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Investigating preferences for dynamic electricity tariffs: The effect of environmental and system benefit disclosure

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Abstract: Dynamic electricity pricing can produce efficiency gains in the electricity sector and help achieve energy policy goals such as increasing electric system reliability and supporting renewable energy deployment. Retail electric companies can offer dynamic pricing to residential electricity customers via smart meter-enabled tariffs that proxy the cost to procure electricity on the wholesale market. Current investments in the smart metering necessary to implement dynamic tariffs show policy makers' resolve for enabling responsive demand and realizing its benefits. However, despite these benefits and the potential bill savings these tariffs can offer, adoption among residential customers remains at low levels. Using a choice experiment approach, this paper seeks to determine whether disclosing the environmental and system benefits of dynamic tariffs to residential customers can increase adoption. Although sampling and design issues preclude wide generalization, we found that our environmentally conscious respondents reduced their required discount to switch to dynamic tariffs around 10% in response to higher awareness of environmental and system benefits. The perception that shifting usage is easy to do also had a significant impact, indicating the potential importance of enabling technology. Perhaps the targeted communication strategy employed by this study is one way to increase adoption and achieve policy goals.

1. Introduction

The deployment of smart electricity meters – devices that can read and relay consumption at discrete time intervals – is progressing quickly. 33% of US households had smart meters as of May 2012, and nearly two-thirds are expected to have them by 2015 (FERC 2011; IEE 2012). In parts of the European Union (EU) the deployment of smart meters is moving even faster (Haney et al. 2009; Torriti et al. 2010). Italy has completed its transition; by 2020, France, the Netherlands, Ireland, Norway, the UK, and Spain are projected to reach almost 100% deployment (DECC and Ofgem 2011; Faruqui et al. 2010; Torriti 2012).

Smart meters enable dynamic electricity pricing: tariffs that allow customers to face the cost of procuring electricity in the wholesale market, which varies by time of day and season (Fox-Penner 2010: 49). Examples are provided in Appendix A. The main benefit of these market-reflective tariffs is that they provide price signals for customers to cut demand during peak, high-priced times (Faruqui and Sergici 2010; Faruqui and Palmer 2012; Filippini 2011). Price-responsive customers can produce efficiency gains for the electricity sector because they: require less infrastructure to generate and distribute power at peak times[1]; cut electricity procurement costs through lower peak prices; and reduce vulnerability to service failures, such as blackouts (Faruqui et al. 2010). Responsive demand – via direct customer response or enabling technologies like smart appliances, energy storage, and distributed generation (Strbac 2008; Clastres 2011) – becomes more valuable if it is "dispatchable": able to be deployed by the system operator with certainty to respond to market conditions. These cost savings can be passed through; switching to these tariffs can save money for the majority of customers (Faruqui 2010).

Responsive demand driven by dynamic pricing can also reduce greenhouse gases and local pollutants. Enhanced price signals can cause customers to shift demand away from peak times,

[1] Safety margins for peak demand conditions cause some power generation and delivery infrastructure to remain unutilized most of the year: 5-12% of power plants serve demand only 1% of the time (Faruqui et al. 2007).

avoiding emission-intensive generators used to serve system peak in some regions.[2] Customers may also cut demand entirely due to enhanced price signals and better consumption information from smart metering (PNNL 2010). Demand that can be dispatched is the largest potential source of environmental benefits. Responsive, dispatchable demand would be able to support higher levels of intermittent renewable generation without compromising reliability (Delucchi and Jacobson 2011). The CO_2 reductions of smart metering and dynamic pricing, and resulting demand response have been quantified in studies, some specific to the US (EPRI 2008; Hledik 2009), others global in scope (IEA 2010; Webb 2008). They show modest direct benefits, at maximum around 5% of total emissions in 2030. Renewable energy deployment in the 25-40% range supported by a smarter grid can deliver another 5-10% of cuts in CO_2 emissions (PNNL 2010).

Despite these environmental and system (E&S) benefits and potential bill savings, in the UK only about 15% of customers opt for a simple dynamic Time of Use tariff with a peak and off-peak price (Faruqui and Palmer 2012). On the other hand, in a US pilot when dynamic tariffs were the default only 10% opted out (Herter 2007). Other studies have confirmed this status quo bias (MMI 2003). An on-going research programme by the US Department of Energy (2013) also highlights the higher recruitment rates for default offers (78% to 87%) in contrast to opt-in methods (5% to 28%). Low uptake does not bode well for smart metering's cost effectiveness. In the EU, smart meters' cost is only justified when dynamic tariffs are offered and customers switch to them at higher levels than traditionally experienced (Faruqui et al. 2010).

Since it may be legally or politically impossible to make dynamic pricing the default option, experts on both sides of the Atlantic (Faruqui et al. 2010; Torriti et al. 2011) have suggested that informing customers about the E&S benefits of dynamic pricing could break this status quo bias and increase switching rates. This short paper uses a survey-based choice experiment to determine the effect of E&S benefits information on household preferences for dynamic pricing.

[2] This direct benefit depends on peak and off-peak generation mix. For example, shifting demand from coal to natural gas is beneficial, while the opposite is not. Hledik 2009 (p. 11) provides an example of two different load shifting scenarios in the United States. We also note that reducing demand completely is not subject to this caveat – it is purely a benefit.

2. Materials and Methods

Choice experiments (CEs) are a popular survey-based stated preference technique. In a CE, respondents choose one option out of sets of multiple options, each with different attributes varying at different levels, where price is one of the attributes (Bateman et al. 2002; Louviere et al. 2003; Champ et al. 2003). Willingness to pay (WTP) or willingness to accept (WTA) is inferred indirectly by analysing how respondents trade off attributes against cost (Holmes and Adamowicz 2003). The key advantage of CEs is the possibility of eliciting values for multiple attributes and options at once. However, CEs can add complexity to valuation (Bateman et al. 2002; Hanley, Mourato and Wright 2001; Foster and Mourato 2002). Although no stated preference study to date has examined the effect of E&S benefits in dynamic tariff choice, relevant studies exist on load-shifting and dynamic tariff choice (MMI 2003 and Platchkov et al. 2011), electricity outages (Pepermans 2011; Carlsson and Martinsson 2008; Abdullah and Mariel 2010), and tariff choice (Goett et al. 2000).

The complexity of electricity tariffs makes designing an appropriate CE difficult, especially for residential customers. Goett et al. (2000), for example, used over 40 different attributes, such as price, 'greenness', customer service, and additional services. The authors chose to accept ambiguity in some attributes to avoid technical complexity, and surveyed more sophisticated business customers. Taking a different tack for households, MMI (2003) focused exclusively on dynamic pricing and a pre-defined tariff set. By limiting the survey's scope, the authors avoided complexity by designing tariffs that communicated cost, possible savings, and behaviours to get those savings (Lineweber 2012).

We use a simple web-based choice experiment to elicit preferences for dynamic pricing. Our design drew on similar studies, especially Platchkov et al. (2011) and MMI (2003).[3] Specifically, we use a labelled CE design (Fimereli and Mourato 2013) where we proxy the choice to switch from a fixed tariff to one of two dynamic tariffs: Time of Use (TOU) and Critical Peak

[3] Survey design was also aided by comments from electric industry consultants, academics, and employees of electricity supply and distribution companies, a full list of whom can be found in the Acknowledgements section.

Pricing (CPP).[4] Together with the tariff label (i.e. fixed tariff, TOU or CPP), we provide a description (via words and graph) of the TOU and CPP tariffs as well as information on the actions required (e.g. shifting appliance usage away from system peak) and risks involved in obtaining the bill discount. Given the complexity of tariff-related information, we opted to vary only the price attribute. The price attribute was framed as an electricity bill discount (i.e. a WTA format) to switch to the dynamic tariff, and varied among 1%, 2%, 5%, 10%, 15%, and 20%. This discount was displayed both in percentage and dollar savings based on bill information entered by respondents.

Respondents were presented with four labelled choice cards.[5] In each, they were asked to choose one among three tariffs – fixed, TOU or CPP – taking into account the information provided about the tariffs and the varying bill discount. To determine the effect of E&S benefits on customer switching, respondents were randomly divided into two sub-samples, with E&S benefits information presented to only one. Appendix B contains examples of choice cards both with and without E&S information.

To model customer preferences for dynamic tariffs we estimated both a conditional and mixed logit model, consistent with other studies reviewed. These models allow the analyst to derive a model of the probability that a respondent will choose one tariff over another, and ultimately WTA, based on the attributes of the tariff and respondent. The conditional logit is a basic model; the mixed logit corrects many of the deficiencies of the conditional, but is more complex. See Appendix C for a technical treatment of these models.

Besides the tariff choice section, the survey also elicited information on the following subjects: electricity usage; use of appliances, heating, and cooling; attitudes toward personal energy consumption and policy goals; tariff choice motivations; attitudes towards technologies and services; and demographic and socioeconomic information. Questions before the tariff choice

[4] The market reflective Real Time Pricing tariff shown in Appendix A is not studied, as existing meta-analyses noted that residential participation in RTP programmes is generally low (DECC, 2013; Barbose et al., 2004).
[5] The full factorial of thirty-six possible dynamic tariff options was used. The options were randomly grouped into nine blocks of four choice cards, which were presented randomly to respondents (Holmes and Adamowicz 2003).

section were designed to warm up the respondent to think about energy usage and shifting activities. Demographic questions were left to the end to avoid protest responses.

The potential for hypothetical bias (i.e. differences between stated and true values) must be taken into account when conducting any stated preference study (Whitehead and Blomquist 2006). CE designs arguably mitigate against this type of bias to some extent as values are inferred indirectly (Hanley, Mourato and Wright 2001; Murphy et al. 2005). We also benefit from being able to proxy a real decision about a familiar product with a non-voluntary payment mechanism (Hanley et al. 2001). Moreover, we provide context: the survey's purpose is to decide whether electricity retailers can offer these tariffs.

3. Results

The survey was implemented online at www.powershiftsurvey.com and ran for three weeks, from 9 to 31 July 2012. It was distributed through social media (e.g. Facebook) and email. A total of 160 usable responses were received. All respondents are residents of the US or EU, and currently pay one or more electricity bills. 88 respondents received the E&S benefits information treatment. This is a "convenient" sample and thus the study should be seen as a pilot with indicative results that should not be generalized.

3.1 Descriptive statistics

Demographic information is summarized in Table 3-1 below. The sample seems to be relatively balanced in terms of gender and region, with women slightly overrepresented. The group is young, with 50% being 25 years of age or below. The majority (nearly 88%) are well-educated, having completed an undergraduate, masters degree or more.

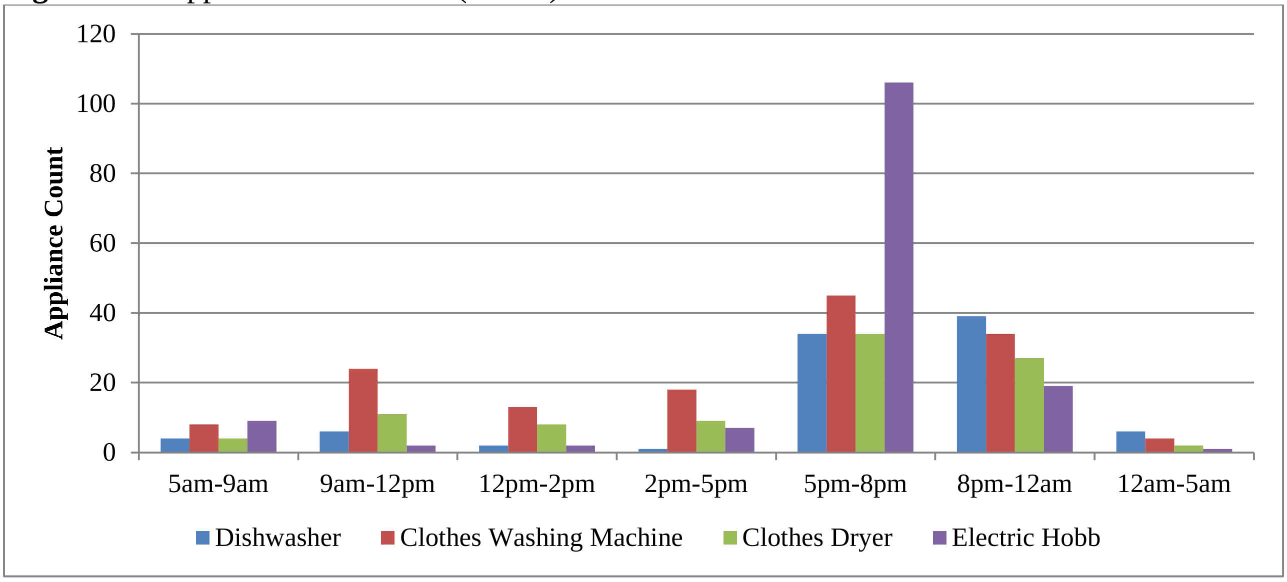
Table 3-1: Demographic and Socio-economic Data (n=160)

Category	Statistic	Category	Statistic
Gender		**Region**	
Female	58.8%	EU	45.6%
		US	54.4%
Age		**Area Type**	
Min	19	Rural	1.9%
Max	70	Suburban	33.8%
Median	25	Urban	64.4%
Highest Degree Completed		**Housing Type**	
No Degree	0.0%	Dormitory	2.5%
High School	1.9%	Apartment	42.5%
Some University	10.6%	Single Family Home	42.5%
Undergraduate	35.0%	Multi Family Home	10.0%
Masters	48.1%	Other	2.5%
Doctorate	1.9%		
Professional Degree	2.5%	**Conservation Organization Member (e.g. Sierra Club)**	
		Yes	11.3%
Current Student			
Yes	55.0%	**Annual Pre-Tax Household Income**	
		Less than $30,000	31.9%
House Occupancy		$30,000 to $60,000	16.3%
w/ less than 7 years of age	10.0%	$60,001 to $110,000	21.9%
w/ 7 to 18 years of age	7.5%	$110,000 or more	21.3%
w/ 18 years of age or more	90.6%	Would rather not say	8.8%
Max Occupancy	10		
Min Occupancy	1		
Median Occupancy	3		

Attitudinal results show that our respondents strongly prefer environmentally friendly energy consumption and supply mix: around 90% would like their electricity usage to be as environmentally responsible as possible; 93% support renewable energy growth; and nearly 96% support homes and businesses energy efficiency. 88% support limiting greenhouse gases to mitigate climate change. Ensuring a reliable electricity supply and energy security are also popular policy goals for 84% and 74% respectively.

Findings from our survey on use of heating and cooling systems indicate potential for load shifting. Air conditioning has the highest potential for shifting during the summer in the US: about 90% of US respondents have central air conditioning, window units, or both. In the EU, electric heating has the highest shifting potential in winter: just over 70% of the sample has central electric heating, ‘space’ heaters, or both.[6] Appliance shifting applies to both regions. Dishwashers are used by over 58% of the group, washing machines by 91%, clothes dryers by nearly 60%, and electric cooking appliances by over 91%. Figure 3-1 shows usage of appliances by time of day. Respondents were found to have substantial appliance use from 5pm-12am, with more usage from 5-8pm. This corresponds to the second half of peak time (2-8pm) and the period immediately after. Potential to shift does not necessarily imply willingness, although over 65% of respondents said it would be easy to shift their usage.

Figure 3-1: Appliance Use Profile (n=160)



Caption: Figure 3-1 shows respondents’ use of appliances by time of day. Respondents were found to have substantial appliance use from 5pm-12am, with more usage from 5-8pm. This corresponds to the second half of peak time (2-8pm) and the period immediately after.

Average bill size was around $80 per month, with 53% paying this amount or less. A third of respondents claimed to be on a fixed tariff while another third did not know their tariff type. In

[6] Use of heating and cooling systems tend to be higher for the surveyed group than among the general population in the US or EU. See Stamminger 2008, Table 3.11.1 for estimated penetrations of a variety of electric appliances and heating systems in European countries (pp 211-12).

the E&S benefit sub-sample, 14% of respondents indicated they were on a dynamic tariff already, this percentage was 21% in the treatment without E&S information.[7]

3.2 Model results

The variables used in the econometric analysis are described in Table 3-2. Three variables are labels or attributes of the choice experiment: the dynamic tariff labels TOU and CPP, and the attribute DISCOUNT. E&S is a dummy variable indicating whether the respondent received the E&S benefits information or not. The remaining variables are customer attributes that enter the model as interactions with each of the tariff labels.

Table 3-2: Variables used in the models

Variable	**Description**
TOU	Alternative-specific constant: 1 if respondent choose TOU
CPP	Alternative-specific constant: 1 if respondent choose CPP
DISCOUNT	Price Attribute: Continuous variable. Values presented to survey respondents were 1%, 2%, 5%, 10%, 15%, and 20%.
Variables used in interactions	
E&S	Dummy variable: 1 if respondent was presented with environmental and system (E&S) benefits of dynamic tariffs, 0 otherwise
MALE	Dummy variable: 1 if male, 0 otherwise
HIBILL	Dummy variable: 1 if pay a bill over $80 per month, 0 otherwise
STUDENT	Dummy variable: 1 if is currently in education, 0 otherwise
EASY	Dummy variable: 1 if considers shifting electricity use from peak (2-8pm) to off-peak (any other time) "easy" or "very easy", 0 otherwise

Results of the conditional and mixed logit models are shown in Table 3-3. Observed heterogeneity in the group's preferences towards dynamic pricing is further included by interacting each tariff with customer attributes. These interactions give insight into how different people respond to dynamic pricing, and also isolate the effect of E&S benefits. The interaction with E&S shows the impact of providing extra information on E&S benefits on preferences for dynamic pricing.

[7] About 25% of respondents indicated they were on a tariff not commonly offered in the areas covered by the survey – the inclining block rate. We hypothesize that these responses were a misunderstanding and that these respondents were probably on fixed tariffs.

Table 3-3: Model Results with Customer Attribute Interactions

	Model 1: Conditional Logit					Model 2: Mixed Logit			
	Coefficient	Std. Error	MWTA[a]	Std. Error[b]		Coefficient	Std. Error	MWTA[a]	Std. Error[b]
DISCOUNT	0.079***	0.010				0.163***	0.020		
TOU[c]	-0.865***	0.308	11.05%	3.71%		-1.993**	0.830	12.22%	4.91%
E&SxTOU	0.958***	0.232	-12.24%	3.32%		1.599***	0.622	-9.81%	3.87%
MALExTOU	-0.991***	0.230	12.67%	3.31%		-1.779***	0.627	10.91%	3.91%
HIBILLxTOU	0.666***	0.230	-8.51%	3.06%		1.255**	0.619	-7.70%	3.82%
STUDENTxTOU	-0.080	0.236	1.02%	3.03%		-0.056	0.629	0.34%	3.86%
EASYxTOU	1.453***	0.226	-18.57%	3.65%		2.848***	0.657	-17.47%	4.19%
CPP[c]	-1.229***	0.355	15.70%	4.34%		-3.009***	1.039	18.45%	6.20%
E&SxCPP	1.225***	0.274	-15.65%	3.91%		2.086***	0.788	-12.80%	4.87%
MALExCPP	-0.840***	0.273	10.73%	3.71%		-1.437*	0.790	8.81%	4.88%
HIBILLxCPP	-0.016	0.270	0.20%	3.45%		-0.390	0.793	2.39%	4.86%
STUDENTxCPP	-0.886***	0.274	11.32%	3.75%		-1.728**	0.804	10.60%	4.97%
EASYxCPP	1.064***	0.267	-13.60%	3.85%		1.981**	0.802	-12.15%	5.01%
						Standard Deviations of Random Coeffs.			
TOU	N/A	N/A				2.776***	0.381		
CPP	N/A	N/A				3.365***	0.535		
Df			13					13	
Replications			N/A					1000	
Observations			1920					1920	
Log likelihood			-541.160					-438.380	
LR χ^2		Coeffs (13)	323.90***				SDs (2)	205.56***	
Pseudo R^2			0.230					N/A	

*p ≤ 0.1; **p ≤ 0.05; ***p ≤ 0.01.
a. Marginal WTA calculated as a bill discount (%).
b. Std. Errors calculated using the Delta method (Hole 2007).
c. Alternative-specific constant.

A Likelihood Ratio test between Models 1 and 2 shows that the mixed logit Model 2 (Table 3-3) provides a better fit for the data at the highest levels of significance (LR= 205.56 > $\chi^2_{(2)}$ (.05) = 5.99). Going forward our discussion will focus on Model 2. In this model, the discount associated with a tariff is the WTA of a base individual: a non-student female with a low bill, who did not see E&S benefits, and does not find it easy to shift electricity consumption away from peak hours. Each interaction effect gives the increase or decrease in discount necessary to keep utility constant from the switch, in relation to the base person, holding all else constant.

4. Discussion

4.1 Time of Use

Model 2 results (Table 3-3) show that, for TOU, the base individual requires a 12.22% discount to switch from the fixed tariff. A male requires an additional 10.91% discount. Having a high bill reduces the necessary discount by 7.70%; we would intuitively expect this result, as a customer with a relatively large bill will see larger savings. This result also aligns with the description of a 'likely taker' from MMI (2003). Being a student has no statistically significant effect. On the other hand, having the attitude that shifting from peak times is easy has the largest effect on respondent WTA, cutting the discount needed by 17.47%. This result indicates that customers in this category will switch for almost any discount. Finally, respondents who were informed about E&S benefits had a 9.81% lower WTA for TOU, an effect second in size only to feeling shifting usage is easy. Interestingly, for the base customer, seeing E&S benefits puts WTA to switch to TOU very near zero, indicating the customer is indifferent between the two tariffs. Most of the WTA estimates have large standard errors, indicating heterogeneity in preferences.

4.2 Critical Peak Pricing

In line with expectations, our results show that the base respondent has a higher WTA to switch from fixed to CPP than to TOU: 18.45% (Model 2, Table 3-3). Male respondents have an 8.81% higher WTA, slightly less than male WTA for TOU. Having a high bill has a statistically insignificant effect, at odds with the positive significant effect found for TOU and MMI (2003). The STUDENT interaction is significant for CPP, unlike for TOU, and increases WTA by 10.60%. It is possible that students respond negatively to CPP because of its complexity, as they may be inexperienced with paying bills. Feeling that shifting usage is easy cuts WTA by 12.15%, a smaller effect than for TOU. Finally, the disclosure of E&S benefits cuts the discount needed by 12.80%, which is slightly larger than its effect on TOU. It causes the largest reduction of any interaction for CPP. Again, for all WTA estimates, large standard errors indicate heterogeneity in preferences.[8]

Debriefing questions indicate respondents preferred TOU to CPP primarily due to the inconvenience associated with cutting substantial usage under CPP. The risk of bill increases is also a factor. A number of enabling technologies and services were offered free of charge to mitigate these concerns. A home battery that locked in savings of 5% for the TOU rate, but also automatically shifted usage, was the most popular. A bill analysis service and automatic usage-shifting app were also seen favourably. Services that ceded customer control of shifting to the utility were seen unfavourably.

5. Conclusions and Policy Implications

This pilot study aimed to determine whether informing customers about E&S benefits of dynamic tariffs could potentially increase their adoption. We found that our environmentally conscious sample reduced their required discount to switch from a fixed to a dynamic tariff by around 10%, although the perception that shifting electricity use is easy to do also had a significant impact on the discount required. This second result indicates the important role that automated forms of shifting may play. We note however that sampling and design issues preclude generalization of these promising results. In this context, the current analysis should be viewed as a feasibility study for a larger study with a more representative sample. Our preliminary results indicate that this topic is worth investigating further.

Should our results hold for a broader population, they indicate an opportunity for policy makers in the electricity sector to lower costs and achieve environmental goals by enabling

[8] It is important to note that the overall magnitude of interaction effects, E&S benefit disclosure and otherwise, likely overstate the response of some customers. The authors ran additional models that included multiple interaction effects to examine the effect of E&S benefit exposure on different groups, such as customers with high bills. In some cases, the E&S benefit effect was muted if a customer already had a lower WTA to start (the case with customers with high bills). Thus, any combination that indicates a negative WTA (or WTP) to switch may be spurious – a result of the limiting assumption that all customers respond to E&S benefits in the same way. Further research with a larger sample size is needed to disentangle and quantify these effects.

electricity retailers to offer dynamic tariffs and services to households. To date, households have largely been viewed as passive participants in the electricity market, served under fixed price contracts that may or may not be adjusted to market conditions. Smart metering deployments allow customers to become more active participants in the electricity market through dynamic tariffs. However, customers have not opted into such tariffs in large enough numbers to justify meter deployment. E&S benefits are technically possible but not realized.

Our results indicate these customers may be more receptive to dynamic tariffs if the E&S benefits of these tariffs are highlighted, and if enabling services such as automated shifting and batteries are bundled with electricity services. Thus, in order for the benefits of smart metering deployments to exceed their costs, regulators and retailers must focus on more than meters – they might need to understand customers' motivations and concerns and move to address them through technology and information.

More flexible household demand, especially if it is technology-enabled and dispatchable, can be a key tool for integrating high levels of intermittent renewable energy and dealing with peaks in demand, as recognised by recent policy documents (DECC 2014). If the structure of the electric power sector shifts to meet new policy goals – incorporating new metering, tariffs, technologies, and clean generation – residential customers cannot be expected to actively participate if they are kept in the dark. Further research is necessary to understand how to connect with customers and what type of response to expect.

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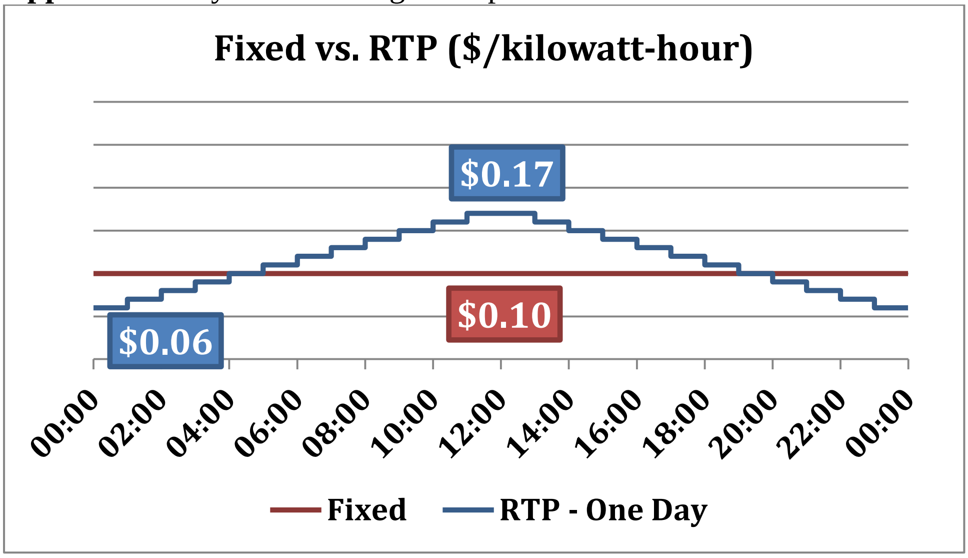
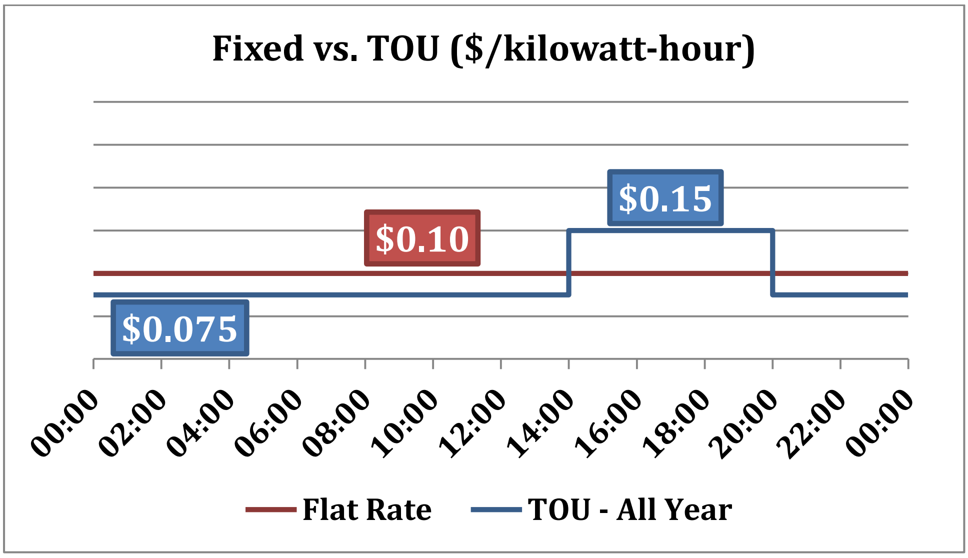
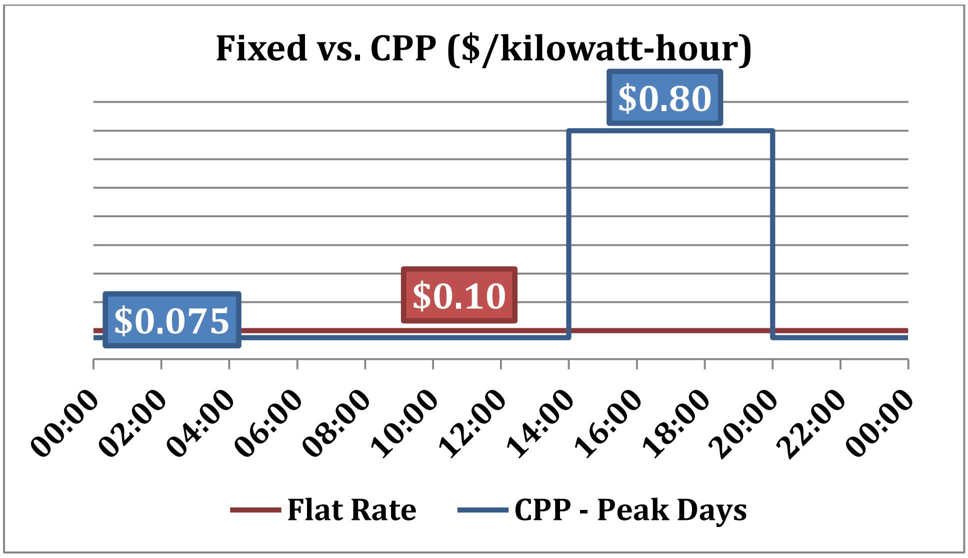
Appendix A: Dynamic Pricing Examples







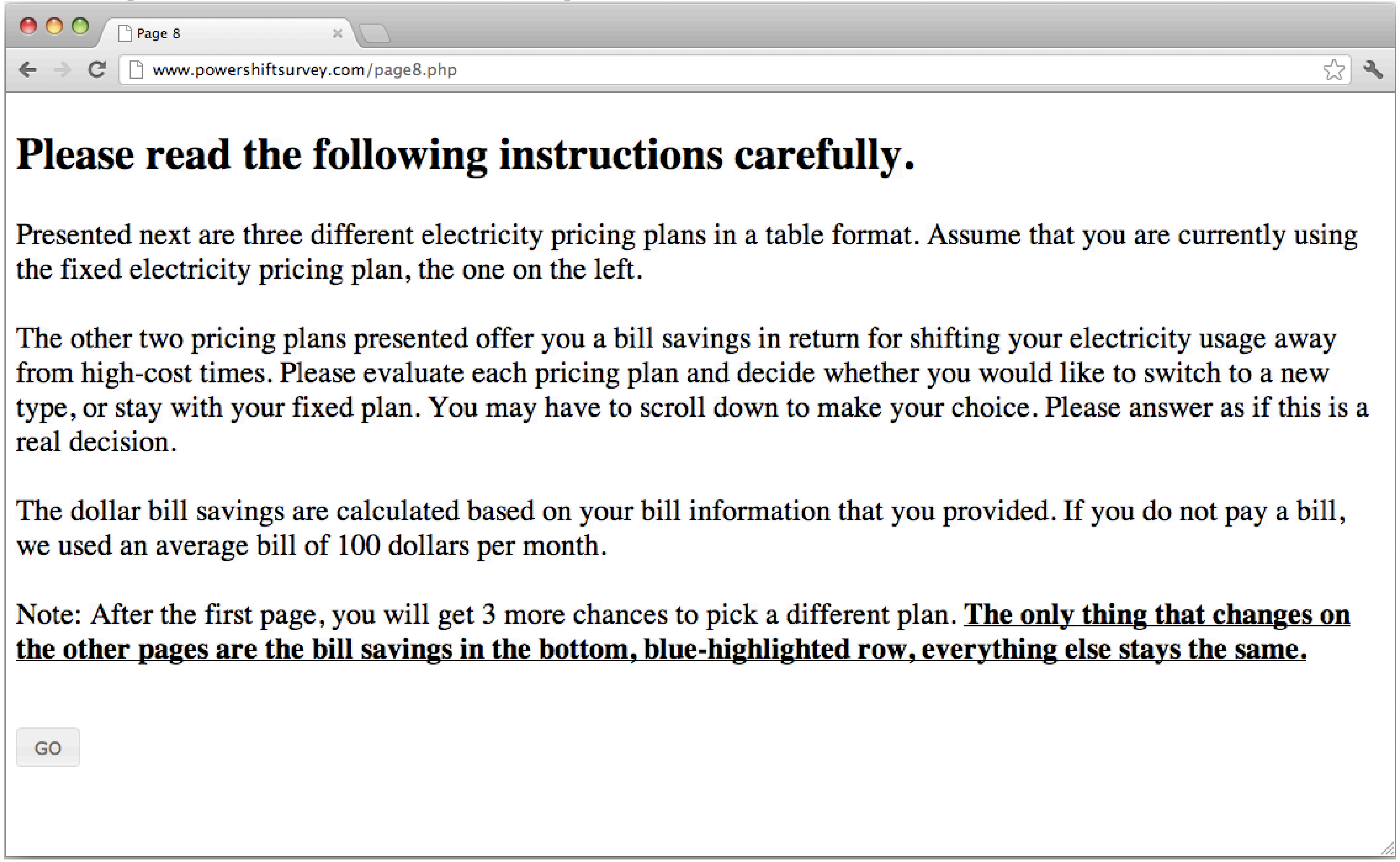
Source: Author's illustrations adapted from Faruqui et al. (2010)

Tariff Descriptions	
Fixed	A fixed electricity tariff charges the same price (per kWh) for electricity over a set period of time. It does not change with day-to-day market conditions.
Real Time Pricing (RTP)	The "purest" variation is real time pricing (RTP), where the customer faces the actual cost of procuring electricity on the market, with price changes every hour or so. Price volatility makes RTP impractical for the residential market.
Time of Use Pricing (TOU)	TOU tariffs have pre-set, high-priced on-peak periods and lower prices during off-peak periods. TOU tariffs are the most prevalent form of dynamic pricing, but also have less of an impact on peak demand, as prices only approximate market conditions.
Critical Peak Pricing (CPP)	CPP tariffs create a better connection to wholesale prices and market conditions than TOU tariffs. On a pre-set number of days (around ten), the retail price of electricity rises substantially during the on-peak period of the day, anywhere from 500% to 1000%. Customers are notified shortly in advance, and face lower prices all other hours of the year to compensate.

Appendix B: Tariff Choice Cards

Page 8a: Pre Choice Card Instructions

Note: A respondent saw four cards in total. Each respondent saw either cards with E&S benefits or without, never a combination.



Please read the following instructions carefully.

Presented next are three different electricity pricing plans in a table format. Assume that you are currently using the fixed electricity pricing plan, the one on the left.

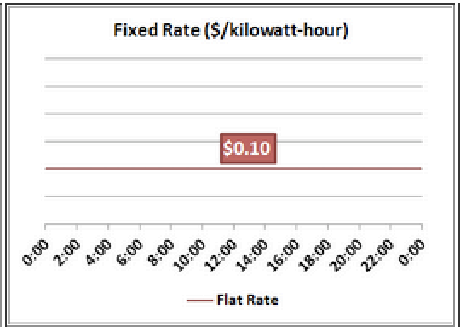
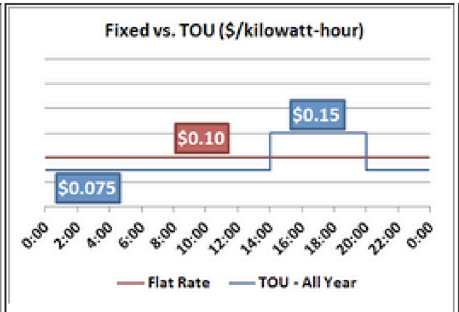
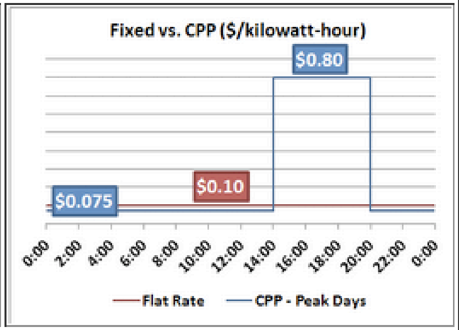
The other two pricing plans presented offer you a bill savings in return for shifting your electricity usage away from high-cost times. Please evaluate each pricing plan and decide whether you would like to switch to a new type, or stay with your fixed plan. You may have to scroll down to make your choice. Please answer as if this is a real decision.

The dollar bill savings are calculated based on your bill information that you provided. If you do not pay a bill, we used an average bill of 100 dollars per month.

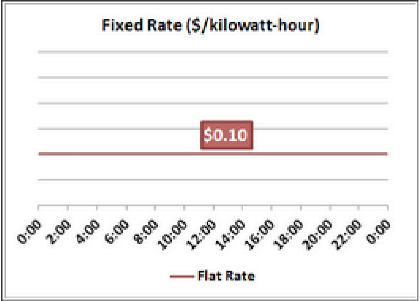
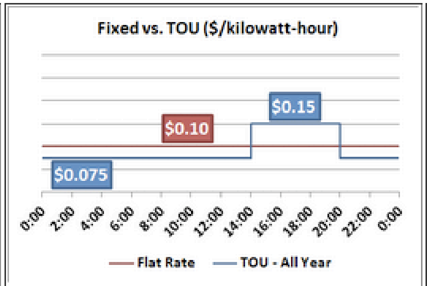
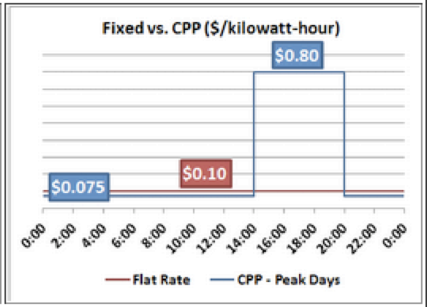
Note: After the first page, you will get 3 more chances to pick a different plan. **The only thing that changes on the other pages are the bill savings in the bottom, blue-highlighted row, everything else stays the same.**

GO

Page 8b: Choice Card Example <u>without</u> E&S Benefits ($100 per month bill)

Tariff Type	**Fixed**	**Time of Use (TOU)**	**Critical Peak Pricing (CPP)**
Description	*Price stays the same throughout the day.	***Cost:** Rate is 50% higher than your current fixed rate 6 hours of the day, every weekday, from 2pm until 8pm. ***Benefit:** Rate is 25% lower than your current fixed rate all other times.	***Cost:** On 10 weekdays selected by the electric company prices will raise 8x from your current fixed rate for 6 hours, from 2pm to 8pm. Your electric company notifies you one day in advance. ***Benefit:** Rate is 25% lower than your current fixed rate all other times that day and all other days in the year.
Graphic			
Required Behavior Change to get Savings	*None - it's your current plan.	**Sustained, moderate changes during daily high priced times:** ***All regions:** Shift all listed appliances. ***U.S.:** Adjust thermostat up by 2F (1C) from 75F (25C) during the summer. ***Europe:** If you use electric heating, adjust your thermostat down by 2F (1C) from 68F (20C) during the winter. Use stand-alone electric room heaters at their lowest setting.	**Oneoff, significant changes during 10 days' high priced times:** ***All regions:** Shift all listed appliances. ***U.S.:** Adjust thermostat up by 5F (2.5C) from 75F (25C) during the summer. Turn off window and room air conditioning units, and all but essential lighting. ***Europe:** If you use electric heating, adjust your thermostat down by 5F (2.5C) from 68F (20C) during the winter. Turn off stand-alone electric room heaters. Turn off all but essential lighting. Restrict use of electric cooking appliances by 50%.
Potential Bill Increase with No Behavior Change	0%	0% to 5% $0 to $5.00 per month	0% to 5% $0 to $5.00 per month
Potential Bill Savings with Behavior Change **Note: the last 2 columns in this row change with each selection.**	0%	15% Approximately $15.00 per month	2% Approximately $2.00 per month
Please Select One	Choice 1	Choice 2	Choice 3

Page 8b: Choice Card Example with E&S Benefits ($100 per month bill)

Tariff Type	Fixed	Time of Use (TOU)	Critical Peak Pricing (CPP)
Description	*Price stays the same throughout the day.	***Cost:** Rate is 50% higher than your current fixed rate 6 hours of the day, every weekday, from 2pm until 8pm, during daily high demand. ***Benefit:** Rate is 25% lower than your current fixed rate all other times.	***Cost:** On 10 weekdays selected by the electric company prices will raise 8x from your current fixed rate for 6 hours, from 2pm to 8pm, during emergency conditions. Your electric company notifies you one day in advance. ***Benefit:** Rate is 25% lower than your current fixed rate all other times that day and all other days in the year.
Environmental and Grid Benefits	*None	*Less water and air pollution. *Aid the expansion of renewable energy. *Increased electricity reliability. *Slow the rate of electricity price increases.	*Less water and air pollution. *Aid the expansion of renewable energy. *Increased electricity reliability. *Slow the rate of electricity price increases.
Graphic			
Required Behavior Change to get Savings	*None - it's your current plan.	**Sustained, moderate changes during daily high priced times:** ***All regions:** Shift all listed appliances. ***U.S.:** Adjust thermostat up by 2F (1C) from 75F (25C) during the summer. ***Europe:** If you use electric heating, adjust your thermostat down by 2F (1C) from 68F (20C) during the winter. Use stand-alone electric room heaters at their lowest setting.	**Oneoff, significant changes during 10 days' high priced times:** ***All regions:** Shift all listed appliances. ***U.S.:** Adjust thermostat up by 5F (2.5C) from 75F (25C) during the summer. Turn off window and room air conditioning units, and all but essential lighting. ***Europe:** If you use electric heating, adjust your thermostat down by 5F (2.5C) from 68F (20C) during the winter. Turn off stand-alone electric room heaters. Turn off all but essential lighting. Restrict use of electric cooking appliances by 50%.
Potential Bill Increase with No Behavior Change	0%	0% to 5% $0 to $5.00 per month	0% to 5% $0 to $5.00 per month
Potential Bill Savings with Behavior Change **Note: the last 2 columns in this row change with each selection.**	0%	10% Approximately $10.00 per month	5% Approximately $5.00 per month
Please Select One	Choice 1	Choice 2	Choice 3

Appendix C: Technical Description of Models Used

To model customer preferences for dynamic tariffs we estimated both a conditional and mixed logit model.[***] Logit models treat the dependent variable as categorical, which is an accurate description of the discrete choice of a tariff. In such situations, logit models are preferred to general linear models, which treat the dependent variable as continuous. The logit family of models is derived from the random utility model (RUM) framework. Under RUM, representative or observed utility (V_{nj}) is a function of tariff (n) and respondent (j) attributes. True utility $U_{nj.}$ includes a representative utility and a stochastic component (ε_{nj}) (Carson et al. 1994). Combining the two yields the following expression:

$$U_{nj} = V_{nj} + \varepsilon_{nj}$$

For the standard conditional logit model, ε_{nj} is assumed to follow the independently, identically distributed extreme value (Gumbel) distribution. This allows an expression to be derived giving the probability that a respondent will choose one tariff over another. For the conditional logit, it can be concisely summarised as:

$$P_{ni} = \frac{\exp(\beta x_{ni})}{\Sigma \exp(\beta x_{nj})}$$

The expression above can be used to derive the welfare measures of marginal WTA or WTP, depending on the context. The ratio of any non-price coefficient to the price coefficient (discount) gives marginal WTA or WTP holding utility constant – the compensating surplus (Hoyos 2010):

$$MWTA \ or \ MWTP = \frac{-\beta_{non-price}}{\beta_{price}} \quad (1$$

There are some limiting assumptions to the conditional logit. First, in the most basic model, preferences are assumed to be homogenous across the respondents. Second, the model

[***] The notation in this section draws from Train (2009).

assumes choices exhibit independence from irrelevant alternatives (IIA). Finally, the model assumes unobserved factors are uncorrelated over a repeated panel of choices (Train 2009).

To relax these three assumptions, a mixed (or random parameters) logit is employed. The mixed logit is used in all tariff choice experiments reviewed since 1999. It assumes that at least one of the βx_{ni}'s estimated is not fixed, but varies over respondents in the population according to a distribution specified by the analyst: $f(\beta)$. The standard logit probability expression is thus integrated over the distribution of possible preferences:

$$P_{ni} = \int \left(\frac{\exp(\beta x_{ni})}{\Sigma \exp(\beta x_{nj})} \right) f(\beta) d\beta$$

Choosing which parameters are random and their distribution are the two key difficulties associated with the mixed logit. Random parameters were chosen by starting with all attributes as random and working backwards to identify those with standard deviations that are statistically significant, as suggested by Hensher and Greene (2003).[†††] In the mixed logit model the dynamic tariff labels, TOU and CCP are found to have highly significant standard deviations. As for choosing the random parameters' distributions, we chose to model our tariff labels with normal distributions, which most recent applications assume (Carlsson and Martinsson 2008; Pepermans 2011).[‡‡‡] In all mixed logit tariff applications that we reviewed since 1999, the price coefficient was fixed due to ease of interpretation and issues with defining an appropriate distribution (See Goett et al. 2000 for a full discussion).

[†††] McFadden and Train (2000) propose the Langrange Multiplier test to pick the random parameters. This more sophisticated approach is appropriate with large number of attributes.

[‡‡‡] Other distributions – log-normal, triangular, and uniform – are possible for the tariff attributes (especially log-normal as their signs are unlikely to be positive). However, other distributions pose problems in inferring WTP or WTA (Hensher and Greene 2003).