Energy Policy 41 (2012) 790–797

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Preparing for smart grid technologies: A behavioral decision research approach to understanding consumer expectations about smart meters

Tamar Krishnamurti[a,b,*], Daniel Schwartz[c], Alexander Davis[c], Baruch Fischhoff[a,c], Wändi Bruine de Bruin[a,c], Lester Lave[a,b], Jack Wang[a,b]

[a] Department of Engineering and Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA
[b] Tepper School of Business, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA
[c] Department of Social and Decision Sciences, Carnegie Mellon University, 5000 Forbes Avenue, Porter Hall 208, Pittsburgh, PA 15213, USA

ARTICLE INFO

Article history:
Received 19 April 2011
Accepted 14 November 2011
Available online 10 December 2011

Keywords:
Smart meters
Perceived risks
Mental models

ABSTRACT

With the enactment of the 2009 American Recovery and Reinvestment Act, U.S. President Obama made a public commitment to a new approach to energy production and transmission in the United States. It features installing smart meters and related technologies in residential homes, as part of transforming the current electrical grid into a "smart grid." Realizing this transformation requires consumers to accept these new technologies and take advantage of the opportunities that they create. We use methods from behavioral decision research to understand consumer beliefs about smart meters, including in-depth mental models interviews and a follow-up survey with a sample of potential smart meter customers of a major U.S. mid-Atlantic electricity utility. In both the surveys and the interviews, most respondents reported wanting smart meters. However, these preferences were often based on erroneous beliefs regarding their purpose and function. Respondents confused smart meters with in-home displays and other enabling technologies, while expecting to realize immediate savings. They also perceived risks, including less control over their electricity usage, violations of their privacy, and increased costs. We discuss the policy implications of our results.

1. Introduction

1.1. Policy context

In February of 2009, U.S. President Obama enacted the 2009 American Recovery and Reinvestment Act (ARRA); a stimulus package of approximately $787 billion intended to promote U.S. spending in response to an economic recession (United States Government Accountability Office, 2009). A significant portion of this funding was allocated to developing more advanced approaches to energy production, transmission, and consumption (Executive Office of the President of the United States, 2010). The current grid consists primarily of a mechanically operated system with over 9200 electric generating units connected to over 300,000 miles of transmission lines. The ARRA promotes a *smart grid,* which utilizes two-way digital communication technology to provide utilities with rapid, detailed information about electricity use, blackouts, and power quality (United States Department of Energy (U.S. DOE), 2009a). For residential customers, the first step towards the smart grid is the installation of a *smart meter,* allowing remote meter reading on a daily or even continuous basis (Federal Energy Regulatory Commission (FERC), 2010).

Based on continuous smart-meter readings, electric utilities can implement *demand response* programs, offering electricity prices sensitive to changes in consumer demand, rather than the flat rates common to U.S. utilities. Indeed, demand–response programs seek to reduce electricity use during peak use hours. Currently, 15% of generation and transmission capacity in the Mid-Atlantic States is used less than 1% of the time to meet that peak demand (Spees and Lave, 2008). Moreover, during peak demand, the system may be over-taxed, producing blackouts and brownouts. As a result, successful demand response programs can provide consumers with more reliable service and decrease the need for new generation, which in turn could reduce energy waste and subsequent carbon emissions (Siddiqui et al., 2008).

Moreover, demand–response programs are expected to decrease utilities' *capacity costs* paid to energy suppliers to ensure availability during peak demand times (Pratt et al., 2010). At present, approximately 91% of residential customers in the United States pay a fixed rate for electricity use (FERC, 2008), even though the utility typically pays more when demand is high (Eyer and Corey, 2010; U.S. DOE, 2006, 2009b). Average U.S. residential demand is 50–100% higher in the early evening than

* Corresponding author at: Department of Engineering and Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA. Tel.: +1 412 268 6837; fax: +1 412 268 8548.
E-mail address: tamar@cmu.edu (T. Krishnamurti).

0301-4215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.11.047

at 3 AM, with the highest levels of demand peaking during hot summer afternoons. Smart grid technology would allow utilities to charge more during those peak-demand periods—offset by lower charges during off-peak hours. Conversely, this same technology would allow utilities to decrease prices in order to increase demand during high supply periods.

To date, there is little evidence of how effective widespread demand–response programs would be. Demand–response programs are relatively rare in the U.S. (FERC, 2008) and the situation is similar internationally. Although smart meter penetration is 85% in Italy, most European countries have less than 8% (Carbon Trust, 2007; European Regulators' Group for Electricity and Gas, 2007; Haney et al., 2009). Our own review (Davis et al., in preparation) found that the majority of demand–response programs were located in the U.S. Exceptions included Korea, the UK, Denmark, Japan, France, Norway, and Australia (Choi et al., 2009; Faruqui et al., 2010; Gaskell and Pike, 1983; Jensen, 2003; Mansouri and Newborough, 1999; Matsukawa, 2004; Ueno et al., 2006; Wood and Newborough, 2003). California's Statewide Pricing Pilot is currently the most extensive program for implementing demand–response and it showed significant peak reductions among the residential customers enrolled in the demand–response pricing programs (Haney et al., 2009).

A variety of social, cultural, economic, and regulatory factors would likely play a role in the success of demand response in individual countries. Yet the common first step for demand–response programs to move forward is consumers' acceptance of smart meters in their residences. Some U.S. locations have experienced customer backlash to smart meters. For example, Pacific Gas and Electric's attempts to deploy smart meters in Northern California have been opposed by customers who fear threats to privacy, health effects from smart meters' radio-frequency radiation (Barringer, 2011), and increased electricity bills (Sullivan and Kahn, 2011). Other major utilities have also experienced customer protests, including Oncor, Dayton Light and Power, Central Maine Power, and San Diego Gas & Electric (Hoey and Maine, 2011; Nesbitt, 2011; Soto, 2010). Both Pacific Gas and Electric and Oncor have faced class-action civil suits claiming that customers were overcharged after smart-meter installation (PG&E Denies Lawsuit Allegations, 2009; Tweed, 2010).

Although public concerns are a legitimate and important input to policy making, they may sometimes arise from misunderstanding the technologies. Smart grid technology could be needlessly delayed if customers underestimate its benefits or overestimate its problems. Alternately, it could be deployed too quickly, if customers have unrealistic expectations of its benefits or are unaware of problems that require resolution. To design policy appropriately, it is crucial to understand consumers' concerns and preferences as well as bridge those gaps in knowledge that may prevent consumers from making a fully informed decision.

2. Studying public perceptions of smart meters

Here, we use methods from behavioral decision research, to more systematically examine public perceptions of smart meters. Behavioral decision research studies individuals' decision making in terms that can be compared to a formal (or *normative*) decision model. Among other things, that comparison identifies which decision-making tasks people have mastered and which they have not, and suggests strategies for improving their decision making (Edwards, 1961; Einhorn and Hogarth, 1981; Fischhoff, 2010; Hastie and Dawes, 2001; Kahneman et al., 1982; Payne et al., 1992). Hence, behavioral decision research involves three interrelated approaches: (a) *normative analysis* of the decision context under consideration; (b) *descriptive research* into how individuals actually view and make those decisions; (c) *prescriptive interventions* attempting to bridge the gaps between the normative ideal and the descriptive reality (Fischhoff, 1992, 2005; Hastie and Dawes, 2001; von Winterfeldt and Edwards, 1986). Behavioral decision research complements other studies of consumer behavior by suggesting the basic decision-making processes contributing to it (e.g., Gardner and Stern, 2002, 2009; Madlener and Harmsen van Hout, 2011; Scholz, 2011).

The next section offers a normative analysis of the expected outcomes to consumers of implementing residential smart meters. It is followed by descriptive findings from in-depth interviews of residential electricity consumers who may soon receive smart meters. We then test hypotheses generated from these interviews with survey data from a larger sample of residential electricity consumers, from which we develop a model of customer responses designed to inform attempts to provide better information.

3. Existing normative data on smart meters

Here, we summarize research into the potential effects of smart meters for utility customers. We consider both direct effects, from the smart meter itself, and indirect effects that arise from implementing those enabling technologies, which require smart meters. Subsequent sections contrast these analyses with consumers' perceptions.

3.1. Benefits of smart meters

One main benefit of smart meters is that they can improve the operational efficiency of the grid and allow for proactive maintenance. For consumers, the benefits of this improvement might be realized through the reduction of such adverse events as blackouts. According to Pratt et al. (2010), automation enabled by smart meters can reduce blackout times from hours to seconds by identifying faults and compensating remotely. Indeed, without smart meters, customers must notify their utility about outages, whereas smart meters allow for immediate outage detection.

Another potential benefit of smart meters is that they may help customers to save money. There are several ways in which smart meters may directly contribute to customer savings. Specifically, smart meters are expected to increase energy efficiency and improve operational efficiency and reliability, as mentioned above, as well as reduce labor costs (Siddiqui et al., 2008), all of which would accrue savings to the utility that may or may not be passed on to consumers. For example, after U.S. penetration in 2009 almost doubled that in 2007 (8.7% vs. 4.7%) (FERC, 2010), Faruqui and Wood (2011) estimated the savings in labor costs alone to be up to $24 per meter over a 20-year horizon, from no longer needing to have an employee physically read the meter.

Additionally, indirect benefits may arise if consumers purchase or are provided with *enabling technologies* that respond to smart meter signals. Most likely, one or more of the following options will be made available to at least some consumers: (a) Central Air Control, (b) Direct Load Control, and (c) In-Home Displays (Ehrhardt-Martinez et al., 2010). First, Central Air Control may be provided by some utilities, and would involve a *smart thermostat* or *smart switch* that responds to user settings (e.g., turning off the air conditioner when no one is home), to time (e.g., turning off the air conditioner on summer afternoons), or to price information (e.g., turning off the air conditioner when prices are high in a demand–response program). Second, Direct Load Control may be provided by some utilities, and would involve allowing the utility to exert remote control over energy use (FERC, 2009), by turning off or cycling a customer's appliances (e.g., air conditioning) to reduce peak-time load or disconnecting a customer after exceeding a pre-defined or pre-paid budget. Third, In-Home Displays are digital devices that can be purchased to give customers information about, for example, their real-time and historical usage and/or their appliance-specific usage, while also giving warnings about peak hours and providing projected bills (e.g., Darby, 2006; Fischer, 2008; Stein and Enbar, 2006). They typically cost $100–250 (Ehrhardt-Martinez et al., 2010). Thus, if available, some of these enabling smart grid technologies may allow customers to make more informed peak-time or overall electricity usage decisions, by providing them with regular and customizable feedback, while others may allow customers the option to enroll in more cost-effective electricity programs.

Lastly, smart grid technologies may have some societal benefits, which would not be immediately realized on the individual level. For example, smart grid technologies may indirectly affect energy efficiency. Siddiqui et al. (2008) estimated that between 2010 and 2015, smart meter enabled communication infrastructure and devices could decrease CO_2 emissions more than other efficiency actions by reducing energy consumption 1–4 percent, depending on how consumers respond to energy usage information.

3.2. *Risks of smart meters*

One potential direct risk of smart-meter installation is that it may lead to increased electricity bills, due to improved bill accuracy. Previously used electromechanical meters gradually run slower over time, thereby underestimating customers' usage (Electric Power Research Institute, 2010). In addition, manual meter reading is subject to human error in recording. Since solid-state smart meters are digital, they avoid these problems. Although consumers would be charged more accurately, that could mean increased bills for those who have been previously undercharged.

An indirect risk from smart meters and their enabling technologies is the violation of consumers' privacy, should there be the release of detailed billing data that could reveal when they are home and how they use their appliances. It is unclear now whether such billing data will be classified as the kind of personal information that utility companies are allowed to sell. Currently, metering information in the U.S. is considered a business record and, therefore, outside fourth amendment privacy protection. However, some states have ruled otherwise. For example, Connecticut explicitly treats "*information that relates to the quantity, time of use, type and destination of electric service information contained in electric service bills*" as protected information (Quinn, 2009, p. 22). EU treatment of "personal data" protects consumers, but can be overridden for criminal investigations or security purposes. Security risks are just beginning to be understood. For instance, hackers might be able to remotely disconnect power to large areas (Anderson and Fuloria, 2010) or obtain decrypted personal information (Anderson and Bezuidenhoudt, 1996).

The public interest group Electronic Frontier Foundation cites four classes of privacy concerns regarding data collected from advanced meters (Quinn, 2009): *Individuated patterns* refers to determining consumers' general behavior patterns from their appliance usage based on the high temporal resolution records provided by the smart meter. *Real-time surveillance* involves monitoring consumer behavior as it happens. *Information detritus* involves selling small pieces of information to third parties to profile individuals for sales or other targeting (e.g., law enforcement). *Physical invasion* involves determining whether a person is at home, for purposes of burglary or assault.

Thus, our normative review shows the possible direct and indirect benefits, financial costs, and potential privacy risks facing consumers making decisions related to smart meters. It is important to note, however, that all of the analyses cited in our review assume smooth, rapid dissemination of smart grid technologies with full consumer understanding and little consumer resistance. The descriptive research that follows asks how well consumers' beliefs actually align with these analyses.

4. Descriptive research

To examine people's beliefs about smart meters, we used a two-stage *mental models* approach (Morgan et al., 2002). The first stage involved open-ended interviews eliciting customers' perceptions, while allowing them to share the beliefs they deem relevant, in a semi-structured design that increasingly directed them toward the topics in the normative analysis. The second stage involved a structured survey that systematically examined the prevalence of the beliefs expressed by interviewees and their relationships with attitudes towards smart meters. The survey drew on the topics revealed in the interviews and the wording used to describe them. This mental models approach has been used with topics as diverse as emergency contraception (Krishnamurti et al., 2008), chemical risk protection in the work place (Cox et al., 2003), inflation (Svenson and Nilsson, 1986), hurricane modification (Klima et al., in preparation), climate change (Bostrom et al., 1994; Sterman and Sweeney, 2007), as well as carbon capture and sequestration and other low-carbon electricity generation technologies (Fleishman et al., 2010; Palmgren et al., 2004).

4.1. *Semi-structured mental models interviews*

4.1.1. *Interview procedure*

Those eligible to participate were contacted to schedule a phone interview. Before the interview began, participants were ensured that they could skip any question that they did not wish to answer, and that any personally identifying information would be removed from their transcripts. Indeed, participants' anonymity was maintained to anyone but the interviewer. After receiving this information, participants provided verbal consent. The interview protocol and recruitment procedure were approved by the University's Institutional Review Board.

Following the strategy described above, the interviews began with general, nondirective questions that allowed interviewees to say whatever came to mind, phrased to suggest that the interviewer had no "correct" response in mind. Neutral follow-up prompts encouraged participants to say as much as they could about each topic, in their own words. For example, the initial question asked about smart meters was "What have you heard about smart meters?" with follow-up questions inviting participants to elaborate on each belief that they expressed (e.g., "Can you tell me more?" "Can you explain how that works?"). We scheduled new interviews until no new beliefs emerged. In addition to questions about smart meters, interviewees were asked about their beliefs about other electricity-use topics, such as conservation and demand–response schemes (including critical peak pricing, critical peak rebate, and air conditioner direct load control, each briefly described to the interviewee). Again, follow-up questions encouraged disclosure of relevant beliefs and the mental models from which they were derived.

All interviews were digitally recorded and transcribed. We examined the transcripts to identify themes on each topic, and then coded interviews into those themes, considering both their content and their accuracy. Here, we present key themes related only to smart meter implementation, with a special focus on misconceptions with potentially important implications for implementing advanced metering infrastructure.

4.1.2. Participants

We conducted telephone interviews with 22 individuals responsible for paying their own electricity bill ($\text{Mean}_{\text{age}}=40.05$ years; SD = 14.48), recruited through an electronic bulletin board (http://www.craigslist.org). Advertisements targeted customers (with an approximate population of 2,022,000) served by a major U.S. Mid-Atlantic utility with plans to implement smart grid technologies within three years. Six interviewees were male and sixteen were female; twelve lived in rented homes and ten owned their homes, with one living in her parents' home; ten were Caucasian and nine African-American. Four reported annual personal incomes more than $100,000, three less than $25,000, and the majority reported between $25,000–50,000.

The advertisement asked for participation in an hour-long interview about electricity use for compensation of $50. They were also required to be at least 18 years old and responsible for paying their own electricity bills, in order to focus on individuals with personal control over their electricity use and potential recipients of their own smart meters.

4.1.3. Interview results

None of our interviewees accurately described the purposes and function of a smart meter. Most seemed to be in favor of smart meters, but had misconceptions that either could lead to disappointment, among those who expected too much from smart meters, or resistance, from those who saw problems that have not been allayed.

We identified three main misconceptions about smart meters (see Table 1). First, 20 of 22 interviewees confused smart meters with enabling technologies (either in-home displays or smart thermostats). Specifically, interviewees expected a smart meter to come with an in-home display that provides detailed feedback about energy use. As such, their perceptions of the benefits of the smart meter, such as being able to see appliance-specific information to help manage their usage, were actually benefits that would be associated with the enabling technologies. Unless dispelled, such misconceptions can create unrealistic expectations and disappointment, when, as likely will be the case, smart meters that are installed will be done so without accompanying enabling technologies.

Table 1
Example quotes showing interviewee misconceptions about smart meter function and purpose.

Interviewee quotes
"[A smart meter] could let me know whether our HD is using the majority of the energy or if it's our TV set." [Caucasian, 52 years old]
" I've heard that if [a smart meter] is there, [the utility] can centrally control your energy use. So if they need to conserve electricity, I don't know if they shut it off or if they just limit how much you can get to your home." [Caucasian, 57 years old]
"[The purpose of the smart meter is] to help people control their bills' cause a lot of people probably have to do payment plans or can't afford their bill once it goes to them" [African-American, 26 years old]
" I would actually see where the energy is coming from, so that would be a form of accountability for them. I would trust them more, I guess." [African-American, 29 years old]
" If [my smart meter is] going to cost me a lot more for something that's helping me save money it just seems kind of to go around in circles." [Caucasian, 24 years old]
"Let's say if I want to cut off the power to everything in the house except maybe the fridge and let's say a clock or something, that I could do it from that meter, the actual meter itself…Or I could lower the power consumption on the fridge if nobody's home and nobody is opening the fridge…That's what I thought when you said smart meters. That you would be able to do smart things like that." [African-American, 50 years old]

A second misconception was that smart meters were designed to control residents' electricity use, both by direct load control of their air conditioning and by shutting off their electricity completely. Indeed, a common concern across interviews was loss of control, with some interviewees worrying about their electricity company using smart meters to act like "big brother." The three interviewees who opposed smart meters all thought that they were designed to cut off electricity to homes that consumed too much. Although smart meters can provide relevant information to the utilities, additional enabling technology is needed to stop electricity flow to a home. Therefore, interviewees with this misconception were again ascribing technological capabilities to the smart meters that they do not have.

A third misconception, held by the majority of the interviewees, was that smart meters were being installed to ensure immediate consumer benefits. Specifically, 11 interviewees believed that the goal of smart meter installation was to help them to save money each month. The few who thought that smart meters primarily served their electricity company mentioned liking them less. While customers may realize eventual financial savings, there is no guarantee that all customers will financially benefit from smart meter installation. The actual distribution of financial costs and benefits, between utilities and consumers, will, of course, depend on regulatory decisions. No participant spontaneously mentioned reduced risks of blackouts due to increased grid efficiency as a benefit, which, as shown in the normative analysis, is the most likely immediate benefit of smart meters to the consumer.

Even accurate assessments of smart meter function can be accompanied by problematic inferences. For example, four interviewees mentioned that the increased accuracy of monthly charges that could result from having a smart meter would be a good means for the utility to build trust with its customers. As noted in the normative analysis smart meter bills will be more accurate; however, demonstrating that benefit is not part of any plans. Moreover, none of these four interviewees mentioned anticipating increased bills, which is a potential resulting risk of increased bill accuracy, although some did mention concerns about up-front costs associated with meter installation.

Overall misperceptions about smart meters may stem from peoples' inferences about what "smart" technology implies. In general, the interviewees viewed smart meters as a technology designed to serve the consumer and tailored specifically to their individual needs.

4.2. Structured survey

Although mental models interviews allow common beliefs to emerge, they are so labor intensive that the resulting sample tends to be too small to assess the prevalence of beliefs, or their correlations to overall attitudes, in this case towards smart meters. Therefore, this section reports on a structured survey using questions based on the beliefs observed in the interviews, incorporating the wording used in them.

4.2.1. Survey design

The survey had multiple-choice, rating-scale, and open-ended questions about smart meters, in-home energy displays, demand response pricing programs, and electricity use. Here we present results regarding smart meters. Participants were first asked a yes-or-no question asking them to indicate whether they had heard of smart meters. They then read a short passage describing it as "…a digital meter that sends your electricity use to the power company in real time." Subsequently, they were asked (a) *"Would you like a smart meter in your home?"* and (b) for their agreement with eight statements about smart meters formulated as *"Smart meters can …,"* on a 5-point Likert scale, anchored at 1 = Strongly disagree and 5 = Strongly agree (Table 3). These statements were based on the direct and indirect risks and benefits that were identified in the normative analysis (Smart meters can reduce the risk of blackouts; Smart meters can save you money; Smart meters can violate your privacy), and additional perceived risks and benefits mentioned in the interviews (e.g., Smart meters can tell you how much electricity each of your appliances is using; Smart meters can let the electricity company control your electricity use; Smart meters control your central air conditioning; Smart meters can cost you money). Lastly, they answered demographic questions and estimated their average monthly electricity bill.

4.2.2. *Survey participants*

Surveys were sent to a randomly selected sample of 500 potential smart meter customers affiliated with a single major Mid-Atlantic utility. The sample was stratified by neighborhood income level. Surveys could be returned by mail or answered online. Of the surveys, 300 were sent with a $5 bill and 200 with no financial incentive, half of which had to be answered online. The overall response rate was 25.2%, with 35.3%, 14.0%, and 6.0%, respectively, in the three groups ($5 incentive, no incentive mail, and no incentive online)[1]. Response rates are consistent with other studies (Church, 1993). Table 2 provides demographic details on the sample.

Table 2
Survey sample demographics.

Variable	Obs.	Mean (SD)/ frequency
Respondents	126	
Age	122	45.5 (17.3)
Gender	125	
Female	50	40%
Male	75	60%
Race	117	
American Indian/native American	1	0.9%
Black/African American	32	27.4%
Asian	10	8.6%
Hispanic/Latino	2	1.7%
White/Caucasian	69	59%
Mixed race	1	0.9%
Others	2	1.7%
Income	101	
0–15k	6	5.9%
16–30k	6	5.9%
31–50k	14	13.9%
51–75k	12	11.9%
76–100k	18	17.8%
101–125k	12	11.9%
126–150k	10	9.9%
151–175k	8	7.9%
176k +	15	14.9%
Education	122	
Less than high school	2	1.6%
High school/GED	10	8.2%
Some college	10	8.2%
2 year college degree (associates)	11	9%
4 year college degree (BA, BS)	38	31.2%
Masters	37	30.3%
Doctoral (PhD) or professional (MD, JD)	14	11.5%
Reported bill average	112	146.5 (98.6)

4.2.3. *Survey results*

Beliefs about smart meters. In response to the request to rate their agreement with a series of statements about things that *"Smart meters can [do],"* most participants indicated that a smart meter would let them check the accuracy of their bill, save them money, and tell them how much electricity each of their appliances used. Table 3 shows respondents' degree of agreement with the eight statements. Most did not believe that it would cost them money, violate their privacy, or let their electricity company control their electricity use. These ratings are generally consistent with the beliefs reported in the interviews and reflect unrealistic expectations from smart meters and confusion of smart meters with enabling technologies[2]. Most participants (55.6%) had not heard about smart meters prior to completing the survey, suggesting that some of these beliefs reflected inferences regarding what "smart" means.

In order to reduce the dimensionality of these responses, we conducted principal component analysis (PCA). Because correlations in the factor correlation matrix were less than a standard cutoff of 0.32, suggesting less than 10% overlap in variance, we used an orthogonal rotation (varimax) procedure (Tabachnick and Fidell, 2007). As seen in Table 4, three principal components emerged from the eight beliefs. We will call them (1) being controlled, (2) tangible costs/benefits, and (3) accountability. Beliefs regarding perceived loss of control and privacy concerns loaded most strongly on the *being controlled*, which explained 28.3% of the variance. Economic concerns loaded most strongly on *tangible benefits*, accounting for 23.8% of the variance. Information issues loaded on *accountability*, accounting for 12.5% of the variance.

Attitudes towards smart meters. Most respondents (69.6%) reported wanting a smart meter, even though half reported no prior knowledge of them. To determine which beliefs drive this reported desire, we ran logit regressions[3] in Table 5. They show that beliefs grouped as "tangible benefits" predict a greater likelihood of wanting a smart meter installed, whereas beliefs grouped as "being controlled" predict a lower likelihood. Beliefs grouped as "accountability" were unrelated[4].

5. Discussion

Attaining smart-grid goals will require consumer acceptance. Our two studies find that consumers are positively predisposed toward smart meters. However, those attitudes are based on expectations about smart meters that are likely to be disappointed. Specifically, consumers incorrectly believe that smart meters will give them specific feedback about their electricity use,

[1] Although response rates differed by recruitment condition (with or without a financial incentive), survey results did not differ by group. Nor did the groups differ in demographic make-up.

[2] Categorizing beliefs as strictly accurate or as misconceptions, even against the normative model, is not straightforward. For example, although utilities need not charge customers for smart meter installation, many do, including the utility that will provide these participants with smart meter rollout. Thus, the belief that "smart meters can cost money," is accurate or inaccurate depending on the individual customer. In addition, we can only surmise about the temporal perspective of our survey respondents. For example, the belief that "smart meters can save you money" may or may not be accurate, depending on the time-horizon with which the respondent is viewing the technology.

[3] When the Exp(β) value of an independent variable is >1, the likelihood that participants desire a smart meter increases. Alternately, when the Exp(β) value of an independent variable is <1, the likelihood of smart meter desire decreases.

[4] We additionally regressed desire for a smart meter on the eight individual belief statements. This regression suggested that wanting smart meters was driven significantly by two beliefs, "smart meters can save you money," $\beta = 1.758$, $p < 0.10$ and "smart meters can let electricity company control your electricity use," $\beta = 0.623$, $p < 0.05$.

Table 3
Participant level of agreement with belief statements.

Belief that *Smart meters can* …	Agreement (%) with belief					
	Mean (S.D.)	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Let you check the accuracy of your electricity bill	4.0 (0.9)	–	5.0	24.0	39.7	31.4
Save you money	3.7 (0.9)	2.5	3.3	36.1	34.4	23.8
Tell you how much electricity each of your appliances is using	3.5 (1.1)	3.3	18.3	25.0	36.7	16.7
Reduce the risk of blackouts	3.3 (1.2)	10.7	13.1	36.1	18.9	21.3
Control your central air conditioning	3.2 (1.2)	9.9	19.8	26.5	28.9	14.9
Let electricity company control your electricity use	2.7 (1.2)	17.5	28.3	27.5	18.3	8.3
Cost you money	2.6 (0.9)	12.4	26.5	47.9	11.6	1.7
Violate your privacy	2.6 (1.0)	14.9	27.3	41.3	13.2	3.3

Table 4
Beliefs and factor loadings.

Belief that *Smart meters can*…	Factor 1 (Being controlled)	Factor 2 (Tangible benefits)	Factor 3 (Accountability)
Let you check the accuracy of your electricity bill	−0.20	0.10	**0.85**
Control your central air conditioning	**0.64**	0.39	0.23
Tell you how much electricity each of your appliances is using	0.24	0.40	**0.68**
Reduce the risk of blackouts	0.06	**0.73**	0.23
Save you money	−0.01	**0.72**	0.25
Cost you money	0.45	**−0.63**	0.33
Violate your privacy	**0.74**	−0.24	−0.03
Let electricity company control your electricity use	**0.80**	0.03	−0.14
Eigenvalue	2.3	1.9	1.0
% variance explained	28.3	23.8	12.5

Table 5
Regression of desire for a smart meter on beliefs about smart meters.

Belief that *Smart meters can*…	Exp(β)	S.E.
Component 1: Being controlled	0.623*	0.146
Component 2: Tangible costs/benefits	1.648*	0.399
Component 3: Accountability	1.258	0.275
Constant	2.446**	0.552
Observations	107	

* $p < 0.05$.
** $p < 0.01$.

which will only be possible if in-home displays are additionally installed with their smart meters. For the most part, they also anticipate tangible benefits from their smart meters.

Moreover, a significant minority of consumers expressed fears regarding privacy and loss of control, including utilities' ability to shut off service. Our studies were conducted before the recent outbreak of concerns about the health effects of radio frequency fears, echoing ones regarding electromagnetic fields a generation ago. These results suggest substantial, unmet challenges for ensuring informed consumer decisions.

Our studies provide the essential first step for effective communication: learning customers' goals, values, and beliefs (Fischhoff et al., 2011). To the best of our knowledge, communications regarding smart meters have to date proceeded without that base. The misconceptions reported here indicate that they have not been as successful as needed.

Our approach, based on behavioral decision research, began with a normative analysis of risks and benefits, as revealed in existing scientific research. It proceeded to semi-structured interviews, allowing consumers' full range of beliefs to emerge, in their own words. A structured survey then assessed the prevalence of these beliefs and their relationship to consumers' preference for smart meters. Together, the studies revealed the picture just described: Consumers mostly desire smart meters, but for reasons reflecting mostly unrealistic expectations of their benefits and a lack of understanding of why they are being installed. Those opposed to smart meters had potentially realistic fears regarding threats to their privacy and loss of control.

In general, misconceptions tended to overestimate rather than underestimate the personal impact of smart-meter deployment. Interviewees felt that they would receive more benefits than would likely occur, at least in the immediate future, and also be exposed to more risks than are likely. The survey results were also consistent with this finding. Most of these misconceptions tended to overestimate the benefits of smart-meters and would lead customers to support smart-meter programs when they otherwise would not have if properly informed. For example, customers may be less likely to support smart-meter implementation with the knowledge that enabling technologies would require additional up-front costs to the customer. Similarly, if customers were aware that the intended use of the smart-meter is not to build trust, transparency, or provide appliance-specific feedback, they may be less willing to support a smart metering program or more invested in finding out about the potential risks. Thus, our findings suggest that the misconceptions of benefits tend to favor utilities, at a potential cost to customer happiness. In contrast, those people overestimating the risks of smart-meters may pass on a technology that has the potential to greatly benefit them and that they would otherwise favor if they possessed better information.

Electric utilities can address misconceptions about the benefits of smart meters in two ways. One is to scale back the expectations, so that consumers do not expect more than smart meters can deliver. The second is to bring implementation of the technology in line with expectations, by adding useful smart thermostats and in-home displays to show consumers their real-time electricity use and help them to save money.

Electric utilities can address concerns about the risks of smart meters in the same two ways: explaining them better and making them better (i.e., smaller). Given the potential for risk beliefs to increase when they are not addressed (Fischhoff, 1996), action is needed to provide and communicate safeguards for concerns about invasions of privacy and loss of control. Consumers and utilities deserve communications addressing customers' concerns regarding risks and benefits, disseminated prior to smart meter implementation. Such communications require careful preparatory research and empirical evaluation, rather than relying on technical experts' intuitive theories about how to reach their audiences (Thompson, 1990). Additionally, policy-makers can play a role in empowering consumers by mandating education that makes the risks and benefits of the smart grid more transparent and clarifies the temporal scope and primary recipients of those risks and benefits.

Future research could assess the generalizability of our findings to other populations[5], as well as follow our target population over time, seeing how its concerns evolve and affect public discourse. Given the stakes riding on smart meters, a national tracking survey of consumers' concerns could help the industry to explain and deploy the technology more effectively. Larger samples would also allow examination of differences among consumer groups. Even within our focal group, electricity bill-paying customers, there might be differences, say, between homeowners and tenants—who might have less incentive to engage in energy saving behaviors, or less opportunity to buy the appliances or make the contracting arrangements needed to take full advantage of smart-grid technology (Davis, 2010; Dillahunt et al., 2010).

That said, we believe that the descriptive research reported here provides cause for concern about consumers' understanding of smart meters and guidance on how to address them. Specifically, they need proactive policies that help meet consumers' expectations, while also developing communications that create realistic expectations of benefits and risks, explicitly addressing the misconceptions commonly found in the mental models of consumers forced to rely on the information currently available to them.

References

Anderson, R.J., Bezuidenhoudt, S.J., 1996. On the reliability of electronic payment systems. IEEE Transactions on Software Engineering 22, 294–301.

Anderson, R., Fuloria, S., 2010. On the security economics of electricity metering. In: Proceedings of the Ninth Workshop on the Economics of Information Security.

Barringer, F., 2011. New Electricity Meters Stirs Fears, 30. The New York Times (A12. print).

Bostrom, A., Morgan, M.G., Fischhoff, B., Read, D., 1994. What do people know about global climate change? 1. Mental models. Risk Analysis 14, 959–970.

Carbon Trust, 2007. Advanced Metering for SMEs: Carbon and Cost Savings. Carbon Trust.

Choi, T.S., Ko, K.R., Park, S.C., Jang, Y.S., Yoon, Y.T., Im, S.K., 2009. Analysis of energy savings using smart metering system and IHD (in-home display). Transmission & Distribution Conference & Exposition: Asia and Pacific, 1–4.

Church, A.H., 1993. Estimating the effects of incentives on mail survey response rates: a meta-analysis. Public Opinion Quarterly 57, 62–79.

Cox, P., Niewőhner, J., Pidgeon, N., Gerrard, S., Fischhoff, B., Riley, D., 2003. The use of mental models in chemical risk protection: developing a generic workplace methodology. Risk Analysis 23, 311–324.

Darby, S., 2006. The Effectiveness of Feedback on Energy Consumption. A Review for DEFRA of the Literature on Metering, Billing, and Direct Displays. Retrieved August 13, 2010 from: 〈http://www.eci.ox.ac.uk/research/energy/electric-metering.php〉.

Davis, L.W., 2010. Evaluating the Slow Adoption of Energy Efficient Investments: Are Renters less Likely to have Energy Efficient Appliances? The National Bureau of Economic Research Working Paper 16114.

Davis, A., Krishnamurti, T., Fischhoff, B., Bruine de Bruin, W. Setting a Standard for Energy Pilot Studies: Guidelines for Design, Representation, and Evaluation. Department of Social and Decision Sciences and Department of Engineering and Public Policy, Carnegie Mellon University, in preparation.

Dillahunt, T., Mankoff, J., Paulos, E., 2010. Understanding conflict between landlords and tenants: implications for energy sensing and feedback. Paper presented at the Conference on Ubiquitous Computing, Copenhagen, Denmark. Retrieved November 7, 2011 from: 〈http://dl.acm.org/citation.cfm?id=1864349&picked=prox&CFID=68088666&CFTOKEN=75737587〉.

Edwards, W., 1961. Behavioral decision theory. Annual Review of Psychology 12, 473–498.

Ehrhardt-Martinez, K., Donnelly, K., Laitner, J., 2010. Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Savings Opportunities. Report no. E105. American Council for an Energy Efficient Economy.

Einhorn, H.J., Hogarth, R.M., 1981. Behavioral decision theory: processes of judgment and choice. Journal of Accounting Research, 1–31.

Electric Power Research Institute, 2010. Accuracy of Digital Electricity Meters. Electric Power Research Institute White Paper.

European Regulators' Group for Electricity and Gas, 2007. Smart Metering with a Focus on Electricity Regulation. Ref: E07-RMF-04-03. European Regulators' Group for Electricity and Gas, Brussels, 31 October 2007.

Executive Office of the President of the United States, 2010. The Recovery Act: Transforming the American Economy Through Innovation. Government Printing Office, Washington, DC. Retrieved September 19, 2011 from: 〈http://www.whitehouse.gov/recovery/innovations/intro〉.

Eyer, J., Corey, G., 2010. Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide. Sandia Report (SAND2010-0815).

Faruqui, A., Harris, D., Hledik, R., 2010. Unlocking the €53 billion savings from smart meters in the EU: how increasing the adoption of dynamic tariffs could make or break the EU's smart grid investment. Energy Policy 38, 6222–6231.

Faruqui, A., Wood, L., 2011. IEE Releases: The Benefits of Smart Meters. NARUC Winter Meetings. Institute for Electric Efficiency, Washington, D.C.

Federal Energy Regulatory Commission, 2008. Assessment of Demand Response and Advanced Metering. Government Printing Office, Washington, DC.

Federal Energy Regulatory Commission, 2009. A National Assessment of Demand Response Potential. Government Printing Office, Washington, DC.

Federal Energy Regulatory Commission, 2010. Assessment of Demand Response and Advanced Metering. Government Printing Office, Washington, DC.

Fischer, C., 2008. Feedback on household electricity consumption: a tool for saving energy? Energy Efficiency 1, 79–104.

Fischhoff, B., 1992. Giving advice: decision theory perspectives on sexual assault. American Psychologist 47, 577–588.

Fischhoff, B., 1996. Risk perception and communication unplugged: twenty years of process. Risk Analysis 15, 137–145.

Fischhoff, B., 2005. Decision research strategies. Health Psychology 21, S9–S16.

Fischhoff, B., 2010. Judgment and decision making. Wiley interdisciplinary reviews. Cognitive Science 1 (5), 724–735.

Fischhoff, B., Brewer, N.T., Downs, J.S. (Eds.), 2011. Communicating Risks and Benefits: An Evidence-Based Users Guide. US Food and Drug Administration, Washington, DC.

Fleishman, L., Bruine de Bruin, W., Morgan, M.G., 2010. Informed public preferences for electricity portfolios with CCS and other low-carbon technologies. Risk Analysis 30, 1399–1410.

Gardner, G.T., Stern, P.C., 2002. Environmental Problems and Human Behavior. Pearson, Boston.

Gardner, G.T., Stern, P.C., 2009. The short list: the most effective actions that US households can take to curb climate change. Environment 50 (5), 5–25.

Gaskell, G., Pike, R., 1983. Residential energy use: an investigation of consumers and conservation strategies. Journal of Consumer Policy 6, 285–302.

Haney, A.B., Jamasb, T., Pollitt, M., 2009. Smart Metering and Electricity Demand: Technology, Economics and International Experience. Electricity Policy Research Group Working Paper-EPRG0903.

Hastie, R., Dawes, R.M., 2001. Rational Choice in an Uncertain World. Sage, Thousand Oaks.

Hoey, D., Maine, P.U.C., 2011. To Seek Flexibility in Installation of Smart Meters. The Portland Press Herald (A1. print).

Jensen, O.M., 2003. Visualisation turns down energy demand. In: ECEEE Summer Study Proceedings. Danish Building and Urban Research.

Kahneman, D., Slovic, P., Tversky, A., 1982. Judgment Under Uncertainty: Heuristics and Biases. Cambridge University Press, New York.

Klima, K., Bruine de Bruin, W., Morgan, M.G., Grossman, I. Public Perception of Hurricanes. Department of Engineering and Public Policy, Carnegie Mellon University, in preparation.

Krishnamurti, T., Eggers, S.L., Fischhoff, B., 2008. The effects of OTC availability of Plan B on teens' contraceptive decision-making. Social Science and Medicine 67, 618–627.

Madlener, R., Harmsen van Hout, M.J.W., 2011. Consumer behaviour and the use of sustainable energy. In: Galarraga, I., González-Eguino, M., Markandya, A. (Eds.), Handbook of Sustainable Energy. Edward Elgar Publishing, Cheltenham (UK)/Northampton (Mass./US).

Mansouri, I., Newborough, M., 1999. Dynamics of energy use in UK households: end-use monitoring of electric cookers. In: Proceedings of the Summer Study of the European Council for an Energy Efficient Economy, pp. 3–8.

Matsukawa, I., 2004. The effects of information on residential demand for electricity. The Energy Journal 25, 1–18.

Morgan, M.G., Fischhoff, B., Bostrom, A., Atman, C.J., 2002. Risk Communication: A Mental Models Approach. Cambridge, New York.

Nesbitt, J., 2011. Westerville City Council Reconsiders 'Smart Meter' Program. The Columbus Dispatch, 10 February, 2001: online. Retrieved February 22, 2011 from: 〈http://www.dispatch.com/live/content/local_news/stories/2011/02/10/city-council-reconsiders-smart-meter-program.html〉.

[5] The results of this article focus on customers from one major U.S. mid-Atlantic electric utility. Data collected from individuals ($n=306$) responding to the same survey on the MTurk online survey platform hosted by Amazon.com revealed similar results for these logit regressions.

Palmgren, C.R., Morgan, M.G., Bruine de Bruin, W., Keith, D.W., 2004. Initial public perceptions of deep geological and oceanic disposal of carbon dioxide. Environmental Science & Technology 38, 6441–6450.

Payne, J.W., Bettman, J.R., Johnson, E.J., 1992. Behavioral decision research: a constructive processing perspective. Annual Review of Psychology 43 (1), 87–131.

PG&E Denies Lawsuit Allegations, Plans Third-party Audit, 2009. Smart Grid Today, 9 November, 2009: online. Retrieved February 22, 2011 from: 〈http://www.smartgridtoday.com/public/935.cfm〉.

Pratt, R.G., Balducci, P., Gerkensmeyer, C., Katipamula, S., Kintner-Meyer, M.C.W., Sanquist, T.F., Schneider, K.P., Secrets, T.J., 2010. The Smart Grid: An Estimation of the Energy and CO_2 Benefits. Prepared for the U.S. Department of Energy by Pacific Northwest National Laboratory (Research Report PNNL-19112 Revision 1).

Quinn, E., 2009. Smart Metering & Privacy: Existing Law and Competing Policies. A Report for the Colorado Public Utilities Commission, Electronic Frontier Foundation.

Scholz, R., 2011. Environmental Literacy in Science and Society. Cambridge University Press, Cambridge.

Siddiqui, O., Hurtado, P., Parmenter, K., 2008. The Green Grid Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid. Electric Power Research Institute (No. 1016905).

Soto, O.R., 2010. SDG&E's New Smart Meters Could Damage TVs. San Diego Union-Tribune, 30 March, 2010: online. Retrieved February 22, 2011 from: 〈http://www.signonsandiego.com/news/2010/mar/30/bn30meters/〉.

Spees, K., Lave, L., 2008. Impacts of responsive load in PJM: load shifting and real time pricing. The Energy Journal 29, 101–122.

Stein, L., Enbar, N., 2006. Direct Energy Feedback Technology Assessment for Southern California Edison Company. Electric Power Research Institute Solutions.

Sterman, J.D., Sweeney, L.B., 2007. Understanding public complacency about climate change: adults' mental models of climate change violate conservation of matter. Climatic Change 80, 213–238.

Sullivan, C., Kahn, D., 2011. Smart Grid: Calif. Agency Mulls 'Opt out' or Wired Substitutes as Fallout Persists. Greenwire, 14 January 2011: online. Retrieved February 22, 2011 from: 〈http://www.eenews.net/Greenwire/print/2011/01/14/1〉.

Svenson, O., Nilsson, G., 1986. Mental economics: subjective representations of factors related to expected inflation. Journal of Economic Psychology 7, 327–349.

Tabachnick, B.G., Fidell, L.S., 2007. Using Multivariate Statistics, 5th ed. Pearson Allyn & Bacon, Upper Saddle River, NJ.

Thompson, P.B., 1990. Risk subjectivism and risk objectivism: when are risks real? Risk: Issues in Health and Safety 1, 3–19.

Tweed, K., 2010. Oncor Reacts to Smart Meter Anger. Green Tech Media, 16 March, 2010: online. Retrieved February 22, 2011, from: 〈http://www.greentechmedia.com/articles/read/oncor-reacts-to-smart-meter-anger/〉.

Ueno, T., Inada, R., Saeki, O., Tsuji, K., 2006. Effectiveness of an energy-consumption information system for residential buildings. Applied Energy 83, 868–883.

United States Department of Energy, 2006. The Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them. Government Printing Office, Washington, DC.

United States Department of Energy, 2009a. Smart Grid System Report. Government Printing Office, Washington, DC.

United States Department of Energy, 2009b. The Smart Grid: An Introduction. Government Printing Office, Washington, DC.

United States Government Accountability Office, 2009. American Recovery and Reinvestment Act: GAO's Role in Helping to Ensure Accountability and Transparency (Publication no. GAO-09-453T). Retrieved September 29, 2011 from: 〈http://www.gao.gov/products/GAO-09-453T〉.

von Winterfeldt, D., Edwards, W., 1986. Decision Analysis and Behavioral Research. Cambridge University Press, New York.

Wood, G., Newborough, M., 2003. Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design. Energy and Buildings 35, 821–841.