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USING FIELD EXPERIMENTS TO ADDRESS ENVIRONMENTAL EXTERNALITIES AND RESOURCE SCARCITY: MAJOR LESSONS LEARNED AND NEW DIRECTIONS FOR FUTURE RESEARCH

Michael Price

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Using Field Experiments to Address Environmental Externalities and Resource Scarcity: Major Lessons Learned and New Directions for Future Research
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ABSTRACT

This article provides an overview of the use of field experiments in energy and resource economics. I concentrate on two areas of study; field experiments that (i) speak to the use of dynamic pricing plans to manage the use of electricity and water and (ii) explore the adoption of energy saving technologies. Viewed in its totality, this work suggests that both neo-classical factors such as prices or search costs and behavioral constructs such as salience or social norms influence the use of energy and water. For academics, the studies reviewed provide a deeper understanding of individual behavior and the factors that drive the private provision of public goods. For policy makers, the studies reviewed provide a blueprint outlining ways to combine insights from neo-classical and behavioral economics to manage energy/water demand and mitigate externalities generated through their use.

Michael Price
Department of Economics
Andrew Young School of Policy Studies
Georgia State University
P.O. Box 3992
Atlanta, GA 30302-3992
and NBER
mprice25@gsu.edu

I. Introduction

The problem of externalities and natural resource scarcity provide a cornerstone upon which environmental economists has developed. The standard economic model of these problems links pollution and related externalities to the lack of markets for scarce environmental goods such as clean air or the common nature of natural resources such as groundwater and fish stocks. Given this focus, traditional solutions center upon mechanisms such as tradable permits or emissions taxes that introduce an added price on pollution or the extraction of groundwater stocks.

Spurred by the growing popularity of behavioral economics, more recent manifestations of these models have been augmented to include non-pecuniary motives such as altruism, social pressures, and moral costs (see, e.g., Kotchen, 2006; Kotchen and Moore, 2007; Jacobsen et al, 2012; Ferraro and Price, 2013; Jacobsen et al., 2014; LaRiviere et al., 2014). The introduction of such motivations reflects a fundamental shift in the literature and creates a direct link with work exploring the private provision of public goods (see, e.g., Becker, 1974; Bergstrom et al., 1986; Andreoni, 1988). Intuitively, such models allow for conservation efforts at the individual level by introducing either an added "cost" of consumption or an added benefit of voluntary reductions in demand.[1] In doing so, such models suggest a role for policy measures such as normative appeals or "green" labels that are designed to target such motives as a means to encourage private provision. Yet, as the goal of any policy action is to improve social welfare, the disparate nature of this literature highlights the need for researchers to take a step back and design studies

[1] An alternate strand of the literature relies upon models that introduce behavioral biases such as temptation (Tsvetanov and Segerson, 2013), limited attention (Allcott, Mullainathan, and Taubinsky, 2014; Sallee, 2014), hyperbolic discounting (Heutel, 2011), or salience (Gilbert and Graff-Zivin, 2014; Sexton, 2014). Intuitively, such biases lead consumers to systematically miscalculate the potential benefits of purchasing energy efficiency technologies or engaging in conservation activities and thus provide scope for a broader array of policy interventions including targeted messaging campaigns or energy efficiency standards. I refer the interested reader to Allcott (2014) for a nice overview of such models and the associated policy implications.

that allow them to disentangle competing theories and identify policies that directly target the underlying cause of observed market failure.

This article provides an overview of the use of field experiments within the realm of energy and resource economics. The primary focus of the article derives from studies designed to explore the use of electricity (water) at the household level and how various policy alternatives impact the demand for such resources. Within this rubric I concentrate on two areas of study; field experiments that (i) speak to the use of dynamic pricing plans as a means to regulate peak load and (ii) explore the origins of the energy-efficiency gap and the adoption of energy saving technologies.

Viewed in its totality, the extant body of work underscores that there is no one-size fits all approach to the management of residential water and energy demand. Both neo-classical factors such as prices or search costs and behavioral constructs such as salience or social norms ultimate impact the use of energy and water resources. For example, there is mounting evidence that one can increase the demand for energy saving technologies by lowering prices/search costs or by targeting behavioral preferences and common decision heuristics such as loss aversion. Moreover, in many instances there are important complementarities between neo-classical and behavioral motives. Even if the demand for electricity is highly inelastic, it is possible to increase price sensitivity by providing households information that makes salient both the prevailing price and the amount of electricity consumed at any given point in time.

For academics, such studies are notable as they speak to the heart of the externalities problem and foster a deeper understanding of individual behavior and the factors that underlie the private provision of public goods (bads). By elucidating the various influences that drive such actions, the collected evidence highlights which models best predict behavior and outlines directions for new theories and associated policy prescriptions. For policy makers, such studies are invaluable in that they provide a blueprint outlining ways to combine insights from neo-classical and behavioral economics to manage the demand for energy/water resources and the associated externalities generated through the use of these resources.

Before proceeding, it is important to note that I have in no way attempted to review the voluminous literature in environmental and resource economics to which field experiments are beginning to add. Rather I limit attention to studies that speak directly to conservation efforts and the private provision of environmental quality; particularly as viewed through the lens of residential households and the individual agent. Within these topics, I discuss a limited number of papers and instead focus my comments on major lessons learned from the collected body of evidence.

I aim for the article to demonstrate how field experiments have been used to advance our understanding of the factors that underlie the private provision of public goods (bads) and identify effective strategies to manage the demand for energy/water as a way to mitigate the externalities that are a direct by-product of their use. In doing so, I wish to highlight the importance of studies such as Allcott and Taubinsky (2014) or LaRiviere et al. (2014) which utilize a battery of experimental manipulations to disentangle competing theories and understand what drives the observed market failure. Such efforts are significant in that they shift attention from measuring changes in energy (resource) use to thinking about how various policies options affect social welfare. Before one can begin to craft effective policies, it is critical to identify *both* the existence and underlying source of observed market failure.

The remainder of the study proceeds as follows. Section II provides an overview of dynamic pricing experiments and outlines factors that influence the effectiveness of such programs. Section III summarizes major lessons learned from a series of field experiments designed to uncover what drives the adoption of energy efficient technologies and measure the impact of such technologies on subsequent energy use. Section IV concludes with directions for future work.

II. Managing the Demand for Electricity – Dynamic Pricing Experiments

Economists have long recognized the promise of dynamic pricing strategies such as "peak load" or "real-time" pricing as a means to manage to manage consumption during periods when the marginal cost of production is high. Yet there are a number of reasons to question whether the promise of such strategies may prove unfulfilled. First, electricity accounts for but a small share of overall expenditures for many households. Second, there are a number of energy using durables in the home – e.g., refrigerators and freezers – for which there is a limited ability to adjust use. Taken jointly, one would expect the demand for electricity to be inelastic thereby limiting the potential impact of prices as a means to manage overall consumption.

Finally, and perhaps most importantly, managing residential energy consumption reflects an incredibly complicated dynamic programming problem – a type of decision task which prior evidence suggests individuals have difficulty solving (e.g., Houser, Keane and McCabe, 2004; Cho and Rust, 2010; Brown, Chua and Camerer, 2009; Li, Kahn, and Nickelsburg, 2014). At any given point in time, a household is engaged in a variety of activities that consume energy but rarely (if ever) observes the marginal contribution of any single activity. Moreover, acquiring such information is prohibitively costly in the absence of technologies that provide the household real-time feedback on appliance level consumption. Faced with a dynamic pricing plan, it is thus reasonable to conjecture that individuals will have troubles identifying the relative benefits of adjusting energy use along various margins thereby dampening the response the changing prices.[2]

In this section I summarize the major lessons learned from a series of field experiments designed to examine the effectiveness of dynamic pricing schemes. I break the discussion out into three distinct periods of interest; (i) pilot experiments on time-of-use pricing initiated by the U.S. Federal Energy Administration in the spring of 1975, (ii) a second wave of pilots during the early to mid-2000s exploring both time-of-use and critical-peak-pricing, and (iii) a more recent set of targeted field experiments designed to isolate the importance of information feedback on price sensitivity.

Taken jointly, this body of literature provides mixed evidence on the effectiveness of dynamic pricing plans as a means to promote energy conservation and a corresponding reduction in greenhouse gas emissions. Time-of-use rates produce but modest reductions in energy use during peak periods as the short-run demand for electricity is found to be highly inelastic. Yet, overall price sensitivity depends on the capital stock of the home with much greater responsiveness observed amongst those with some form of air conditioning system in the home. Critical-peak pricing tariffs induce greater reductions in use during peak periods but the overall effectiveness of such programs depends on the way in which the tariff is framed – e.g., as a carrot for conserving energy relative to prior peak periods or a stick for consuming energy during peak periods. Finally, this literature is ubiquitous in demonstrating a strong complementarity between dynamic pricing plans and enabling technologies that provide the household real-time feedback on energy consumption and the prevailing price of electricity. As such, it is likely that

[2] For example, Atarri et al. (2010) provide evidence that many individuals incorrectly perceive the amount of energy used when operating energy intensive appliances such as a dish-washer or a central air conditioner relative to that used by a standard incandescent lightbulb. As such, it is reasonable to assume that individuals facing dynamic pricing plans will disproportionately adjust use along lower "benefit" margins such as lighting rather than adjusting use by changing thermostat settings.

the extant literature provides a lower bound on the "true" impact of dynamic pricing plans as it does not capture and account for long-run capital adjustments that would enhance observed price sensitivity.

The Early Federal Energy Administration Time-of-Use Pilots

Beginning in the spring of 1975, the U.S. Federal Energy Administration initiated a cooperative program sponsoring a series of pilot studies on time-of-use pricing. The aim of these early experiments was to explore the extent to which TOU pricing could be used to shift the load profile of residential consumers. In the decade that followed the initiation of these pilots, a number of academic papers and consulting reports summarizing the impact of these programs were written. The primary focus of this work was to derive estimates for the own-price elasticity of demand and explore how the ratio of peak to off-peak consumption was affected by the introduction of TOU pricing (see, e.g., Atkinson, 1979; Granger et al., 1979; Hendricks, Koenker, and Poirier, 1979; Lawrence and Braithwait, 1979; Caves and Christensen, 1980; Caves, Christiansen, and Herriges, 1984; Aigner, 1985).

Despite the amount of attention garnered by these pilots, there was little consensus as to the overall impact and resulting promise of TOU pricing. For example, Aigner (1985) reports incredibly diffuse estimates of own-price elasticities for pilot studies in Arizona, Connecticut and Wisconsin – estimates for these study range from approximately -0.20 to -0.85. Similar variation is reported in other measures of interest including estimates of cross-price elasticities capturing the extent to which changing prices affect the temporal pattern of consumption across peak and off-peak hours.[3]

[3] Whereas Lawrence and Brathwait (1979) obtain results from the Connecticut experiment suggesting a degree of substitutability between consumption in peak and off-peak hours Caves and Christensen (1980) obtain results from the Wisconsin experiments suggesting that the relationship between peak and off-peak consumption depends on whether one considers compensated or uncompensated demand.

Although point estimates for the various measures of substitution varied widely across pilots, there were a number of common themes that arose from this early work. First and foremost, all studies found that price sensitivity and related elasticity measures were greater during the broader peak period (approximately noon to 7pm) than during off-peak hours. Moreover, observed substitution possibilities and changes in the ratio of peak to off-peak consumption depend critically on the prevailing price ratio. For example, Caves and Christensen (1980) find that the estimated partial price elasticity of demand is approximately 40 percent greater (-0.812 versus -0.574) when calculated using a peak to off-peak price ratio of 8:1 as opposed to that derived under a 2:1 ratio.

Second, estimated elasticities and related measures of conservation depend crucially on the type of appliances within the home. For example, Granger et al. (1979) examine data form the Connecticut Light and Power pilot study and show that observed shift in consumption between peak and off-peak hours is more pronounced for households with electric heating and dishwashers. Similar results are presented in Caves, Christensen, and Herriges (1984) who examine data from pilot studies across five utilities and find that substitution between peak and off-peak periods is significantly greater for households with common appliances such as electric heating and cooling systems, electric water heaters, electric washers and dryers, and dish washers. That estimated substitution possibilities depend on capital stocks in the home suggests the importance of adjustment costs and associated optimization frictions as factors that serve to dampen price sensitivity.

Finally, estimated elasticities and shifts in consumption between peak and off-peak hours vary both with seasons and climatic conditions. Caves, Christensen, and Herriges (1984) find that substitution between peak and off-peak hours during summer months is greater in warm climates than what is observed in cooler climates. As would be expected, this pattern is reversed during winter months – substitution is greater in cooler climates. Moreover, for households with electric heating and cooling, substitution is greater in winter months whereas the opposite is true for households that do not rely upon electric heating or cooling. Such differences again highlight the importance of adjustment costs as a factor that limits the willingness of households to alter energy use in response to price changes.

Before proceeding, it is worth noting that one should interpret the results of these early pilot studies with a degree of caution. There are a number of design features inherent in each that undoubtedly impacted observed behavior. First and foremost, participants in the various pilots selected into the program and were provided a guarantee that their overall monthly energy bill would not increase during the sample period. This is problematic for two reasons; (i) it introduce the possibility of Hawthorne effects and (ii) the guarantee of no bill increase dampens the incentive for households to conserve energy during periods of high prices. Second, across most of the pilots, there was limited variation in prices between peak and off-peak hours. From an econometric perspective, this makes it difficult to estimate the subsequent substitution possibilities. Finally, the pilots were conducted over a relatively short time horizon and thus captures little more than short-run substitution patterns. Given that demand in the short-run is less elastic than that in the long-run and the critical import of capital stock on such measures, results from the pilot likely provide a lower bound on the types of substitution/conservation one would expect to see if TOU pricing were made permanent and households allowed to adjust capital stocks – a point largely overlooked in the existing literature.

The Second Wave – Critical Peak Pricing

Despite the results of the early TOU pricing experiments, interest in dynamic pricing plans largely faded in the two decades following the initial DOE pilots. In the wake of the California energy crisis, interest in time-varying prices was renewed and a second wave of fifteen pilots exploring time-varying prices was launched in the early 2000s. Unlike the initial pilot studies, the second wave of experiments focused on pricing during critical peak events where approximately nine to seventeen percent of annual peak energy is generated. Moreover, the second wave of pilots were designed with an eye towards evaluation and relied more heavily upon randomization and observation of households in both a pre- and a post-intervention period allowing impacts to be measured using a difference-in-differences estimator. The remainder of the section summarizes the major lessons learned from these pilots and how they have shaped our understanding of residential energy demand.[4]

Unlike the initial TOU experiments, the second round of pilots provided a more consistent pattern of savings. Across the various pilots, critical peak pricing tariffs induced reductions in peak demand that range from 13 to 20 percent. For example, Wolak (2006) evaluates data from a CPP pilot involving residential consumers of the City of Anaheim Public Utilities where customers in the treatment group received a rebate of 35 cents/KWh for reductions in use relative to a reference level – an average of the three highest peak consumption levels over all prior non-CPP days. Results from the APU pilot show the promise of CPP tariffs. Relative to counterparts in the control group, treated households consumed approximately 12 percent less electricity during peak hours on CPP days. However, nearly half of the estimated treatment effect arose through a perverse effect whereby households in the treatment group significantly increased use during peak periods on non-CPP days.

[4] For a more detailed summary of these fifteen pilots, I refer the interested reader to Faruqui and Sergici (2010).

Similar results are reported in both Faruqui and George (2005) and Herter et al. (2007) who summarize findings from a statewide pricing pilot in California that was designed to compare the relative impact of TOU and CPP pricing plans. Empirical findings demonstrate the relative superiority of CPP plans – particularly for households provided enabling technology. Whereas households facing TOU pricing reduced peak use by 5.9 percent during the summer 2003, those facing a CPP plan reduced peak use on critical days by approximately 13.1 percent over this same period.[5] Furthermore, whereas the impact of the TOU plan was found to dissipate in the second year of the pilot, households facing the CPP tariff reduced peak use by approximately 4.7 percent over the life of pilot.

As with the initial TOU experiments, the estimated impact of critical peak pricing tariffs was found to depend on a number of factors. An important feature of several of the second wave pilots was the inclusion of enabling technology that provided households real-time feedback on energy use and the ability to remotely adjust settings for various energy consuming durables within the home. For example, a subset of participants in the California statewide pricing pilot was provided enabling technology such as a two-way communicating smart thermostat. For such households, observed reductions in energy use during critical peak periods ranged from 15 to 27 percent – figures that are significantly greater than those realized amongst counterparts facing a CPP tariff alone. Similar impacts were observed in a number of the other pilots where the combination of CPP tariffs and enabling technology generated reductions in peak energy demand that was approximately twice that observed amongst households facing a CPP tariff without such technologies (Faruqui and Sergeci, 2010).

[5] Of course it is important to recognize that a direct comparison of TOU and CPP plans is somewhat misleading as CPP programs enact substantially larger price changes that arise on a limited subset of days..

Taken in its totality, results from the second wave of dynamic pricing pilots underscore three challenges associated with managing residential electricity demand. First and foremost, the impacts of such programs are heterogeneous and depend critically on both climatic conditions and the types of technologies (durables) in the home. For example, households in California's statewide pricing pilot were drawn from four distinct climatic zones across which the estimated impact of CPP tariffs vary substantially – the observed reductions on critical peak days range from 7.6 to 15.8 percent. Similar differences are observed in this pilot if one compares effects across summer (a 14.4 percent reduction in use) and late spring/early fall months (8.1 percent reductions in use).

Second, the complementarity between enabling technology and dynamic pricing plans underscores the uncertainty/difficulties most consumers face when attempting to adjust energy use. It is thus not particularly surprising that the demand for electricity is found to be highly inelastic and response to dynamic pricing plans lower than what some would expect – consumers face an incredibly challenging programming problem and face frictions that limit the extent to which they are willing and able to adjust consumption. Enabling technologies reduce such frictions by making contemporaneous energy use salient and providing a low cost means for households to identify and adjust use along numerous margins. Finally, the perverse impact identified in Wolak (2006) – increased use on non-critical peak event days – highlights that policy makers need to take care when designing and implementing dynamic pricing plans.

Before proceeding, it is again worth noting that one should interpret the results of the second wave of pilot studies with a degree of caution as each included a number of design features that undoubtedly impacted observed behavior. First and foremost, the pilots were conducted over a relatively short time horizon. Observed impacts thus reflect short-run substitution possibilities. As with the early TOU pilots, results from the second wave of pilots therefore provide a lower bound of the effects one would expect should the pricing plan be made permanent and households allowed to adjust the capital stock in their home. Second, many of the pilots were based upon a small set of self-selected customers and are thus under-powered – particularly for pilots/households that did not receive enabling technologies. Moreover, it is unclear how one should think about selection effects and how it impacts external validity. Finally, there are a number of exogenous factors that were shown to impact observed treatment effects. Readers should thus take caution in attempting to project the impact of CPP tariffs or related dynamic pricing plans to other customers/utilities. To do so, one would first want to specify and estimate a structural model of residential energy demand that allows for endogenous technical change and use the results from such models to construct out of sample counterfactual policy simulations.

The Third Generation – Using Behavioral Economics to Improve Dynamic Pricing Plans

The initial waves of dynamic pricing pilots offer a somewhat cautionary tale. Although dynamic plans provide a means for regulators to promote conservation efforts and a shift of use between peak and off-peak hours, the ultimate impact of such programs is highly variable and depends critically on a few important design features. The most recent wave of pricing experiments, has set forth to explore the design of such programs and identify low cost ways to increase their impact. Much of this work has drawn upon insights from the behavioral economics literature and has focused on two primary themes; (i) framing and (ii) salience. The remainder of this section summarizes the major lessons learned from the most recent set of pricing experiments and how they have advanced our understanding of residential electricity demand.

There is a growing body of work in behavioral economics suggesting the importance of framing on the way in which individuals respond to incentives (see, e.g., Hossian and List, 2012; Fryer et al., 2012; Levitt et al., 2012). In particular, this literature highlights the importance of loss aversion for the design of performance contracts - incentives framed as losses (penalties) loom larger than those framed as gains (rebates). For regulators, this distinction has practical import for the design of critical peak pricing tariffs – ceteris paribus, the impact of such programs should be greater when the incentive is framed as a penalty (increased prices for energy consumed) rather than a reward (rebate for reductions in peak consumption).

Wolak (2011) provides evidence from a pilot study in Washington, DC designed to speak directly to this question. As part of this pilot, a representative sample of more than 1,200 residential consumers were randomly assigned into either a control group or one of three treatment groups that faced either (i) TOU pricing, (ii) a CPP tariff, or (iii) a CPP tariff with rebate.[6] Results from the pilot confirm prior findings on the effective of dynamic pricing plans – treated customers reduce electricity use during high-priced periods and peak events. However, consonant with the broader behavioral literature, the average treatment effect for households in the critical peak pricing treatment is significantly greater (13 versus 5.3 percent) than that for counterparts in the critical peak pricing with rebate treatment.

A related line of inquiry explores the importance of salience and incomplete information on the effectiveness of prices as a means to regulate residential electricity demand. There is a growing body of work highlighting how imperfect information about product attributes and prices impacts choice across a variety of settings (see, e.g., Jin and Leslie, 2003; Gabaix and

[6] Households in the CPP treatment faced a reduced block schedule but paid an additional 78 cents/KWh during critical peak events. Households in the CPP with rebate treatment faced the prevailing block schedule but received rebates for reductions in consumption during CPP events. And those in the hourly pricing treatment were charged according to prices that tracked the day-ahead wholesale market for the District of Columbia.

Laibson, 2006; Hossain and Morgan, 2006; Chetty et al., 2009). A similar issue arises in the context of residential electricity consumption. Households rarely observe the amount of energy consumed at any point in time and are thus uncertain about the associated marginal costs/benefits of their actions. In fact, many scholars have argued that such uncertainty underlies the noted tendency for residential electricity customers to adopt a crude heuristic whereby they respond to average rather than marginal electricity prices (see, e.g., Shin, 1985; Borenstein, 2009; Ito, 2014).

Despite these concerns, there is a growing body of work highlighting that policy-makers can influence choice in such settings by providing decision-makers simple bits of information (see, e.g., Duflo and Saez, 2003; Grubb and Osborne, 2015). Moreover, in the context of energy consumption, the early dynamic pricing pilots made clear that enabling technologies led to increased conservation efforts and a greater substitution of use between peak and off-peak periods. Yet these early studies were unable to disentangle the reason/s why enabling technologies impacted behavior. Did they simply lower the costs of adjusting use or did they provide information that made prices and use more salient?

The most recent wave of pricing pilots includes a number of studies that set forth to disentangle these channels and explore the extent to which salience (or the lack thereof) underlies the inelastic nature of electricity demand. For example, Jessoe and Rapson (2014) use data from a real time pricing experiment to explore the effect of information feedback on the price elasticity of demand. In their study, a subset of households facing a critical peak-pricing tariff were provided an in-home display that provided real-time feedback on both prevailing prices and quantity consumed. Although households facing real-time prices reduced energy use by up to seven percent, those provided real-time feedback realized substantially greater reductions – the average treatment effect for such households was approximately three standard deviations greater than that observed amongst counterparts who did not receive such feedback.[7] Moreover, analysis of event notification receipts suggests that increased price sensitivity does not reflect salience of prices, rather it reflects consumer learning and enhanced salience along quantity dimension.

Kahn and Wolak (2013) design a series of field experiments to explore the extent to providing information detailing how a consumer's energy use translates into monthly electricity bills impacts how that household responds to nonlinear price schedules – a prevalent price structure for residential households in the United States. Treated households were provided an on-line educational program that detailed how their monthly electricity bill was determined given the prevailing nonlinear price schedule they faced. In addition, each participant was given information explaining how various changes in major electricity-consuming activities would impact their monthly bill given historical patterns of consumption and the underlying nonlinear price schedule.

Empirical results provide evidence consonant with the view that incomplete information leads residential consumers to base consumption decisions on crude heuristics based on average (rather than marginal) electricity prices. Treated households consume less energy in the post-intervention period than do counterparts in the control group. However, there is systematic heterogeneity in such changes – customers who learn that they face higher marginal prices tend to *reduce* monthly consumption following treatment whereas those who learn they face lower marginal prices tend to *increase* their consumption.

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[7] Similar findings are reported in Allcott (2011) who examines data from a real-time pricing experiment in Chicago and shows that households who received a glowing plastic orb that changed colors to indicate current prices were significantly more responsive to price changes

Viewed in its totality, this body of literature highlights the importance of salience for managing residential electricity consumption. Although dynamic pricing plans and nonlinear price schedules provide a means to promote energy conservation and an associated reduction in greenhouse gas emissions, such effects are dampened by incomplete information and the lack of salience over both prices and quantity consumed. Thus, providing consumers real time feedback on prices and use is an effective way to increase the sensitivity to prices. In this regard, policies designed to promote the uptake of in-home electricity displays and/or disseminate information on real-time energy use should be viewed as complements to pecuniary strategies that rely upon financial incentives to influence demand.

III. The Adoption and Use of Energy-Saving Technologies

The traditional approach to technology adoption posits that both the purchase and dissemination of new products is driven solely by the relative costs and benefits of adoption. Yet, over the past thirty years, a growing body of literature has provided evidence that calls into question the neoclassical model of technology adoption. Perhaps the most prominent example of behavior at odds with the neoclassical approach arises in the context of electricity markets. Many residential households eschew the purchase of energy-savings technology and, in doing so, leave significant amounts of money on the table (see, e.g., Jaffe and Stavins, 1994; Allcott and Greenstone, 2012; Gillingham and Palmer, 2013). Despite the empirical evidence suggesting the presence of an energy-efficiency gap, there is little consensus as to the underlying reasons it arises.

In this section, I first summarize findings from a series of field experiments designed to disentangle the channels that underlie the adoption of energy-saving technologies and thus drive the energy-efficiency gap. In doing so, I provide evidence highlighting the importance of three factors on the adoption decision; (i) search costs and incomplete information about both the availability and potential benefits of energy-saving technologies, (ii) moral costs and the desire to do the right thing, and (iii) financial incentives and the up-front costs required to purchase and install such technologies. I conclude the section by summarizing findings from a series of experiments designed to measure the impact of enabling technologies and real-time feedback on subsequent energy use. As with work exploring the relationship between dynamic pricing and enabling technologies, results from these studies highlight how uncertainty and the coarse nature of information on energy consumption (particularly at the appliance level) adversely impact consumption decision and lead to inefficient patterns of energy use in the home. For policy-makers, these pilots demonstrate the promise of such technologies and disaggregation as a strategy to promote energy conservation.

Uncovering the Factors that Drive the Adoption of "Green" Technologies

A common refrain amongst policy-makers is that consumers do not understand energy efficiency and are inattentive to energy costs. In fact, such "biases" are often invoked to justify minimum efficiency standards and subsidies for the purchase of energy efficient goods. A recent body of work (Allcott and Sweeney, 2014; Allcott and Taubinsky, 2014) sets forth to examine the extent to which imperfect information and inattention to energy costs effect the demand for energy saving durables – Energy Star water heaters and CFLs. Results from these studies suggest that providing customers information on energy use and the associated reductions in energy expenditures has no impact on the demand for energy-efficient durables. Taken jointly, this evidence calls into question the common belief that consumers are confused about energy efficiency and that the lack of hard information about such reflects a market failure which reduces the demand for energy efficient durables.

In what follows, I summarize the major lessons learned from a burgeoning literature that implements randomized field experiments to uncover the drivers of the adoption decision and inform policies to increase the uptake of energy-saving technologies. In doing so, I provide evidence highlighting the importance of both neo-classical (search and up-front costs) and behavioral (moral costs) channels on the adoption decision.

A growing body of literature suggests that normative appeals – particularly those that provide social comparisons – provide an effective strategy to promote the conservation of both energy (see, e.g., Allcott, 2011; Ayres et al., 2013) and water (see, e.g., Ferraro and Price, 2013) resources. As noted in Ferraro and Price (2013), such messages serve to frame conservation efforts as a social norm and thus increase the "moral" cost of any given level of consumption. As such, one would expect households that receive such messages to reduce consumption to offset the increased costs.

A more recent strand of this literature has set forth to explore whether and to what extent social comparisons and related normative appeals can be used to promote the adoption of energy-saving technologies. Allcott and Rogers (2014) use data provided by Opower to explore how normative comparisons influence enrollment in utility sponsored energy efficiency programs. Across two distinct sites, participation rates in the post-intervention period amongst households receiving Opower's "home energy report" were approximately 0.35 to 0.42 percentage points greater than that observed for counterparts in the control group.[8] Similar effects are noted in Herberich et al. (2012) and Toledo (2013) who explore the impact of normative appeals on the purchase of energy-efficient lighting and find that households receiving information on the

[8] The HER is a multiple-page letter that includes a social comparison module detailing the household's electricity consumption over the past twelve months to both the mean and 20th percentile of its comparison group, and an 'action steps module' that suggests ways in which the household could conserve energy.

ownership decisions of others are more likely to purchase efficient lighting than counterparts in the control group who observe no such message.

Brandon et al. (2014) extend this basic line of inquiry by exploiting a unique feature of Opower's home energy report – in certain months, a random subset of households observe an augmented action steps module that provides information on a specific energy efficiency program available through the recipient's utility. Intuitively, such inserts serve to reduce search costs by making salient both the availability and benefits of enrolling in the given program. Results from this study highlight the importance of search costs and/or related frictions on the adoption decision – households that observe the augmented action steps module are significantly more likely to enroll in a utility sponsored EE program than are counterparts in both the control group and treated households that do not observe such advertisements. Moreover, Brandon et al. (2014) find important heterogeneity in the impact of social comparisons on the adoption decision – such messages are more effective amongst high use households.

LaRiviere et al. (2014) extend this body of work to examine whether and how the framing of social comparisons (monthly energy use, monthly energy expenditures, or annual CO2 emissions) impacts the uptake of in-home energy audits and subsequent energy use. Results from their experiment highlight a fundamental difference in the effect of a social comparison that is privately framed (kWhs or expenditures) and opposed to those that frame behavior in terms of a public good (CO2 emissions). Whereas privately framed comparisons serve to induce audits, comparisons that focus on CO2 emissions affect use but have no impact on the uptake of audits.[9] Such differences are noteworthy and suggest that policy-makers may be

[9] LaRivere et al (2014) also vary the price of the in-home audit by offering households a rebate should they sign-up for an audit. Although such subsidies have little impact on audit rates, LaRiviere et al (2014) estimate that providing households a privately framed social comparison is equivalent to offering the household an approximate $40 reduction in the price of the audit.

able to influence behavior along different margins simply by changing the way in which social comparisons are framed.

A related line of inquiry, explores the role of up-front costs on the adoption decision and how subsidies that lower such costs interact with other policy options such as normative appeals. For example, Herberich et al. (2012) sets forth to compare the relative impact of price reductions and normative appeals on the decision to purchase compact fluorescent light bulbs. Results from this study suggest that, in isolation, such policies work along different margins – whereas social comparisons impact behavior exclusively along the extensive margin, price changes impact both whether or not the consumer buys a CFL and the corresponding number of bulbs purchased. However, Herberich et al (2012) identify an important complementarity between normative messages and prices suggesting that consumers are trying to "buy" morality.[10]

Taken in its totality, evidence from these studies highlight the importance of both neo-classical (search and up-front costs) and behavioral (moral costs) channels on the adoption decision. For academicians, such results are of note in that they elucidate the various factors underlying the adoption decision and outline directions for new theories. For policy makers, results from this line of work highlight that there is no one-size fits all approach to stimulate the adoption of energy-efficient technologies. Rather policies designed to address the energy-efficiency gap should target a variety of channels and exploit the observed complementarity between prices and norms.

Identifying the Link between Real-Time Feedback and Energy Consumption

[10] Allcott and Sweeney (2014) examine a similar question – the interaction between policies that lower up-front costs and those that incentivize sales agents. Results from their study suggest an important complementarity between sales incentives and rebates. While rebates in and of themselves lead to increased purchases of Energy Star water heaters, such effects are significantly enhanced when the sales agent is incentivized.

It is well documented that residential consumers have difficulty keeping track of current electricity use and predicting future energy demand (see, e.g., Borenstein, 2009). As such, a number of scholars and practitioners alike have argued that providing information and feedback on consumption would promote more efficient patterns of energy use and thus promote conservation efforts. As noted in Faruqui et al. (2010), "…In-home Displays (IHDs) provide consumers with direct feedback…and turn a once opaque and static electric bill into a transparent, dynamic, and controllable process."

In what follows, I summarize findings from a series of experiments designed to measure the impact of enabling technologies and real-time feedback on subsequent energy use. As with work exploring the relationship between dynamic pricing and enabling technologies, results from these studies highlight how uncertainty and the coarse nature of information on energy consumption (particularly at the appliance level) adversely impact consumption decision and lead to inefficient patterns of energy use in the home.

Faruqui et al. (2010) review evidence from a dozen utility sponsored pilot programs to explore the extent to which consumers respond to the direct feedback provided by IHDs. Although the design of the pilots varied along several dimensions, direct feedback provided by IHDs was found to encourage households to rethink the consumption decision and use energy more efficiently. Such households reduced consumption by an average of approximately seven percent with observed reductions in energy use ranging from three to thirteen percent across the various pilots with even greater reductions noted amongst households that pre-pay for electricity.[11] Exploring the nature of such adjustments, Farugui et al (2010) provide survey evidence from a pilot study in Massachusetts that almost all of the observed conservation came

[11] Similar findings are noted in Gans et al (2013) who explore data from an advanced metering project in Northern Ireland that provided households who pre-pay for their electricity real-time feedback on energy use. Receipt of the advanced meter caused households to reduce electricity use somewhere between 11 and 17 percent.

through behavioral changes – e.g., turning off lights when leaving a room, turning off TVs/computers when not in use, etc. – rather than purchases of new capital.

Before proceeding, it is worth noting that one should interpret the results of these pilot studies with a degree of caution. Many of the studies infer the impact of the IHD on energy use via non-experimental methods while others rely upon self-reported use data. Moreover, many of the pilots included a small-number of households that self-selected into the experiment. Further, consumer demographics and the underlying tariff schedules vary widely across pilots. Finally, the duration of the pilots varied dramatically with some of the pilots exploring use over the course of a few months while others explored use of the course of a few years. Readers should thus take caution in attempting to project the impact of providing consumers IHDs and real-time feedback on energy use to other customers/utilities.

Ivanov et al. (2013) examine data from a smart meter pilot conducted by Connexus Energy whereby treated households were provided a programmable thermostat and an in-home display. Unlike early pilot studies that focused on energy efficiency and overall conservation efforts, the Connexus pilot set forth to explore the promise of IHDs and associated information as a way to manage peak demand on "red-alert" (critical peak) days.[12] The experimental evidence suggest the promise of such technologies as a tool to promote demand response; treated households consumed approximately 0.47 kWh less per hour on "red alert" days than did counterparts in the control group. This reflects an approximate 15 percent reduction in peak energy use on such days. However, much of the reductions over peak periods reflect little more than load shifting. Invanov et al. (2013) document significant increases in use over the early

[12] In addition to providing real-time feedback on energy use and its costs, the IHDs displayed a message each morning indicating projected peak hours for the day and if there were any "red alerts" during which time the household should avoid running energy intensive durables.. Moreover, during peak periods of event days, Connexus remotely increased the temperature setting for air conditioners in treated households by 3 degrees.

morning and late evening hours of event days and increased use during peak periods on non-event days. Hence, the IHDs appear to have little impact on overall energy use but do provide a viable strategy for demand response.

Viewed in its totality, this literature highlights the importance of salience for managing residential electricity use. The coarse nature of information on energy consumption (particularly at the appliance level) adversely impact consumption decision and lead to inefficient patterns of energy use in the home. Providing real time feedback on energy use allows households to overcome this friction and serves to promote more efficient consumption patterns.

IV. Lessons Learned and Next Steps

Before outlining what I view as fruitful avenues for future research, I would like to summarize the important lessons learned from the extant literature. Within the context of real-time pricing and resource demand, the extant literature provides mixed evidence on the effectiveness of dynamic pricing plans as a means to promote energy conservation. Time-of-use rates produce but modest reductions in energy use during peak periods. Yet, overall price sensitivity depends on the capital stock of the home with much greater responsiveness observed amongst those with some form of air conditioning system in the home. Critical-peak pricing tariffs induce greater reductions in use during peak periods. Finally, the literature is ubiquitous in demonstrating a strong complementarity between dynamic pricing plans and enabling technologies that provide the household real-time feedback on energy consumption and the prevailing price of electricity.

Within the context of energy efficiency and the adoption of energy-saving durables, I identify three factors that are important drivers of the adoption decision; (i) search costs and incomplete information about the availability of energy-saving technologies, (ii) moral costs and the desire to do the right thing, and (iii) financial incentives and the up-front costs required to purchase and install such technologies. This suggests that there is no one-size fits all approach to stimulate the adoption of energy-efficient technologies. Rather policies designed to address the energy-efficiency gap should target a variety of channels and exploit the observed complementarity between prices and norms.

Given these lessons learned, what do I view as fruitful avenues for future research? To date, almost all of the literature on energy efficiency and demand response has focused on a single outcome – changes in energy use. Yet, from a policy perspective, one should be equally interested in how various policy options affect social welfare. To address this question, it is important for researchers to take a step back and design experiments which aim to disentangle competing theories and identify policies that directly target the underlying cause of observed market failure. In this regard, studies such as Allcott and Taubinsky (2014) hold promise and provide a blueprint for future research.

Another important area of future research is making better use of behavioral economics to promote our policy goals and offset the external costs of our consumption decisions. For example, consider the power of defaults. Economists have found dramatic effects of using a default option: most people stick to the default rather than choosing other available options. Lofgren et al (2009) use an arefactual field experiment to explore the power of defaults within the context of an important question for environmental economists – whether or not to offset the CO2 emissions from air travel. I thus see incredible promise in work exploring how policymakers can use insights from behavioral economics to prompt compensatory actions such as the purchase of green energy blocks or carbon offsets.

A related use of behavioral economics as a means to promote our policy objectives is to explore the use of goal setting as a way to reduce energy consumption amongst present-biased consumers with reference-dependent preferences. In this regard, I view the natural field experiment of Harding and Hsiaw (2012) an important foundation upon which to build. Similarly, I see great potential for work that explores other mechanisms which target loss aversion and reference-dependence as a means to promote energy efficiency and more efficient resource use.

Within the realm of real-time pricing, I see tremendous opportunity for researchers to compare TOU and CPP plans which restrain peak prices to an alternative scheme whereby consumers face prices determined via the wholesale market. Similarly, I see significant promise for work exploring the effect of such pricing plans on the long-run demand for electricity and whether the introduction of such programs prompts households to adjust its stock of energy-intensive durables. Finally, I see great promise for studies that explore the use of normative comparisons and targeted messages as a means to manage peak demand. Although such policies have proven an effective way to promote energy efficiency, it is unclear whether they can also be used as a tool for demand response.

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