2010

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ABSTRACT

A variety of approaches have been proposed to explaining individual household energy consumption, its variation, and its potential reduction. Some focus on technology, some on costs, and some on a combination of behaviors, attitudes, intentions, and norms. All try to make sense of a problem that, from a modeling perspective, involves hundreds of potentially important factors, yet is supported by highly inadequate or at best selective data. While there is value in "doing the best one can" with the resources at hand, building a defensible science requires a cold hard look at the quality of theory, research and data. This paper draws upon the authors' assessment of data and critical literature review to examine the implications of common "sticky points" in modeling residential energy consumption. These include: variability in consumption within and across households, data quality issues, conflicts among various modeling approaches and underlying theoretical constructs, and tacit beliefs about causal relationships. The combination of uncertainties in these areas can lead to adoption of cautious (and sometimes misleading) assumptions, and to conservative policy approaches that hedge against behavioral failures in efforts to secure energy savings.

Defining the Problem

This paper is occasioned by the convergence of two energy efficiency policy imperatives. The first is an interest in "behavioral" approaches to accelerating efficiency hardware adoption, along with behavior change as a source of energy conservation. The second is the increased use of models and modeling to inform efficiency policy development, implementation and evaluation. As participants in both movements, our aim is to explore how well behavioral understandings can translate into better models and, as a result, into better policies.

Why Models and Modeling?

Models have become indispensable to modern science, government and business. Models are used to capture the workings of biophysical systems, technologies, economies, investment options, and a host of other important activities. Models inform the thinking and guide the conclusions of climate scientists, policy analysts, and designers of buildings and technological devices. In the energy efficiency (EE) world, models are used to forecast demand, predict adoption of new technologies, and estimate the impacts of EE programs.

But in the worlds of energy efficiency and climate change research, none of the models are very good at rendering the structure and variability of consumption at the household level (Lutzenhiser & Moezzi 2010).[1] In *climate models* (IPCC 2007), household energy use is

[1] This has not historically been a concern for energy efficiency policy and programs, which have had modest aims of marginal demand reductions. More ambitious carbon emissions reduction goals require higher resolution models.

understood to be an important driver of green house gas (GHG) emissions, but is treated as highly aggregated and with likely future consumption levels similar to those observed in the past. It is assumed that innovations in EE technologies will be adopted, but at fairly slow rates, while population growth and economic expansion will continue to increase GHGs from the household sector. Econometric demand forecasting models treat household consumption similarly.

In *end-use forecasting models* (e.g., CEC 2010), the aggregated demand of households is decomposed into "end-use" averages for particular appliances, primarily for the purpose of tracking changes in energy consumption attributable to program or standards-induced changes to the appliance stock.[2] Individual residences are aggregated into dwelling types within climate zones. While this additional detail does provide some help in tracking policy impacts, those impacts are necessarily treated mechanistically—that is, predicted consumption for a household is a product of the house type, weather and average loads of energy-using devices. Behavioral differences that aren't well represented by these factors, for a number of reasons discussed below, are treated statistically as variation. From the policymaker's perspective, these models, despite their detail, cannot inform policy decisions regarding behavioral issues. At best, programs or policy decisions that seek behavior changes can only be modeled as changes in adoption rates or average usage.

The finest-grained simulation models of *single building energy performance* are used in efficiency auditing (HES 2010) and to improve the energy efficiency of alternative designs for new buildings (EnergyPlus 2010). They are able to take behavior more explicitly into account, but generally fail to do so (at least very effectively). The details of energy use in these models are blurred by simplifying assumptions about average, typical or expected behaviors. They are essentially lost when results are fed into successive stages of modeling to account for weather, economic conditions and other global factors and calibrated to observed consumption—e.g., in establishing performance benchmarks for building codes and standards.

The global models cannot predict the future, of course, so they use scenario analysis cautiously to consider different possible conditions for households in the future. The forecasting models that operate at national or regional scales offer an often crude fit to actual, observed conditions and measured energy use, and must be "calibrated" (adjusted after the fact) for cautious use in producing both "business-as-usual" and alternative policy scenarios. The differences between building-level simulation model results and real world energy use is commonly as much as 80-100%. Here, calibration is more difficult, since all of the factors that should affect energy use in the physical world have been measured and specified as carefully as possible. In addition to measurement error, occupant behavior appears to be the culprit of last resort. But this raises questions about the use of averages and assumptions of "typicality" all up and down the different levels of modeling.

If behavior is variable across the population rather than typical, how good could modeling be? Now it certainly may be the case that the current modeling state-of-the-art is "good enough" for the policy purposes at hand. Even though we certainly want to "do our best" (within the limits of our knowledge and our various personal stakes) to inform policy with modeling, our collective decisions about climate conditions in 50 years or electricity demands a decade from now obviously involve a high degree of uncertainty. What's more, policy and its instruments cannot necessarily be designed with a great deal of precision even when conditions are well-

[2] The U.S. Energy Information Administration also operates a similar model in the National Energy Modeling System (EIA 2010). These detailed "bottom-up" (non-econometric) forecasting models are actually an exception rather than the rule.

known; there are many often-competing criteria and a limited set of levers. Fair enough. But the picture is a bit different when we perform detailed "scientific" audits of homes in the present and make expensive investment recommendations and energy savings/pay-back predictions on the basis of modeling.[3] The "misses" in this case need to be understood and rectified in order to honestly and effectively deal with our policy options (and households' bank accounts) in the present.[4]

In a general sense, contemporary policy discourse rests on the assumption that science-based modeling can improve policy deliberations about uncertain futures—acknowledging that modeling needs to be improved with continual improvement of understandings of the processes involved, and improved measures of causes and effects. If we hold to those principles, then shouldn't we expect our best understandings of household energy use to inform improved modeling at a variety of scales? If the answer is "yes"—and the authors believe that it is—then it is necessary to ask, "What do we actually know about residential energy demand?" "What don't we know?" "What can we reasonably expect to learn?" and "What are the policy consequences of both not knowing and of getting it wrong?" These are all questions about uncertainty. In this paper, we explore two fundamental sources of uncertainty about residential energy use that limit models and constrain policy choices. These are uncertainty in our knowledge of the structure and dynamics of consumption, and uncertainty in the measurement and estimation of energy flows.[5] We then consider the energy efficiency policy and program implications of uncertainty in behavioral modeling.

What Do We Know About Household Energy Use? Uncertainty in Theory and Research

The question "what do we know about household energy use?" has been asked numerous times and almost always answered in one of two ways, either (1) "from the point of view of discipline X, we can say that households do A" or (2) "because of fundamental differences between disciplines X, Y and Z's interests, theories, methods, and conclusions, all we know for sure is that we're not sure" (e.g., Crosbie 2006; Keirstead 2006). The divergence of views is particularly prominent when we consider the *behavioral* parts of the system—i.e., the ways in which residents' activities are understood to be instrumental in shaping energy flows, but where no "physics" of household action and choice exists.

It's long been recognized that the perspectives and theories about the household of different disciplines—from engineering to economics, architecture to sociology, and psychology to anthropology—differ considerably from one another. Each looks at the parts of the residential

[3] We identify a science-based modeling approach as one that is consciously attached to theory and committed to the use of empirical observations in specifying relationships and parameters.
[4] The use of simulation modeling in Home Energy Rating Systems (HERS) is generally for the purposes of "asset valuation," which uses a standard set of assumed occupancy characteristics so that buildings can be compared to one another or to a benchmark standard (e.g., a similar building built to stringent energy codes). In this case, the variability of real-world operational characteristics are much less important, since specific cost-benefit, energy savings and pay-back estimates are not being made for homeowners.
[5] The paper draws upon the preliminary work now being undertaken by the authors (both as researchers and technical project advisors) in the Advanced Residential Energy and Behavior Analysis (AREBA) project at Portland State University. The goal of AREBA is to advance the state-of-the-art in residential demand analysis, and particularly the modeling of household behaviors and their interactions with buildings, technologies, social contexts, and the natural environment.

consumption system in a different way, picking out certain features to emphasize while ignoring or making blanket assumptions about others. Often the "blind spots" (Stern 1986) are intentional when they "black box" (hold constant, treat as random, or treat as outside the frame) those parts of the system in which they're not interested. At other times, the omissions are unacknowledged and disciplinary analysts may be so "frame-bound" as to not even be aware of them. So when we attempt to look at the literatures, we find a Tower of Babel comprised of disconnected strands and compartmentalized theories. At the same time, they sit beside a simple mechanical model used in EE policy and evaluation that focuses narrowly on devices, prices and rationalized behavior sometimes called the physical-technical-economic model (PTEM).[6] While the PTEM has been widely criticized as inaccurate and misleading, it continues to dominate EE discourse, as it has for several decades. This is not inappropriate since the PTEM satisfies some fundamental needs of a regulated utility environment interested in securing relatively modest EE gains at the margins of an expanding energy system (see Lutzenhiser et al. 2009). But it is not adequate to provide a scientific basis for policies that would dramatically *reduce* the GHG emissions that accompany energy system expansion. And the muddle of disciplinary voices has added little in the way of improvement.

What are the alternatives? An alternative strategy would be to broaden disciplinary views. In fact, a number of observers have encouraged specific disciplines to adopt enlarged models (e.g., Reiss & White 2005; Wilson & Dowlatabadi 2007; Kristöm 2008; Gifford 2008). A number of others have explicitly called for interdisciplinary *integrated models* that synthesize elements of disciplinary approaches in order to provide a more thorough depiction of the residential consumption complex (e.g., Dholakia et al. 1983; van Raaij & Verhallen 1983; Lutzenhiser 1992; Hitchcock 1993; and Wilk 2002). However, when Keirstead (2006) recently reviewed literature in this area published over the past two decades, he found little evidence of progress toward the integration of disciplinary models.

Multiple Models: A Clash of Views

It's not our aim to review in any detail the various perspectives on household energy consumption here. But we do attempt to isolate some of the most important strands of thinking that impact on our efforts to make progress toward better, more integrated models. We first identify some of the key features in the technology-centered approach of the PTEM. We then discuss some efforts by the social and behavioral sciences to explain and alter consumer behaviors related to technology.

Technology focus. In the PTEM, the physical world—properties of structures, equipment, fuels, and nature—create the skeleton for household energy use. In the policy discourse around the model, "technical potential" (for EE) has been a central concept in imagining changes in energy use. Technologies of demand and supply are typically seen as the fundamental levers for consumption changes and reductions of energy-related emissions, especially in the long term. Technology, however, is only a partial explanation for energy use. The fact that technology development, technology choice, and technology performance depend upon people means that technology and people must be considered jointly to understand and potentially influence energy use, energy technologies, and structures, quite beyond a mechanistic view of adoption. For example, whether a programmable thermostat designed to save energy does so in a particular

[6] See Lutzenhiser (1993) and Lutzenhiser et al. (2009) on the PTEM and alternative models.

household depends on whether the programmable features are used in a more energy-conserving regime than the household previously managed the thermostat; whether air-conditioning is needed depends on how comfort is defined socially as well as physiologically, and what alternative methods of cooling seem possible.

Difficulties in understanding, predicting, and influencing behavior have helped shape technological strategies that minimize the importance of human behavior on technology performance. An example might be improvements in control of technology, where technological controls substitute for desired human actions (e.g., programmable thermostats, direct load control, lighting sensors), as a route to reduced energy use and emissions. However, in practice, households constructed to be efficient and that have more efficient equipment may use more energy than conventional households (e.g., Harris et al. 2008; RLW Analytics and SERA 2007). This raises questions about how to relate efficiency to actual consumption and savings. Social perspectives (discussed below) also point out that technologies, as social products, thereby create and shape "needs" as well as fulfill them.

Economics. In considering how households acquire technologies in general, and more energy efficient technologies in particular, economics addresses the problem through the lenses of investment and utility. The overarching economic argument in promoting efficiency in the residential sector has been that efficiency saves money. However, there is widespread agreement that people tend to "have high implicit discount rates" and thus under-invest in energy efficiency compared with other investment opportunities, but with mixed opinions on the size of the shortfall, solutions, and the framing of the problem. Recent work estimating the extent of split-incentives in residential energy use suggests that this problem may be quite large, reducing the applicability of the standard efficiency investment model (IEA 2007).

Prices of energy should make a difference in this calculus, and energy price *elasticity* is a commonly used quantitative summary of changes in energy consumption in response to changes in price. Short-run price elasticity is comprised primarily by changes in usage behavior, while long run elasticity includes changes in usage and in equipment/structural efficiency. Most residential customers have only crude information about prices and costs, which do not support any precise utility calculation even for *homo economicus*. So problems in establishing price elasticities and explaining their origins shouldn't be surprising. Estimates of price elasticity are wide-ranging and vary by method, location, and other factors (Dahl 1993). Using estimates of end use consumption, Reiss and White (2005) suggest that in California, only households with electric heating or cooling (56% of households) were price-sensitive. Kristöm (2008) reviewed a wide range of studies of residential energy demand and concluded that there was little evidence of short-term elasticity. The evidence of long-term price effects (while these are certainly likely to exist) is likewise difficult to isolate.

The great strength of economics, however, is that it can give clear statements that can be expressed with numbers, symbols, and mathematical relationships. It is simple to understand and reason with, and, in reference to "money" as the stock in trade, is easily oriented to policy debates. It is also thus difficult to disprove economic models or for alternative models to compete with economic models head-on (deCanio 2006), though the clear structure of economic models makes it easier to identify questionable assumptions and issues that fall outside of the established framework. For example, as Lutzenhiser and Hackett (1993) note, economic models do not recognize that energy use and economic action are socially situated, nor do they acknowledge the importance of altruism or cultural values in shaping economic behavior.

Behavioral economics offers a partial corrective, reinterpreting economic decision-making with greater attention to real-world context and a softened view of rationality, by introducing a more psychological viewpoint. Behavioral economics suggests that with modifications it is possible to improve predictions of deviations from the "rational man" model and offers a set of soft rules, patterns, and clues to make these improvements (Gowdy 2008). Stemming from this line of reasoning are arguments about "choice architecture," that argue that various non-price details of how purchase decisions are presented to consumer have a substantial effect on what decisions are made (Thaler & Sunstein 2008). However, the behavioral economics literature specifically on energy consumption is sparse (Gillingham et al. 2009).

Psychology. Most of what has been requested of the social and behavioral sciences by the dominant policy perspective, and much of what has been delivered, has focused on closing the "energy efficiency gap" and finding ways to motivate altruistic actions. Insights from psychology are the easiest to apply in this realm, because of that discipline's focus on individual decision-making, grounding in experimental methods, and traditions of quantification and schematizing harmonize well with a PTEM perspective—in contrast to sociology and anthropology. The major thrust of psychological approaches has been to try to find methods to persuade people to use less energy. In focusing on the shortcomings of purely economic explanations of energy-relevant purchases and/or the need to "correct" consumer behavior, most psychological work is also formulated around micro decision-making in analogue to economic models.

Many psychological models can be broadly grouped as ABC (Attitude-Behavior-Context, or variably, "Constraints" or "external Conditions") models (Martiskainen 2007; Stern 2000). Individuals' attitudes and values are seen to be related to social norms and complexly related to changes in behaviors. For example, empirical studies suggest that conveying "norms" of energy use may lead households to adjust their usage closer to the normal levels (Schultz et al. 2007). Similarly, the demonstration by others of "normal" or "desired" energy-relevant behaviors may influence households to alter their behavior (although the persistence of these changes is an open question). The emphasis on individual mental states, and frequent de-emphasis of external factors and forces that influence behavior and choice, is a problem for at least some psychological models.[7] Most agree, in principle, about the importance of social context in decision-making and energy usage. Acknowledging external conditions or "context" factors theoretically situates attitudes and beliefs within larger social systems and provides at least symbolic integration of the individual with the rest of the world. However what "context" means differs for psychologists versus sociologists, with each working at different scopes and scales of analysis.

Sociology, anthropology and social studies of technology. These fields tend to focus on larger systems and longer-term changes in technology and behavior. Their energy-related agendas have often been more concerned with understanding patterns of consumption, than with efforts to change those patterns directly. And while all three study the fine-grained details of everyday persons' lives, actions and choices, these disciplines are also interested in the ways in which individual (and, more precisely, household) actions are patterned, shared across groups, and

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[7] Paul Stern's (2000) work on the relative importance of psychological versus context variables is a notable exception.

shaped by large-scale social, cultural, institutional, and political-economic forces. They are all about "context" and how household life is actually *an aspect of larger patterns and processes*.

The social sciences are sometimes enlisted to help close the efficiency gap, but those efforts have been sporadic and weak.[8] There are several reasons for this. First, their analysis can be quantitative, but apart from measuring broad socio-demographic differences, the contributions have not been quantitatively linked to policy in the ways that economics, engineering and even psychology have. A number of studies have shown statistically significant relationships between energy consumption and income levels, lifecycle stage, and ethnicity (e.g., Lutzenhiser 1993; O'Neill & Chen 2002). But because of sample size limitations and the granularity of most socio-demographic data, it has been difficult to estimate the importance of these various factors. Second, the use of macro-social group differences in "lifestyle" to explain variations in household energy use is a familiar aim of EE policy. There is a hope that households could be induced to change their lifestyles to reduce their energy use. Some intriguing theoretical work has been done in this area (e.g., Aune 2007; Lutzenhiser & Gossard 2000). But apart from identifying socio-demographic patterns, there is limited methodological or empirical work exploring these notions.

Despite these limitations, the social sciences have offered some important insights that could, at least in principle, improve policy, modeling and behavior-change efforts. For example, it is well accepted that most household energy use is habitual rather than a series of conscious decisions. Energy use results from practices that are engrained by social and technical structures, personal histories, and cultural interpretations (Carlsson-Kanyama & Lindén 2007). This helps to explain why exhortations to change behavior may not have much effect.

It also means that behaviors may be "chosen" much less often than assumed, and external influences on behavior may often be much greater than assumed. A central problem in sociology is the "structure/actor" dynamic: i.e., understanding the interplay between how the individual acts and chooses and the structures (social, cultural, technological) that shape and constrain his/her actions. This dynamic creates a useful vantage point for balancing the effects of individual choices about energy use with structural elements at many levels (e.g., how the configuration of a house might script consumption, the social implications of a particular purchase, how comfort is defined), and enriches the view of "context" as used in psychological approaches. It also widens the focus from questions about individual choice of efficient goods or conservation actions to questions about how technologies and practices are "needed" and why.

The concept of structural "lock-in," by which individuals are forced to consume in particular ways, turns the lens of explanatory power and of policy to larger structural issues, such as systems of work, transport, and commerce (e.g., Sanne 2002; Shove 2003). An example of research in this vein is studies of how the technological development of air-conditioning has shaped energy-relevant social patterns and behaviors (e.g., Cooper 1998; Shove 2003). However, these perspectives on structure and choice do not depict a world of persons and devices frozen in time. To the contrary, they also emphasize that norms and behaviors are evolving through constant negotiation, and that there are important differences between what people think is "normal" (beliefs about others) and what is actually the "norm" (empirical patterns).

[8] We use the term "social sciences" to refer to those disciplines that focus on the actions of human groups and institutions. In the household consumption arena, these are primarily sociology, anthropology and the social study of technology. Some social psychologists and institutional economists would also be included under this heading.

Can We Measure Household Energy Use? Uncertainty in Data, Metrics and Dynamism

If theoretical models are to be more than thought experiments, they need to be examined in the light of facts. Uncertainty in theory and differences in perspective can, in principle, be tested and refined or resolved. Unfortunately, the empirical realities of energy use in households are difficult to capture through simple observation. People are not always welcoming of ethnographers in their kitchens and living rooms, and, although there is considerable room for more good quality ethnographic data collection and careful surveys about what people do and why they do it, household-level data collection is difficult, time-consuming, and usually costly. To the extent that empirical studies of home energy use have been undertaken (and they are relatively rare), they have tended to rely upon either small samples, with attendant reliability problems, or relatively superficial polling about actions, attitudes and opinions, with obvious validity problems. Researchers would generally like to have actual *measured* electricity and natural gas usage data to study the recorded effects of past behaviors. However, even with metered and recorded information, there are significant uncertainties. Our overall assessments of available data lead us to conclude that:

1) Relatively little household-level data are available. Most are reported in the aggregate.
2) Overall, electricity has been the focus of more data collection than natural gas. Electricity and natural gas data are not often simultaneously reported for a given housing unit.
3) Comprehensive data are lacking. Where household-level information is available, details on some dimensions may be good but missing for others (e.g., household characteristics or numerous questions about attitudes, perceptions, motivations, and other socio-psychological variables, but no information about the dwelling or energy use).
4) The availability of basic energy data, in particular data on end use consumption within a household, is poor. Most end use estimates used in policy or research are based on engineering models or on limited, dated, end use metering. These may be adequate for certain questions about aggregate or average use, but less so for understanding energy flows within the household and the diversity and dynamics of energy use at larger scales.
5) While data can be combined across different data sets to make inferences, scales and coverage are usually of limited compatibility, which blurs the ability to identify relationships and patterns. It also calls into question the validity of inferences, particularly those supported by elaborate statistical adjustments. Even when household-level data are available, precise identification is often masked, limiting the accuracy of data merges.
6) Except for data sets with highly developed statistical sampling and data collection plans (e.g., EIA/RECS or U.S. Census Bureau data), the sampling characteristics and representation of most data sets are often unknown or poorly documented.
7) Some types of data might be technically available, but access is difficult (e.g., electricity and natural gas billing data at the household level) and once obtained come with restrictions that limit their use (e.g., short time periods; use for program evaluation only; partial identifying information). While there are signs that availability of utility data may be easing up (e.g., Aroonruengsawat & Auffhammer 2009), restrictions and the rationales behind them remain consequential for researchers.

8) Few data sets are sufficiently similar to support time-series analysis. In fact, differences among them are often pronounced due to different scales of data collection, different sample frames, different measures of similar concepts, etc.

In terms of *measurement uncertainty,* it is important to note that behavior itself can rarely be observed directly on any statistical scale, and self-reported data from surveys are rarely nuanced and not necessarily accurate. Also, complex concepts are difficult to assess with simple measures. For example, understanding a household's decision making process for purchasing an energy efficient furnace may require an assessment of their beliefs, habits, and constraints on making this decision, not just knowing if a person engaged in such a behavior and then assigning them to a "consumer segment" on the basis of some socio-demographic attributes.

The *dynamism* of household consumption also introduces uncertainty, even when electricity loads and natural gas flows can be carefully measured. The moment-to-moment variations in consumption are considerable, as different pieces of energy-using equipment and systems are turned on and off in the household, both under direct behavioral control and automated control (thermostats, timers, etc.). At the system level, aggregate residential consumption is seen as smooth peaks and valleys. But the reality at the level of the single residence is anything but. Also, differences *between households* are often extreme—the result of differences in environmental conditions, building performance, appliances, and the interactions behavior with the other factors. As a result, the overall distribution of household consumption is highly varied, with some households consuming 10-15 times as much energy as others (Lutzenhiser & Bender 2008). Even within households, there is at best only a probability that empirically established consumption patterns (e.g., dinner at 6:00) can be observed on a particular day. And even those that are fairly regular change over time.

The combination of data limitations, measurement uncertainty and dynamism at the level of the household, across households, and in aggregate energy flows mean that we should be very cautious about placing confidence in formal models of household energy use—even if we could theoretically specify those models correctly and completely (which we cannot). This fact has considerable significance for the use in policy of models incorporating (even implicitly) forms of household behavior.

Implications of Uncertainty for Policy and Modeling

The uncertainties about human behavior, data limitations, and the inherent dynamism of consumption lead to several important effects on policy and the policy process. In the balance of this paper, we consider how models and modeling can be used and misused to inform policies, how the uncertainties in our understanding of household energy use behavior affect policy debates and policy development, and ways forward that put the use of models into perspective.

The Role(s) of Models in Policy

Why do regulatory and policy agencies build models? What do policy makers do with them? The systems that demand policy attention are widely acknowledged to be large, complex and always, to some degree, uncertain. This is as true of residential energy use as it is for educational achievement or climate change impacts on crop yields. The main purpose of building a policy-useful model is to simplify a complex system *in order to better understand it*—to boil it down to its most critical elements, which allows the most necessary data to be reliably collected and used to track changes and forecast outcomes. Policy makers use models to identify problems and opportunities that justify their actions, inform choices between possible initiatives, and to document the impacts of policies and regulatory actions.

This sort of modeling assumes that the data adequately represent underlying variables of interest and that the variables in the model (and the relationships among them) adequately represent the dynamics of the system. But in the case of household energy use, modelers' understandings of variations in consumption are sketchy at best. Based on the theory and measurement issues discussed above, we know that some households will have stable patterns (e.g., rigid work/school/home schedules), while others are more highly variable, and all will change over time. Aggregate patterns can be observed (e.g., gross patterns of occupancy and absence from the house at different times of the day; long-term trends in dwelling size, household size, employment rates, etc.). But there are no direct linkages to a causal structure at the household level. And efforts to make assumptions about household behavior based on aggregate patterns are fraught with danger.

Mistaking the Forest for the Trees

There is a temptation to reason that, because there are peaks and valleys in total demand, these characteristics of the aggregate are probably mirrored at the household level. The Smith family's peak is likely similar to the system peak (i.e., the latter is a "close enough" estimate for policy modeling). The same is true for averages at the system level and estimates of average energy usage at the device level. The system average annual consumption is close enough to Mr. Jones' annual energy use. The aggregate average lighting usage is close enough to Mrs. Wong's. Of course, modelers and policy makers don't ordinarily have the Smiths, Joneses or Wongs in mind. In their efforts to sketch big picture trends, identify opportunities and assess hoped-for outcomes, there are rarely opportunities for careful consideration of variations in demand at the household level or their implications for policy. And an argument might be made that "close enough" is all that's necessary to move an average or a distribution in the direction of energy savings. But is that true? And, is variability recognized and simply deemed unimportant, or are representations being made about consumers and behavior that can have negative effects on policy outcomes?

We don't take a strong position on this question. But we have observed in policy and modeling discussions, reports, and public testimony a tendency to refer to household energy-use behavior as "typical," "usual," "routine," "normal," or "average" (not in a statistical sense). What's more, when consumer surveys are used to explore attitudes and behavior for program purposes, they commonly ask people to report their "usual" or "ordinary" actions and assessments. The body of theory and research suggests lots of problems with posing such questions, and knowing what to do with the answers. But the more important point we're trying to make here is that there is a very common, probably un-reflected and certainly un-discussed, assumption of typicality and, therefore, misrepresentation of variation, in residential sector policy modeling.

Why is this problematic? There are several reasons. If policies target a "typical" case, identified from an average, they may fall short and leave few clues as to why that occurred. Program planners are required to craft programs for "generic consumers," and program implementers are asked to try to find that person and replace his/her refrigerator. We believe that is often artfully accomplished, but generally don't know how or why (Lutzenhiser et al. 2009). In the absence of a more nuanced social understanding of the structure of consumption and its variation, modeling has no way to understand changes in averages over time. And, as we note below, uncertainty about models and outcomes leads to skepticism about the potentials for behavior-focused policies and interventions.

Effects upon Policy Debates

At the policy level, limits to understanding and problems with models have not gone unnoticed. There are concerns about the power of commonly-used policy models to adequately capture, even in the aggregate, the relative effects of energy efficiency regulations (e.g., building codes, appliance standards), program interventions (e.g., hardware subsidies, technical assistance, information campaigns), and secular socio-technical-economic developments (e.g., the evolution of technologies, the introduction of new devices, the invention of new usage patterns).

These uncertainties around behavior and measurement give rise to debates among evaluators, efficiency program planners, regulators, and public interveners about what savings may have taken place and for what reasons. The can be a swirl of technical claims and counter-claims around "net to gross savings ratios," "rebounds" (or "take-back" effects), "free-riders," "market effects," and "spill-over." While a fair amount of additional modeling might support these debates, the accuracy of the models and their levels of precision are probably quite low given how dependent they are on the input assumptions.

Because of a lack of good understanding among policy makers and utility planners about how behavior affects energy use, they share prudent caution about the reliability of both ex-ante and ex-post estimates of savings from efficiency hardware upgrades. Behavior and choice clearly matter, but "how" and "how much" in the light of efficiency gaps, uncertain savings, the evolution of household activity patterns, etc. is an open question. This makes it harder to use efficiency savings estimates with confidence in procurement decisions. Despite the high priority of efficiency acquisition in energy policy in California and elsewhere, lead times for power plant construction are long and the consequences of inadequate supply can be severe. Thus the real benefits of efficiency tend to be forecast cautiously and the potential benefits of behavior change or conservation tend to be valued not at all, with the exception of where such change is incorporated in historical consumption trends.

So the lack of a confident understanding of behavior also makes it harder to consider instituting behavior-focused efficiency programs. Regulators and utilities alike are very cautious about behavior change programs—both in terms of their possible effectiveness, and the likelihood of *persistence* of effects (with concerns that consumers might revert to old behaviors and savings lifetimes could be too short to matter). A real problem with this view is that it is *circular* and *self-fulfilling*. Given the distrust of behavior programs (grounded in necessarily limited understandings of consumption and behavior), if attempted, many such programs would likely prove only marginally effective, and without a longer-term commitment to understanding why, the distrust is proven warranted.

In Favor of Humility and Considered Action

From the policy maker's point of view, even if models are necessarily crude, can't accurately parse cause and effect, and are even possibly misleading, there is not a choice to walk away from models or to not consider policy options. Policy makers and program implementers can impose rigid and rationalistic policy frames (and work within them), but they also recognize that their common goal is to ultimately reduce what both believe are likely large amounts of energy waste. So a more realistic understanding of consumer behavior is clearly necessary. This may lead to more accurate and useful models, and we believe that it is worth the effort—but not for the sake of modeling per se or to approximate a probably unattainable scientific precision. The impulse to improve the models should be a desire to get closer to reality, and then to see whether or not we can model it.

A place to start is with the recognition that in the domain of household energy use, the actions we're interested in separating out and affecting are, for the people using the energy, only peripheral elements of what they're actually doing. When the things they're doing are very routine and predictable, and the energy use implications clear (arrive home → use energy), the modeling and predictions work better. But this may be true for only a few actions within a few parts of the population (and even some strongly consistent routines may only be small parts of people's lives). If we want to affect behavior—hopefully in ways that people may find intelligible and helpful—it is important to know the "what" it is that people are doing, particularly from their own points of view. If a family is "fixing dinner," then it is *not* simply "turning on the stove" or "running the dishwasher." It is certainly *not* consciously "using energy" or "energy services." And simply observing *what* happens doesn't tell us much about *why* it happens—and why in that way rather than some other. It is crucial that we know "why" because ultimately policy incentives need to be designed around some understanding of why people are *not using less energy* or why people *might change*.

In reality, policy and programs have rarely come close to understanding and acting to support consumer behavior change efforts in the contexts of persons' own lives and circumstances. Most energy policy and program actions have focused on technology substitution and thus only on relatively rare "purchase" or "adoption" behavior. The only levers at their command have been to alter the price of the substitute and to provide information. Attempts to really change energy consumption behavior would require developing theories about why people do what they do, crafting interventions and larger-scale changes to support efforts to change behaviors and reduce waste, and carefully observing how those efforts unfold. Policies and programs of this sort in the residential energy arena would be more like those of public health interventions, in which studies around interventions and outcomes are used to refine understandings (and theory and data) at the micro scale, while tracking progress (e.g., through aggregate health, mortality, cost, etc. outcomes) at the macro scale. Modeling can and is carried out across scales. But in the context of an array of interventions intended to affect many causes and contributing factors (and to stimulate synergistic effects that are not yet fully understood, as well as their unintended consequences), modeling does not drive the action. In the case of household activities, behaviors, technology use, and energy consumption, our understanding is less well developed than in public health. So our use of models should be with a critical eye to their architectures and assumptions, exercising extreme caution in the use of limited data about dynamic processes, and with great humility in policy development, efficiency program implementation and evaluation.

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