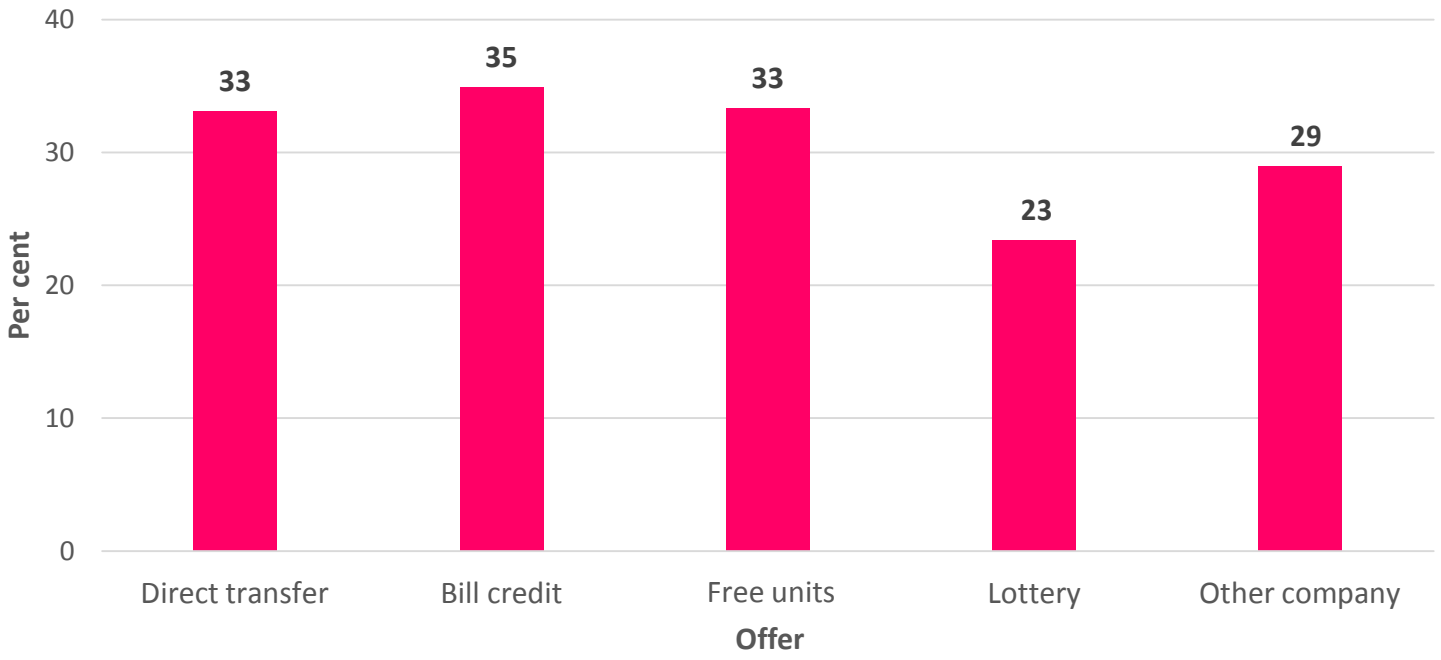
CPR experiment: Example

Winter Savers is a new offer from your present electricity supplier that is an add-on to your existing tariff.

- On up to 15 weekdays over the winter (excluding bank holidays) a Saver Day may be announced.
- On a Saver Day you will be asked to keep your electricity use to below the average you used over the previous three days.
- If you successfully reduce your usage on at least 10 saver days, you will receive a £20 payment into your bank account at the end of the winter.
- You are notified the day before by your choice of text, phone or email.

Imagine this new Winter Savers electricity offer was available to you today. Based on the information you've just read, would you sign up to this offer?

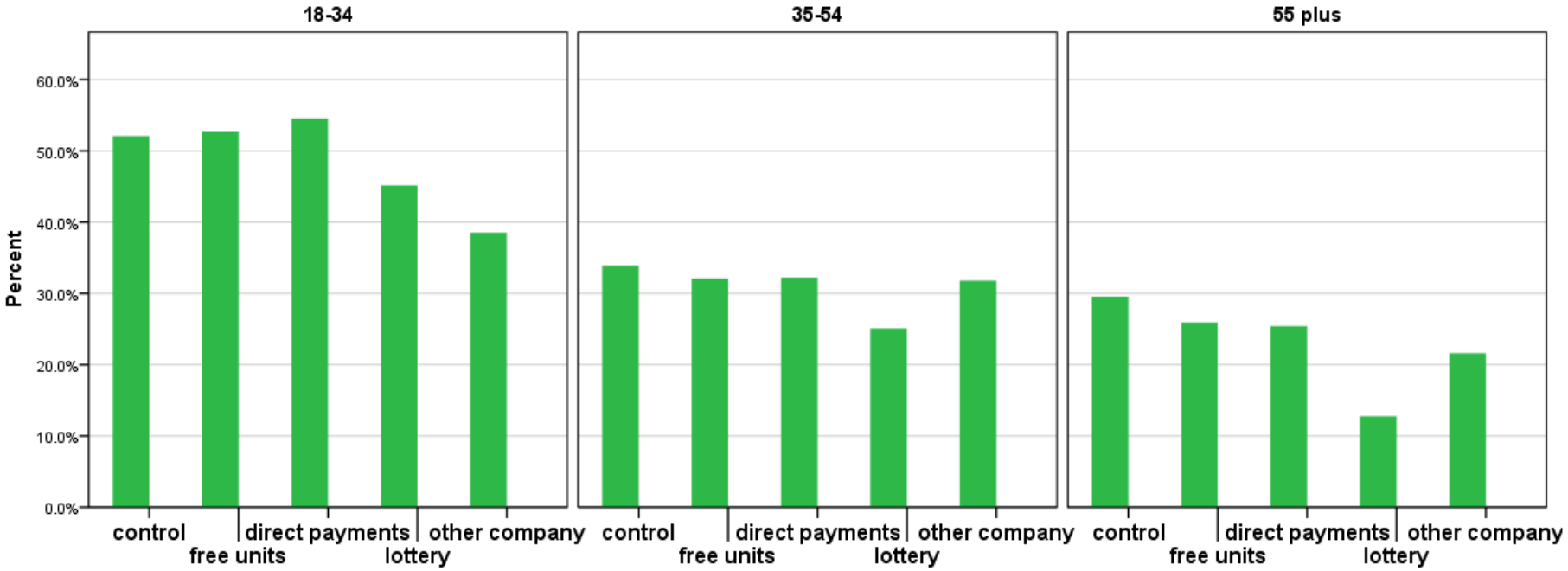
CPR experiment: percentage uptake to different offers



CPR Experiment: offer type, regression analysis (controlling for age/gender)

	B	S.E.	Odds ratio	p
Constant	-0.711	0.109	0.491	< .001***
Offer (ref. cat. = direct payment)				
Bill credit	0.101	0.125	1.106	0.422
Free units	-0.003	0.126	0.997	0.979
Lottery	-0.5	0.133	0.607	< .001***
Other company	-0.225	0.129	0.799	0.081
age 18-34	0.75	0.11	2.118	< .001***
age 55+	-0.408	0.092	0.665	< .001***
Male	0.063	0.082	1.065	0.445

CPR: Variation in uptake by age group



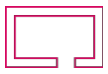
NB Category 'control' above refers to the bill credit option.

CPR: Findings and implications

- Lottery saw significantly less uptake; people may have recognized poor value.
- No other significant differences between offer mode, even though free units represents substantially worse value for consumers.
- This does suggest tactics such as offering free units could help provide critical peak reductions at substantially lower cost – although consumers lose out.
- No (but close to) significant difference with different company offering, suggesting good potential for non-supplier actors in this market (such as DNOs).
- Offer significantly more popular amongst younger consumers.
- Consumers may need help to spot the best deals – a possible role for consumer advocates or comparison services?

Thermostat experiment: Aims

- Aim:
  - Test effect of direct/automated load control conditions (temperature range and override ability) on uptake
  - Test effect of choice of thermostat on uptake
- Rationale:
  - Risk that some consumers could be subject to potentially uncomfortable or harmful conditions with limited reward.
  - Interest in extent to which giving consumers choice may promote uptake.



Thermostat experiment: Method

- Participants randomly allocated to see one of five thermostat offers, and asked if they would sign up (response: Yes/No).
- The consumers were offered a free smart thermostat (pictured) in return for giving the supplier ability to turn the temperature up/down under these conditions:
  - 1 ^{o}C up/down, with override available
  - 3 ^{o}C up/down, with override available
  - 1 ^{o}C up/down, NO override available
  - 3 ^{o}C up/down, NO override available

- A final offer gave participants a choice of three thermostats, with the first DLC condition above.

Thermostat experiment: Example

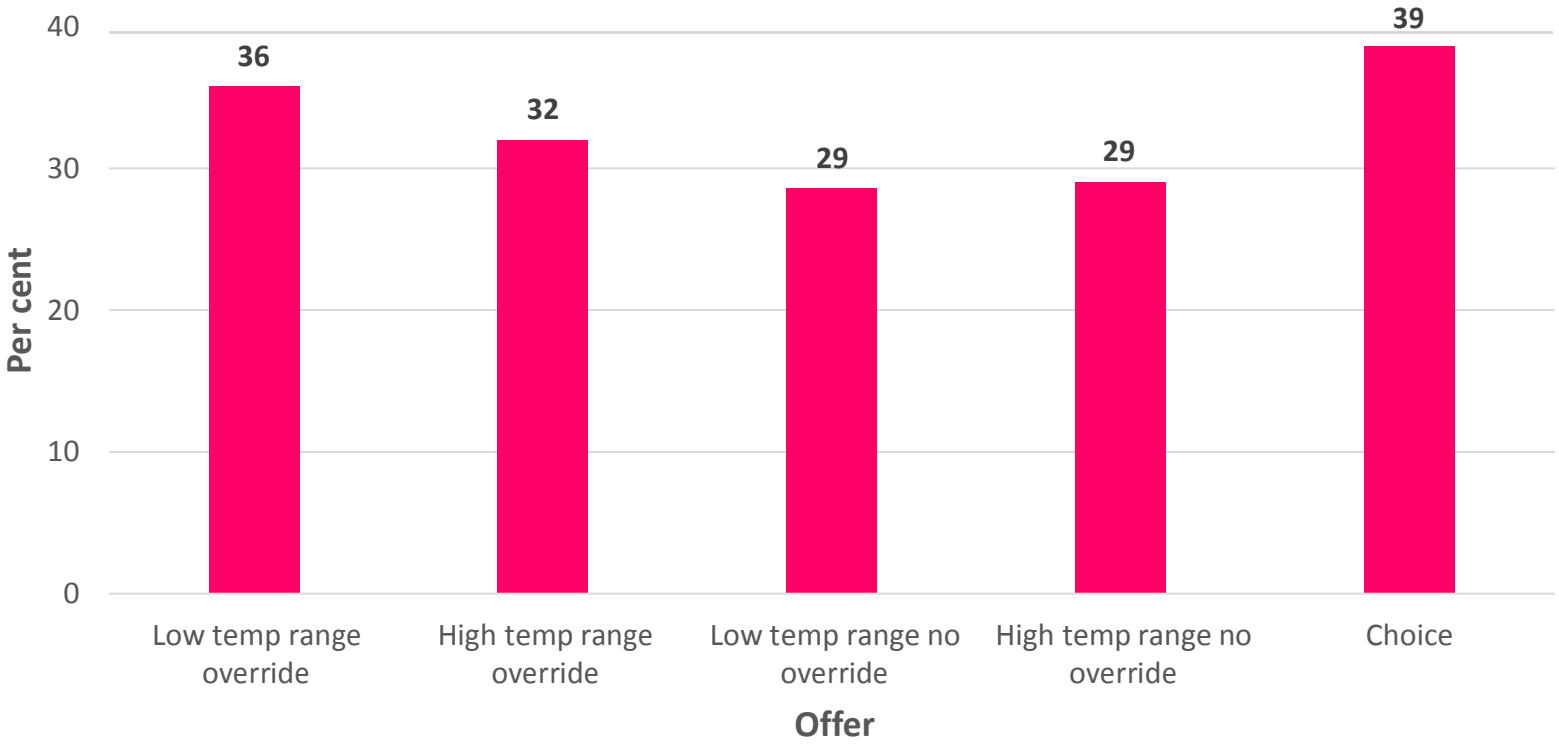
Your present electricity supplier has another offer, called Direct Savers.

They will give you a free smart thermostat to control your heating. This allows you to change your heating settings from a smartphone or computer. You wi receive the following thermostat:

The thermostat also allows your electricity supplier to turn your heating up and down for short periods at times depending on overall energy demand but this will only have a small (up to 1 degree Celsius up or down) effect on the temperature of your home. You can override this at any time.

Imagine this new Direct Savers offer was available to you today. Based on the information you've just read, would you sign up to this offer?

Thermostat experiment: percentage uptake to different offers



Thermostat Experiment: temperature and override, regression analysis (controlling for age/gender)

	B	S.E.	Odds ratio	p
Constant	-0.617	0.111	0.54	< .001***
Offer (ref cat = 1 °C, override)				
Any 3 °C offer	-0.206	0.126	0.814	0.102
Any offer with **no** override	-0.351	0.128	0.704	0.006**
Offer with 3 °C and no override (interaction)	0.217	0.182	1.243	0.233
Age 18-34	0.824	0.122	2.28	< .001***
Age 55+	-0.465	0.103	0.628	< .001***
Male	0.153	0.092	1.166	0.094

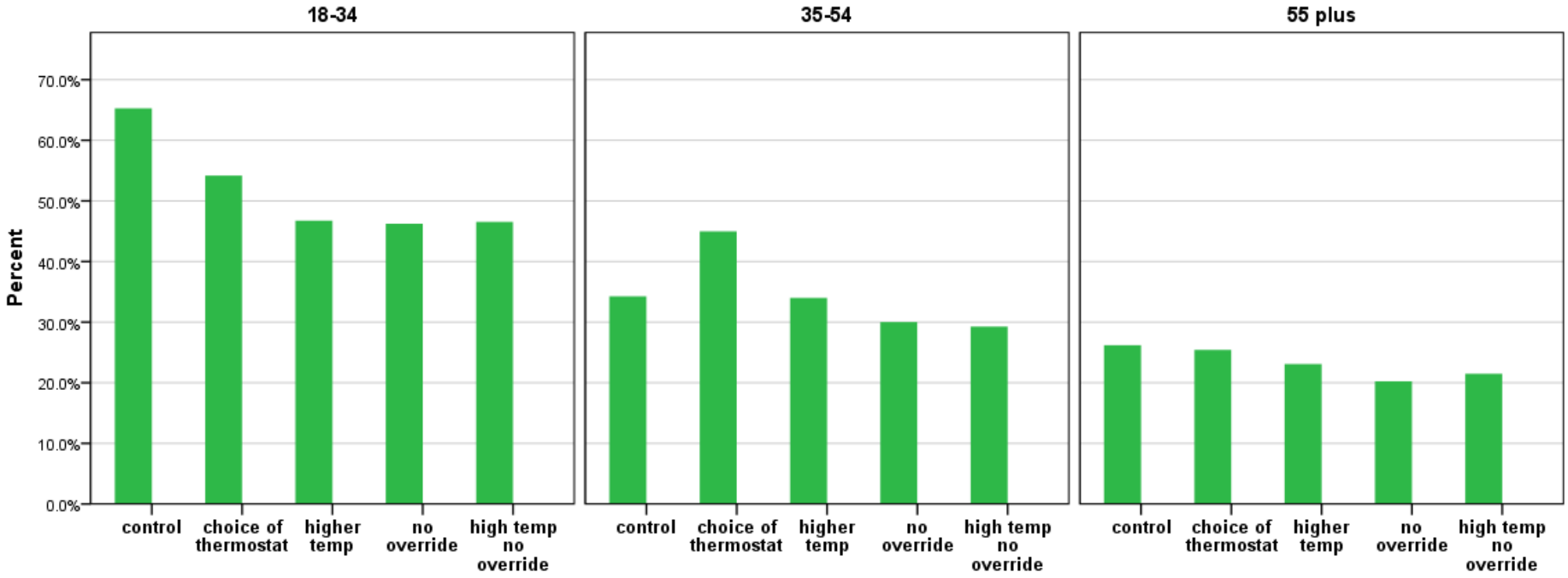
NB Analysis excludes thermostat choice group.

Thermostat Experiment: thermostat choice, regression analysis (controlling for age/gender)

	B	S.E.	Odds ratio	p
Constant	-0.558	0.127	0.572	< .001***
Offer (ref cat = no choice)				
Choice of thermostat	0.121	0.124	1.128	0.33
Age 18-34	0.832	0.174	2.297	< .001***
Age 55+	-0.631	0.137	0.532	< .001***
Male	0.154	0.124	1.167	0.214

NB Analysis includes only non-choice and choice groups.

Thermostat: Variation in uptake by age group



NB Category 'control' above refers to the 1 °C with override condition.

Thermostat: Findings and implications

- No significant effect of higher vs. lower temperature range.
- However, permitting no overriding significantly lowers uptake.
- Consumers will accept a very wide temperature range so long as they can override it.
- Even the high range with no override saw 29% uptake, with no reward but the upfront provision of the thermostat.
- This could be a concern, especially for vulnerable consumers – regulators and consumer advocates should remain alert to this risk.
- However, is the 'no override' option likely or even practical? Rather an alert that vigilance is likely to be required around such consumer offerings.
- Offering a choice of thermostat had no significant effect on uptake.
- Again, significantly higher uptake amongst younger people with two-thirds signing up to the basic offer (1 ^{o}C with override).

Trust experiment: Aims

- Aim:
  - Test whether offering TVTs affects people's trust in energy suppliers
  - Test whether any effect is different when TVTs are framed as being driven by government or consumer organizations
- Rationale:
  - A reduction in trust associated with TVTs could act as a barrier to suppliers offering them.
  - If the above is the case, it is important to find a way to mitigate this.

Trust experiment: Method

- Participants randomly allocated into four groups, all of which require them to respond to four items measuring trust (i.e. trust in providing reliable supply, providing clear information, charging a fair price, acting in consumers' best interests).
- Last three items combined to create general trust measure.
- First group only sees the question; in other it is preceded by statements suggesting:
  - That suppliers (including theirs) are planning on introducing more TVTs
  - That government is encouraging suppliers to introduce more TVTs
  - That consumer organizations are encouraging suppliers to introduce more TVTs

Trust experiment: Example

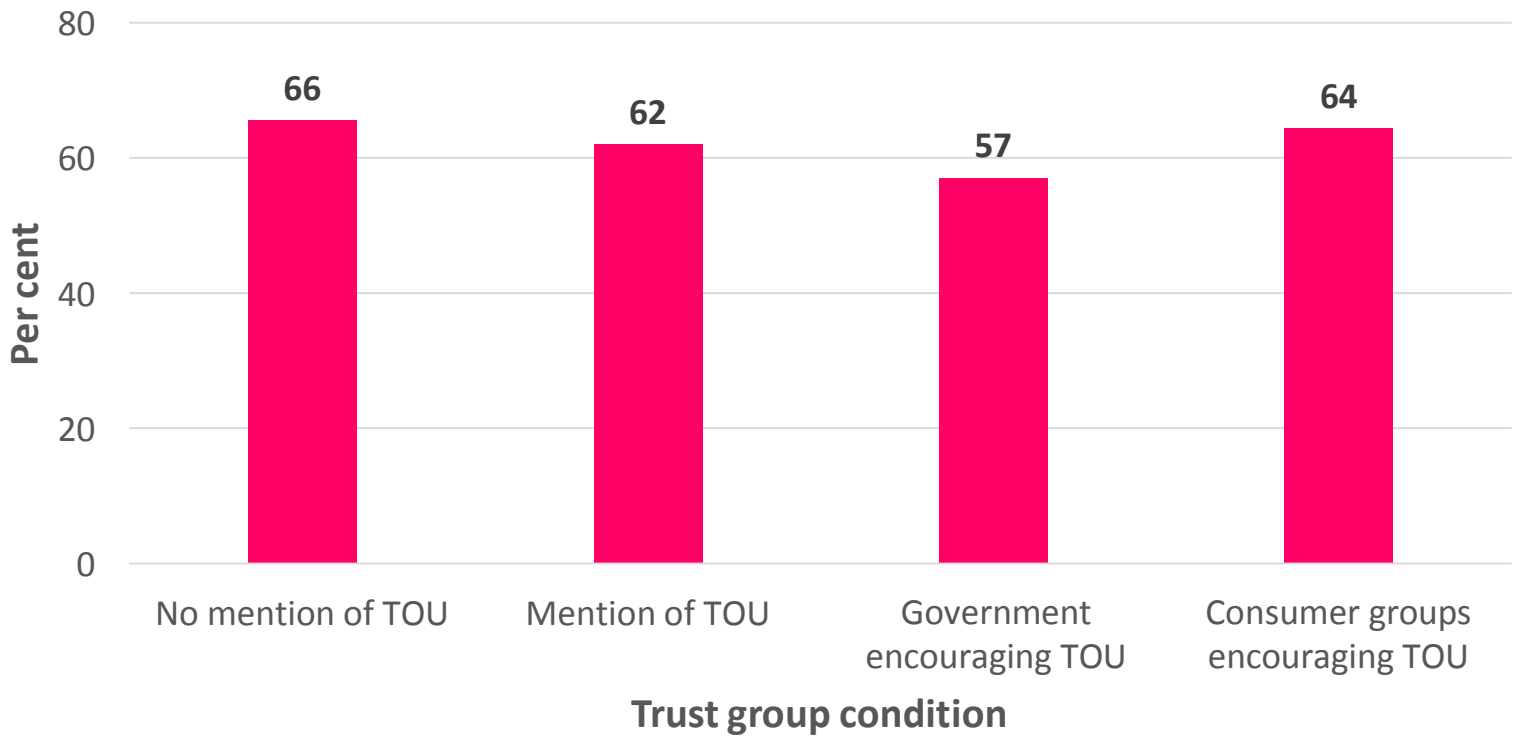
Earlier in the questionnaire you were asked to say who your present electricity supplier is.

The Government wants all suppliers, including yours, to consider introducing optional new 'time of use' tariffs where the price of electricity varies depending on the time of day.

These tariffs allow people to save money by changing when they use electricity, which can reduce demand on the grid at certain times and help keep the lights on.

To what extent do you think your electricity supplier is trustworthy or untrustworthy with regard to the following…

Trust experiment: percentage viewing their supplier as very/fairly trustworthy



Trust Experiment: regression analysis (controlling for age/gender)

	Unstandardized Coefficients		Standardized Coefficients	p
	B	**S.E.**	**Beta**	
Constant	3.498	0.041		< .001***
Ref cat = no mention of TVTs				
Mention TVTs	-0.136	0.046	-0.066	0.003**
TVTs encouraged by government	-0.162	0.046	-0.079	< .001***
TVTs encouraged by consumer organizations	-0.071	0.046	-0.034	0.124
Age 18-34	0.069	0.047	0.029	0.143
Age 55+	0.131	0.036	0.072	< .001***
Male	-0.06	0.033	-0.034	0.068

Trust: Findings and implications

- Trust in energy suppliers significantly lower when TVTs explicitly mentioned, but with small effect size – potentially a barrier to introduction by energy suppliers.
- Larger negative effect when framed as encouraged by government, but no effect when driven by consumer organizations.
- Suggests that trusted non-governmental third parties could have a role in promoting introduction of TVTs if negative trust impact is to be minimized.
- Caveat – people less likely to be explicitly informed about wide introduction of TVTs than just to see them start to become available.

Supplementary information

Loss-aversion questions

Please imagine that you are offered the opportunity to take a series of coin flipping 'heads or tails' gambles and then tell us whether you would take the gamble in each case.

- if you take the gamble, then you could hypothetically win or lose money
- if you don't take the gamble, then you can't win or lose anything

Please remember that there are no right or wrong answers for these questions - it's just about your preferences.

Gamble	Yes I would take this gamble	No, I would not take this gamble
#1 If the coin turns up heads then you lose £2; if the coin turns up tails then you win £6	○	○
#2 If the coin turns up heads then you lose £3; if the coin turns up tails then you win £6	○	○
#3 If the coin turns up heads then you lose £4; if the coin turns up tails then you win £6	○	○
#4 If the coin turns up heads then you lose £5; if the coin turns up tails then you win £6	○	○
#5 If the coin turns up heads then you lose £6; if the coin turns up tails then you win £6	○	○
#6 If the coin turns up heads then you lose £7; if the coin turns up tails then you win £6	○	○

Reference: Fell, M. J., Nicolson, M. L., Huebner, G.M., Shipworth, D. "Is it Time? Consumers and time of use tariffs: trialling the effect of tariff design and marketing on consumer demand for demand-side response tariffs". Report to Smart Energy GB. March 2015.

Coding loss aversion

Loss aversion is coded as an interval variable representing the number of net positive gambles rejected and implemented into the regression analysis such that loss-averse people are compared to those who are not loss-averse (people who reject no net positive gambles). This allows us to measure the impact of rejecting all four gambles on uptake of the time-varying tariff relative to not being loss-averse at all as well as the impact of rejecting 3 gambles, 2 gambles and just 1 gamble relative to rejecting none respectively.

Gamble	
#1 If the coin turns up heads then you lose £2; if the coin turns up tails then you win £6	Net positive gambles
#2 If the coin turns up heads then you lose £3; if the coin turns up tails then you win £6	
#3 If the coin turns up heads then you lose £4; if the coin turns up tails then you win £6	
#4 If the coin turns up heads then you lose £5; if the coin turns up tails then you win £6	
#5 If the coin turns up heads then you lose £6; if the coin turns up tails then you win £6	
#6 If the coin turns up heads then you lose £7; if the coin turns up tails then you win £6