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Information strategies and energy conservation behavior: A meta-analysis of experimental studies from 1975 to 2012

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HIGHLIGHTS

- We conduct a meta-analysis of information-based energy conservation experiments.
- We analyze 156 published trials and 524,479 study subjects from 1975 to 2012.
- On average, individuals in the experiments reduced electricity consumption by 7.4%.
- Individualized feedback via audits and consulting results in the largest reductions. Pecuniary feedback and incentives lead to a relative increase in energy usage.

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ABSTRACT

Strategies that provide information about the environmental impact of activities are increasingly seen as effective to encourage conservation behavior. This article offers the most comprehensive meta-analysis of information based energy conservation experiments conducted to date. Based on evidence from 156 published field trials and 525,479 study subjects from 1975 to 2012, we quantify the energy savings from information based strategies. On average, individuals in the experiments reduced their electricity consumption by 7.4%. Our results also show that strategies providing individualized audits and consulting are comparatively more effective for conservation behavior than strategies that provide historical, peer comparison energy feedback. Interestingly, we find that pecuniary feedback and incentives lead to a relative increase in energy usage rather than induce conservation. We also find that the conservation effect diminishes with the rigor of the study, indicating potential methodological issues in the current literature.

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1. Introduction

The environmental impact of everyday activities is often invisible to consumers. Information strategies that aim at correcting this information asymmetry are increasingly common. These include ecolabels (Crespi and Marette, 2005; Leire and Thidell, 2005), and mandatory and voluntary corporate disclosure (Khanna, 2001; Delmas et al., 2010). Information strategies are based on the principle that more and better information about the environmental impact of activities will encourage consumers to conserve. While theory suggests that information programs may be effective, the empirical evidence seems to indicate important differences in effectiveness according to type of information provided and the context in which

the information is communicated (Delmas and Grant, 2010; Delmas et al., 2010).

Electricity conservation has been an especially active context for the deployment of information strategies. Energy use accounts for 40% of greenhouse gases across the world and effective conservation programs could contribute to significant environmental improvements. A large number of energy conservation experiments have been conducted using various information strategies to reduce energy use (Abrahamse et al., 2005; Fischer, 2008; Vining and Ebreo, 2002). These include providing users with savings tips, historical individual usage, real time energy usage, peer usage etc. Yet despite the accumulated experimental evidence, analyses of the effectiveness of such strategies have provided mixed results. Some researchers claim that more information has little or no effect on energy use (Abrahamse et al., 2005), while others estimate that information programs could result in energy use reductions on the order of 22 to 30% over the next 5 to 8 years (Laitner et al., 2009; Gardner and Stern,

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2008). However, these claims are not backed up by rigorous empirical comparison and include very different types of information strategies.

Information strategies are varied. Pricing information has been widely used to induce individuals to save energy (Battalio et al., 1979; Katzev and Johnson, 1984; Nielsen, 1993; Reiss and White, 2008; Sexton et al., 1987; Slavin et al., 1981). Despite the direct financial benefits of saving energy, research indicates that providing information about the cost of energy use does not necessarily affect energy use behavior among households (Lindén et al., 2006). At the same time, research on the influence of non-price strategies such as peer comparisons (Katzev and Johnson, 1983; McCalley and Midden, 2002; Schultz et al., 2007; Stern, 1992) has highlighted approaches beyond price information that may drive conservation behavior. At this point, an authoritative comparison of price vs. non-price experiments is lacking. Comparing these different approaches may shed light on the debate of what best motivates energy conservation behavior.

In this paper, we compare the impact of different types of information strategies on energy use to strengthen our understanding of energy conservation information-based strategies. Information strategies include savings tips, energy audits, different forms of energy use feedback, and pecuniary strategies. Experiments generally use one, or at most two or three of these strategies, leaving open the question of how these strategies compare overall. We conduct a meta-analysis of existing field experiments to quantify the effect of information strategies on energy conservation. We focus on experiments trying to lower overall consumption (energy conservation) as opposed to shifting usage in time from periods of high demand to off-peak periods (load shifting). We limit our study to residential settings. We build a dataset of experimental studies within economics, psychology and related fields, incorporating all available evidence. We normalize reported effects to reflect mean changes in energy usage between control and treatment groups. We find a significant overall effect of information strategies on energy savings with a weighted average of 7.4%. Our results also show that strategies providing individualized audits and consulting are comparatively more effective for conservation behavior than strategies that provide historical, peer comparison energy feedback and pecuniary feedback. This indicates that information delivered in person might be more effective than information provided through other media such as mail or e-mail. Interestingly, we find that pecuniary feedback tends to lead to a relative increase in energy usage rather than induce conservation. We also observe that the effect differ across studies depending on the rigor of the methodology used. Indeed the savings are down to 2% for the studies of the highest quality that include a control group as well as weather and demographics controls.

Several authors have provided descriptive reviews of this research area, comparing methods used across studies (Abrahamse et al., 2005), discussing factors influencing residential energy conservation (Burgess and Nye, 2008; Steg, 2008), classifying studies by theoretical approach (Fischer, 2008; Vining and Ebreo, 2002), or presenting comparative case studies of residential energy efficiency programs in certain geographic areas (Faruqui et al., 2010; Mullaly, 1998). While providing interesting insights, these qualitative reviews do not constitute a firm basis for estimating the average treatment effect of behavioral energy conservation programs. Our study is the first to quantify the conservation potential of energy conservation information-based strategies and provides insights into the relative effectiveness of different strategies, which has important policy implications for the future design of such programs.

The paper proceeds as follows. In Section 2, we develop hypotheses on the impact of different types of information strategies. In Section 3, we describe the data-collection and

meta-regression methodology. In Section 4 we present the results. In Section 5 we outline steps for advancing methods and theory in this field. A conclusion follows.

2. Understanding levers for energy conservation behavior

The failure to engage in energy efficiency can be characterized as a market failure: individuals lack the relevant information or knowledge to engage in energy saving behaviors (DeYoung, 2000; Hungerford and Volk, 1990; Schultz, 2002) and acquiring such information is costly. Therefore detailed and immediate feedback is a frequently proposed solution to remedy wasteful energy use patterns (Van Houwelingen and Van Raaij, 1989).

We first describe how information about individual energy usage such as historical feedback, and real time feedback, as well as information on saving approaches might facilitate conservation behavior. While these strategies aim at reducing the cost of acquiring information, they do not touch on the potential motivations that might trigger conservation. We then describe the potential effectiveness of information strategies based on social norms and pecuniary incentives.

2.1. Energy feedback

Feedback can be described as “the mechanism that directs attention to a specific goal” (McCalley, 2006). The most common form of feedback informs participants about their own energy usage, often drawing comparisons to the past (e.g., Nielsen, 1993; Winett et al., 1979). Because most individuals have low awareness about their energy usage or its impacts (Attari et al., 2010; Kempton and Montgomery, 1982; Read et al., 1994), periodical energy use reminders, may render energy usage more salient and help trigger conservation activities. In addition, learning about one’s own electricity use may increase the sense of relevance of taking action to conserve. If individuals perceive their own impact as negligible, they might not behave in a prosocial manner (Larrick and Soll, 2008). Consequently, making an individual more aware of their own energy usage may contribute to conservation.

We therefore hypothesize the following:

H1. Information on past energy use will result in reduced energy use.

2.2. Information on problem solving strategies

Another set of information strategies provide participants with energy savings tips (e.g., Schultz et al., 2007; Slavin et al., 1981) or conduct home energy audits (e.g., Nielsen, 1993; Winett et al., 1982). Both of these information strategies involve teaching consumers about new behaviors to lower their energy consumption.

The implicit assumption behind the use of information strategies to reduce energy usage is that these strategies will result in a higher level of knowledge and therefore enable participants to change their behavior (Van Dam et al., 2010; Ouyang and Hokao, 2009). According to norm activation theory, changes in behavior occur when a person is aware of an issue and thinks he can influence it (Fischer, 2008; Schwartz, 1977; Vining and Ebreo, 2002). These preconditions to taking action may be enhanced if the person receives additional information on how to perform certain activities and on the outcomes of these activities. With regard to energy conservation behavior, it is conceivable that learning about the impacts of energy usage and receiving conservation tips will lower the barrier to actions. Energy

savings tips and audits are likely to contribute to both awareness and perceived behavioral control. Providing such information in an easily accessible manner lowers the cost of information on conservation strategies for the consumer.

We therefore formulate the following prediction about the impact of problem solving strategies on energy use:

H2. Information on conservation strategies will result in reduced energy use.

Conservation strategies based on energy feedback and information increase individual awareness of the problem and of the possibilities to influence the problem. Once individuals have this information, they will weigh motives versus the cost of actions. The following information strategies frame the message to motivate behavior by focusing on pecuniary incentives or social norms.

2.3. Pecuniary strategies

Pecuniary strategies represent another set of strategies commonly used in conservation behavior studies. Lowered energy use results in immediate financial benefits to a household, provided the household pays its own electricity bill. Individuals should be expected to take up energy conservation as long as the benefits of doing so are larger than the costs. Researchers have pointed out the importance of financial incentives and price signals for conserving energy (Hutton and McNeill, 1981).

Many energy conservation experiments inform participants about the financial expenses and/or savings potential associated with their energy usage (e.g., Bittle et al., 1979; Wilhite and Ling, 1995). Some studies include actual price incentives. These may take the form of rewards or rebate payments (e.g., Slavin et al., 1981), where participants receive a monetary payment for achieving certain energy savings goals. Other studies change the price of electricity (e.g., Sexton et al., 1987), raising for example the price per kWh or introducing rate schedules that change with the time of day or demand levels.

Two recent meta-analysis studies found strong effects of price signals on the timing of electricity consumption (Faruqui and Sergici, 2010; Newsham and Bowker, 2010), demonstrating that price signals affect behavior. Furthermore, several studies have shown that electricity demand responds to prices, although price-elasticity can be low in the short-term (for an overview see Branch, 1993; Gillingham et al., 2009).

However, other studies indicate that pecuniary incentives might be counterproductive for energy conservation because they might crowd out more altruistic or prosocial motivations (Bénabou and Tirole, 2005; Bowles, 2008). Furthermore, pecuniary strategies might not be effective if the monetary incentives are negligible. Potential savings from conservation as well as price incentives used in the experiments are often small, in order to bear some relation to the actual price of electricity. For instance, a study by Hayes and Cone (1977) provided a \$3 weekly rebate payments for up to a 20% reduction in energy use. In experiments using time of day pricing or critical peak pricing,¹ price differences can be more substantial (e.g., 1:9 ratio used by Aigner and Lillard (1984), as well as Sexton et al. (1987)). The literature is therefore not unanimous about the effectiveness of pecuniary strategies in the current context. Based on the above discussion, we test the following hypothesis:

H3. Information on monetary savings will result in reduced energy use.

¹ In time of day pricing, prices follow a daily schedule, rising during high demand times. In critical peak pricing, prices are only raised on days with high load forecasts.

2.4. The power of norms

Comparative feedback provides comparisons to others (e.g., Alcott, 2011; Kantola et al., 1984; Schultz et al., 2007) and can also be called a motivational strategy, or nudge. Such strategies send non-price signals to participants that activate intrinsic and extrinsic motivation. Besides comparative feedback, motivational strategies also include the use of competitions (e.g., McMakin et al., 2002) and goal-setting (e.g., Katzev and Johnson, 1984) where participants are assigned or select non-binding goals over a defined period of time.

Recognizing the importance of social and psychological aspects, a number of studies on energy use behavior have made use of comparative feedback (Alcott, 2011; Schultz et al., 2007). These studies illuminate other motivations for changing energy use behavior. In particular, the theory of normative conduct points to the importance of social norms in guiding conservation behavior. Norms influence behavior by giving cues as to what is appropriate and desirable. The effectiveness of social norms in bringing about conservation behavior is empirically supported by several studies. For example, Hopper and Nielsen (1991) find that recruiting neighbors to encourage and remind others in their community about recycling significantly increased recycling behavior. In an experiment presenting participants with the choice between a conventional, and a green, but inferior product, participants were more likely to choose the green product if their choices were publicly visible (Griskevicius et al., 2010). Similarly, Nolan et al. (2008) find that comparing individuals to the average energy user was more effective than other strategies at reducing energy usage. Overall, behavioral approaches predict that comparative feedback strategies making use of social norms will be effective in bringing about changes in behavior. We therefore hypothesize the following:

H4. Information on peer consumption will result in reduced energy use.

In our hypotheses, we focus on the most common strategies used in energy conservation experiments. In sum, we propose that providing information on past energy use, conservation strategies, financial savings and peer consumption will all contribute to increase energy savings. We now turn to a description of the methods and data collection, before testing our hypotheses and the comparative effectiveness of these strategies.

3. Methods

3.1. Data collection

We used three complementary search strategies to identify relevant field studies for our analysis. First, we consulted prior narrative review articles in energy conservation (e.g., Abrahamse et al., 2005; Darby, 2006; Fischer, 2008; Ehrhardt-Martinez et al., 2010). Second, we did a hand search of cited papers in these reviews. Third, we searched the following online databases: (1) EconLit, (2) PsychINFO, (3) Academic Search Complete, (4) Business Source Complete, (5) JSTOR, (6) GreenFILE, (7) Environmental Sciences and Pollution Management, (8) Social Science Research Network (SSRN), (9) GeoRef, (10) Ecology Abstracts, and (11) the NBER database, covering a breadth of disciplines. We compiled a list of keywords using a Boolean search with the following logic: (i) terms relating to energy or electricity², e.g., ["energy usage" "energy conservation" "energy demand"], and (ii) terms relating to

² We use the terms "energy" and "electricity" interchangeably.

study type or strategy, e.g., [“behavior”, “feedback”, “information”, “randomized field trial”, “rewards”, “incentives”, “smart meter”, “pricing”, “rebates,”] and (iii) terms relating to household or individual level as the unit of analysis, e.g., [“household”, “residential”, “dormitories”, “building”, “individual.”] This resulted in a list of 6858 scholarly peer-reviewed publications, of which 3511 were most relevant to our topic. We read all article abstracts and eliminated those not relevant to the topic. We developed a coding protocol and arrived at a short list of 365 articles, of which 59 were experimental studies used in the meta-analysis.

Studies were selected for inclusion on the basis of four criteria. First, as a measure of quality, we focused on peer-reviewed publications as well as the NBER database. Second, we selected only those studies involving behavioral experiments in electricity usage. Gas or water conservation studies, for example, were screened out. Third, only electricity feedback studies at the residential level were selected. Fourth, conditional on the above, we only included studies that reported a quantitative treatment effect, either in percentage relative to a baseline or in kilowatt hours (kWh) per unit time. Experiments focused on the timing of electricity use (e.g. dynamic pricing) were therefore included if they reported conservation effects (changes in kWh), but not if they only referenced load effects (changes in kW).

A number of relevant studies were excluded from the meta-analysis because (1) they did not report quantitative effect sizes relative to baseline levels, or (2) they did not use actual energy readings through individual metering or other verifiable measurement. Electricity use information based strictly on self-reported surveys or questionnaires were excluded from this analysis of experimental studies. Upon completion of the literature screening process, we obtained 59 unique papers, representing 156 field experiments in 13 countries and 525,479 study subjects and covering the period from 1975 to 2012. Appendix A1 lists all included studies and information coded in the meta-analysis. Appendix A2 contains a complete listing of scholarly journals. All papers were read and coded by two researchers to assure reliable extraction of the effect size and numerical coding of behavioral strategies and of the experimental methods used.

3.2. Overview of meta-analysis methodology

Meta-analysis is the art of calibrating and combining statistical evidence from separate studies into a single analysis to provide a quantitative, systematic overview of an empirical effect in the literature. The goal in meta-analysis is to derive a common summary statistic for the effect size of a study and to derive corresponding confidence intervals. Meta-analysis methods have become widely used and cited in the economics and management literature (see for example Stanley and Jarrell (1989) Geyskens et al., 2009). The techniques for analysis generally result in increased statistical power – roughly equal to the sum of individual sample sizes – and can result in improved parameter significance and accuracy relative to primary studies alone (see Bijmolt and Pieters, 2001).

This study uses meta-regression analysis (MRA) to estimate the effects of conservation strategies across many behavioral experiments. This advanced meta-analysis method addresses statistical issues of heterogeneity (Field, 2001; Lipsey and Wilson, 2001; Nelson and Kennedy, 2009). Heterogeneity in this context occurs when effect sizes in primary studies do not consistently converge to a central population mean, which is certainly the case in energy conservation studies with heterogeneous treatment effects (see Alcott, 2011; Costa and Kahn, 2010). A key advantage of meta-regression analysis is the ability to model excess heterogeneity in effect size distributions, particularly when combining empirical evidence across groups of studies.

3.3. The meta-regression model

For the j th study and L number of studies included in the analysis, the reported empirical estimates of average treatment effects, b_j are regressed on a vector of study-level characteristics Z_{jk} (typically dummy or indicator variables) as follows:

$$b_j = \beta_j + \sum_{k=1}^K \alpha_k \cdot Z_{jk} + e_j \quad \text{where } j = (1, 2, \dots, L) \quad (1)$$

In equation (1), we adopt standard meta-analytic notation advocated by Stanley and Jarrell (1989). The meta-regression coefficients α_k provide an estimate of the biasing effect of K number of moderating variables, for example, the incentive type or duration of the study. Positive values of the meta-regression coefficients imply a positive bias (increased energy use relative to a control group or baseline) and negative values imply a negative bias (decreased energy use relative to a control group or baseline). β_j is the ‘true value’ of the treatment effect, net of the biasing effect. It is indexed by j because we allow for heterogeneous treatment effects by study. The residual errors are captured in e_j . When individual study standard errors are known, we normalize expression (1) by dividing each term by the respective primary study standard errors (S_b) in order to combine unequal variances and mitigate heteroskedasticity; see Stanley and Jarrell (1989) and Roberts and Stanley (2005). In reduced form, we estimate the ‘true’ empirical effect of moderating variables as follows:

$$t_j = \frac{b_j}{S_{bj}} = \frac{\beta_j}{S_{bj}} + \sum_{k=1}^K \alpha_k \frac{Z_{jk}}{S_{bj}} + \frac{u_j}{S_{bj}} \quad \text{where } j = (1, 2, \dots, L) \quad (2)$$

In the absence of publication bias (i.e. the tendency to favor significant or positive results in published studies), observed effect sizes should vary randomly around the ‘true’ value and we can empirically estimate meta-regression coefficients for our moderating variables of interest directly from Eq. (2).

Because most of the standard errors in our data set are missing or not reported in primary studies, we take a commonly used approach in meta-regression analysis, that is, to proxy the effect size variance and hence the primary study standard errors using a monotonic transformation of the primary study sample size (see Nelson and Kennedy, 2009; Horowitz and McConnell, 2002). We estimate Eq. (2) by generalized least squares (GLS) and use the square root of the sample sizes as analytical weights. We use a more conservative specification by GLS panel clustered by publication ID (as compared with standard OLS or simple weighted least squares which tend to downward bias the standard errors) to remove heteroskedasticity in the disturbances of the regression model. This offers the advantage of adequately capturing variation in the estimated effect, correlation between effect sizes within the same study and any unobserved component. Our meta-regression model mitigates known heteroskedasticity, provides analytical weights to studies with larger sample sizes, and is less sensitive to estimation bias from small sample studies. In this way, we present robust estimates that allow for multiple effect sizes, model excess heterogeneity, and differences in precision due to sample size.

3.4. Measures

3.4.1. Dependent variable

Our dependent variable is the reported “effect size” in percentage units. This is a normalized measure across all studies and is defined as the percent change in the treatment group minus the percent change in the control group. Effect sizes can take on both positive and negative values. A negative effect size estimate implies energy savings (conservation) relative to a control group or baseline, whereas a positive effect size estimate implies energy increases relative to a control group or other baseline.

3.4.2. Independent variables

We model the effect sizes as a function of study characteristics falling into one of three classes (i) feedback on energy usage feedback and problem solving strategies, (ii) pecuniary strategies, (iii) normative feedback, and (iv) study-level controls, such as weather or demographics. We code these behavioral strategies as dummy variables, taking the value of 1 if the strategy was applied and 0 otherwise.

Energy feedback studies employ *Usage Feedback*: this means participants receive information about their own energy use as a self-comparison to their prior energy use (within subject comparison). We also test whether more specific feedback is helpful, by including a variable called *Real-time*: participants can access energy use information updated at frequencies greater than once per hour. Conservation strategies are measured by two variables, (1) *Energy Saving Tips*: participants receive information on how to save energy (leaflets, alerts or prompts) and (2) *Audits and Consulting*: participants receive in person advice on how to conserve energy or receive visits by technical personnel for home energy audits and consulting.

Pecuniary information strategies include: *Monetary Savings Information*: participants receive information about financial impacts or potential monetary savings from actions to conserve energy. This also includes information about available incentive programs (utility rewards, rebates, tax credits, etc.) but does not involve direct financial transfers; *Monetary Incentives*: participants are involved in direct monetary incentives like rebates, cash rewards and/or tiered pricing or dynamic pricing. Participants can also receive other monetary incentives for conserving energy or achieving certain consumption targets.

Finally, the social norm strategy is presented as the variable *Comparative Feedback*: participants receive information about their own energy use in comparison with others such as their neighbor (s) or community.

Study-level controls include the following variables: *Control Group* indicates whether the study includes a control group as a measure of baseline consumption or treatment counterfactual. When a study does not contain an in-situ or blind control group, the value of this variable is set to zero. *Weather Controls* indicates if the study adjusts for the effects of weather, for example, using heating and cooling degree days. The lack of weather controls are known to over- or under- estimate the impacts of conservation efforts, depending on the season. *Demographic Controls* specifies if the study adjusts for internal characteristics of the population such

as income, education, etc. *Feedback Duration* identifies the time period for the behavioral treatment, measured in months.

4. Results

4.1. Descriptive statistics

Table 1 presents the means, standard deviations and percentages of all observations and Table 2 presents the correlations. We see that in general, the effect sizes are not strongly correlated with treatment categories presented in Table 2. This is reasonable and to be expected, given that treatment selection is typically randomized. Among the more significant correlations presented in Table 2, we observe that monetary savings information is strongly correlated with both individual and social comparison feedback strategies. Feedback strategies in conservation studies are often combined with residential billing data, which includes cost savings information as a combined treatment. In Table 4, we quantify the separate effects of these interventions with meta-regression technique.

Our results indicate that quantitative feedback studies in energy conservation date back to at least the mid-1970s (Winett and Nietzel, 1975) with usage feedback representing 75.6% of all experimental observations and 76.9% of the papers.

While direct feedback studies are far more common in this literature, the use of comparative feedback in energy conservation dates back to the early 1980s (Midden et al., 1983) but remained largely dormant as a behavioral treatment until rediscovered in the late 2000s, following an influential paper by Schultz et al. (2007)—whose insights from behavioral psychology demonstrated the potential of comparative feedback in residential electricity experiments. Since then, a number of larger studies have recently emerged that use comparative feedback or “social norms” to motivate household conservation (see for example, Alcott, 2011). In Table 1, we see that these comparative feedback studies now represent approximately 1/5 of all entries (23.7% of the observations and 20% of papers). Real-time feedback is still relatively rare and was used in only 22% of studies, for 12.2% of observations. Other incentives tested include strategies such as energy savings tips (72.4% of observations and 63.1% of papers) and audits and consulting (8.3% of observations and 6.2% of papers).

Price information and incentives are also directly tested. From Table 1, we see that monetary savings information represent 30.1%

Table 1
Descriptive statistics.

Study characteristic	Field observations	Mean	Std. Dev	Min	Max	Percent of Observations (%)	Percent of Papers (%)	Weighted average treatment effect (%)
Dependent variable								
Effect size (Percent)	156	-7.441	10.02	-55.00	18.80			-7.4%
Independent variables								
Individual usage feedback	156	0.7564	0.43	0	1	75.6	76.9	-8.5
Energy saving tips	156	0.7243	0.45	0	1	72.4	63.1	-9.6
Real time feedback	156	0.1217	0.33	0	1	12.2	22.0	-11.0
Audits and consulting	156	0.0833	0.28	0	1	8.3	6.2	-13.5
Monetary savings Info	156	0.3012	0.46	0	1	30.1	26.2	-7.7
Monetary incentives	156	0.2179	0.22	0	1	21.8	27.7	-5.7
Social comparisons	156	0.2371	0.42	0	1	23.7	20.0	-11.5
Study level controls								
Control group	156	0.7115	0.45	0	1	71.1	61.5	
Weather	156	0.3141	0.46	0	1	31.4	24.6	
Demographics	156	0.1795	0.38	0	1	17.9	15.4	
Treatment duration (months)	156	7.6872	12.53	0.3	60	100	100	

Table 2
Correlations.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) Effect size (Percent)	1.00											
(2) Energy savings tips	0.00	1.00										
(3) Audits and consulting	-0.10	0.13	1.00									
(4) Monetary savings info	0.16*	0.00	-0.05	1.00								
(5) Monetary incentives	0.12	-0.09	0.01	-0.08	1.00							
(6) Individual usage feedback	0.12	-0.08	-0.05	0.34*	0.08	1.00						
(7) Social comparison feedback	0.12	0.11	-0.17*	0.46*	-0.26*	0.32*	1.00					
(8) Real time feedback	-0.07	-0.38*	-0.11	-0.03	-0.01	0.21*	0.07	1.00				
(9) Control group	-0.09	-0.20*	-0.12	0.05	-0.32*	-0.26*	0.09	0.02	1.00			
(10) Weather control	0.12	0.05	-0.15*	0.31*	0.11	0.13	0.3*	-0.13	-0.03	1.00		
(11) Demographic control	0.22*	0.06	-0.14	0.42*	-0.04	0.23*	0.49*	-0.02	0.15	0.55*	1.00	
(12) Treatment duration	0.18*	-0.12	0.24*	0.28*	0.29*	0.03	-0.05	0.00	-0.18*	-0.08	0.04	1.00

$n = 156$ field observations.

* $p < 0.05$.

Table 3
Summary of treatment effects.

Description	Field observations	Mean (%)	St. Dev.	Min	Max
All experimental studies 1975–2012 (unweighted)	156	-7.441	10.0	-55.00	18.50
High quality studies with statistical controls (weather, demographics, and control group)	22	-1.992	1.05	-5.00	5.50
Lower quality studies without statistical controls (weather, demographics or control group)	75	-9.565	12.1	-55.00	8.18

of observations and 26.2% of papers; monetary incentives (rebates, cash rewards and tiered pricing) represent 21.8% of observations and 27.7% of papers. These publications generally fall into one of two categories: (1) small-scale behavioral field experiments, typically psychology, building science or engineering, or (2) utility-scale conservation pilot projects, typically economics and related fields. Our sample also distinguishes between monetary incentives and monetary savings information, as we see no significant correlation between these two strategies in Table 2.

4.2. Average treatment effect

Across all studies (Table 3), we find the weighted average treatment effect to be -7.40%. In other words, a typical behavioral study, on average, will produce more than 7% savings potential, although the range can span significantly from -55% to +18.5%, depending on the study. These numbers are the most comprehensive field experimental figures to date. Interestingly, the average treatment effect differs between more and less methodologically rigorous studies. A savings effect of 1.99% is found for high quality studies that include statistical controls such as weather, demographics, and – most importantly – a control group. In contrast, lower quality studies without such statistical controls find a savings effect of 9.57%. This suggests that savings effects may be overestimated in some of these studies.

We also calculated weighted average treatment effects for each type of treatment (Table 1). On average, field studies using energy audits saw the highest average energy savings, at 13.5%, followed by social comparisons, at 11.5% savings.

Fig. 1 shows a funnel plot of the primary study treatment effect against a measure of sample size. While a large number of effect size observations are negative, implying energy savings, there is also a considerable number of non-negative experimental effect sizes reported. In Fig. 1, we see a high degree of symmetry (no major truncation about the vertical axis) in our group of studies, which suggests that publication bias is likely not a significant issue in this literature. More generally, we observe strong evidence for heterogeneous responses to behavioral treatments, consistent with prior literature (see Costa and Kahn, 2010; Freedman, 2006).

In Fig. 2, we plot the reported experimental effect sizes by publication year. Fig. 2 shows little convergence across effect size over the years, suggesting that the field has not converged on optimal strategies.

4.3. Outcomes of different strategies

Table 4 summarizes the results of the meta-regression model for the different classes of behavioral strategies. In Model 1, we include controls relating to study design. These include Control Group, Weather, Demographics, and Treatment Duration. All of these, except for weather, are significant across specifications. For studies with dedicated control groups, we find a negative bias ranging between 1 and 2% in specifications 1–5. This negative control group bias suggests that higher quality studies with control groups in the study design are more likely to report treatment effects as energy savings. We find that studies without demographic controls over-estimate energy savings between 5.8 and 7.3%. This result is consistent with the view that demographic characteristics are important statistical controls to include with randomly sampled experimental populations. In terms of treatment duration, for each additional month of treatment, there is a small, but significant increase in energy usage in both the simple and full models in Table 4.

This finding indicates that the effect of information programs may be subject to attrition over time, and the dynamic effects of repeated interventions over time merits further investigation. Close to 60% of the field studies in our sample lasted for three months or less, suggesting that studies of longer duration are needed to understand *durability* of treatment effects during experimental periods, and *persistence*, whether information effects disappear over time.

In Model 2, we test the effects of informational feedback: individual feedback about past usage and real-time feedback, controlling for various study level characteristics. Both types of feedback are significant. Interestingly, energy usage increased relative to the control group for studies employing individual feedback strategies. By contrast, conditional on providing

Table 4
Meta-regression results.

Study characteristic	(1) Controls only	(2) Individual feedback	(3) Conservation strategies	(4) Monetary information	(5) Comparative feedback	(6) Full model
Experimental treatment						
Energy use feedback						
Individual usage feedback		1.858** (0.796)			2.384*** (0.787)	1.346 (1.000)
Real-time feedback		-2.849*** (0.555)			-2.197*** (0.743)	-1.175 (1.205)
Conservation strategies						
Energy saving tips			1.695** (0.781)			1.547 (1.109)
Audits and consulting			-5.124*** (1.364)			-5.678*** (1.609)
Monetary information						
Monetary savings				2.225*** (0.521)		-0.067 (0.991)
Monetary incentives				2.189*** (0.435)		2.174** (1.028)
Peer consumption feedback						
					0.262 (0.940)	0.617 (1.374)
Study-level controls						
Control group	-1.950*** (0.735)	-2.028** (0.827)	-1.369* (0.792)	-1.340*** (0.460)	-1.227* (0.735)	-0.034 (1.144)
Weather controls	-0.125 (0.668)	-0.756 (0.683)	-1.008 (0.700)	-0.900* (0.471)	-0.882 (0.653)	-2.025*** (0.728)
Demographic controls	7.306*** (0.662)	7.294*** (0.804)	6.766*** (0.717)	6.633*** (0.484)	6.207*** (1.056)	5.833*** (1.236)
Treatment duration	0.059** (0.029)	0.023 (0.032)	0.149*** (0.031)	0.011 (0.019)	0.016 (0.035)	0.120*** (0.044)
Constant	-8.130*** (0.718)	-8.531*** (1.142)	-9.596*** (1.115)	-9.007*** (0.188)	-9.191*** (1.024)	-10.899*** (2.094)
Number of observations	156	156	156	156	156	156
Number of publications	58	58	58	58	58	58
Wald chi-square	199.6	759.6	177.0	1446	276.5	146.5

Estimation by generalized least squares (GLS) with inverse square root of the sample size as analytical weights. Standard errors in parentheses.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

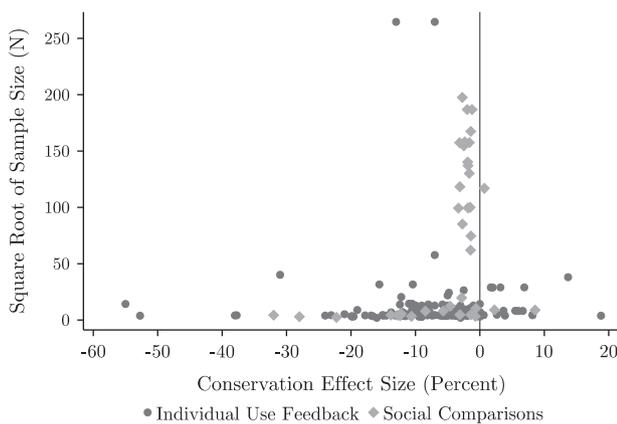


Fig. 1. Funnel plot of conservation effect size vs sample size.

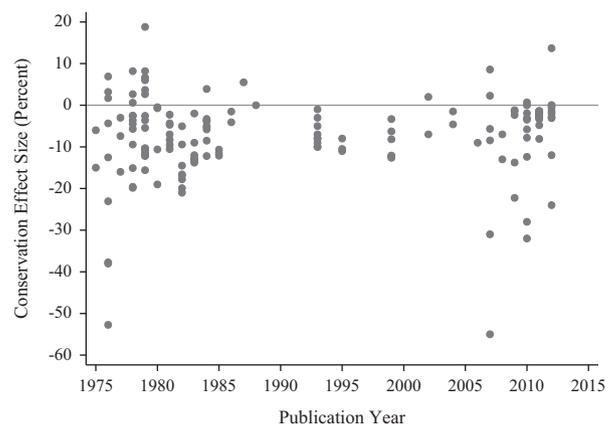


Fig. 2. Effect size by publication year.

information, real-time feedback drives significant energy savings. However, in combination with all other interventions, the effects of feedback are no longer significant in the full specification (Model 6), which combines statistical evidence with other interventions. This is an interesting finding, because it suggests that informational feedback alone (e.g., for example, via smart metering) may be a necessary but not a sufficient condition to produce conservation.

In Model 3, we test information strategies further by examining the effect of ‘Energy Saving Tips’ a relatively low involvement

strategy and ‘Audits and Consulting,’ a relatively high involvement strategy. Controlling for additional study characteristics, we see that these education strategies are both significant in specification 3, but work in opposing directions. These results demonstrate the powerful role of information in motivating energy conservation and provide insight into whether experiments can stimulate learning effects to encourage conservation. As it turns out, low involvement information-based strategies, i.e. energy saving tips, are not effective at reducing energy use, while high involvement information strategies, i. e. home energy audits and consulting, do support our hypothesis that

non-price, information strategies can lead to favorable energy use reductions. While most energy savings tips are provided either in billing or website data, these results suggest that simply providing energy saving tips does not sufficiently motivate subjects to conserve.

For the pecuniary strategies (Model 4), we find 'Monetary Savings Information' or in other words, providing information about potential cost savings, to be significant predictors of energy use behavior, although the effect is opposite to what is predicted by theory. Controlling for major study characteristics, monetary savings information alone did not induce conservation outcomes among study participants but in fact increased usage. However, the significant effect vanishes in the full model (Model 6). Similarly, 'Monetary Incentives' in energy feedback studies, which include rebates, tiered pricing and/or cash rewards is consistently positive and significant in Model 4 and in the full model (Model 6) which includes monetary savings in addition to other experimental treatments. There are several plausible explanations for this empirical finding. One reason for an increase in consumption in response to savings information is that people might simply ignore the potential savings, or that the actual savings might be too small to be meaningful especially given the low price elasticity of electricity use in the short term (Lijesen, 2007; Reiss and White, 2008) and the small contribution of electricity cost to household expenses.

We also test the effect of comparative or normative feedback strategies in Model 5. Although studies using comparative feedback had the second highest average treatment effect of all strategies (Table 1), the variable is not significant in the full specification. Note, however, that our analysis places analytical weights on experimental studies with larger study sample sizes (weighted by square root of the sample size). As Fig. 2 demonstrates, there is a difference in sampling distribution between studies that use individual feedback and those that use comparative feedback. With very few exceptions, studies using social comparisons have smaller sample sizes. This suggests that further, larger scale studies using comparative feedback are needed to evaluate behavioral effects at scale.

5. Discussion

Our study presents the first quantitative comparison of different information strategies used in studies targeted at energy conservation. At most, individual field experiments reported in the literature compare up to three of the six different strategies evaluated in this article. Our meta-analysis allows for a more expansive comparison, because it accounts for differences in strategies across many field experiments. We test some specific predictions about the effectiveness of information with and without financial incentives finding that neither the low-level information strategies (energy saving tips), nor the two feedback strategies (individual usage feedback; comparative feedback) lead to additional energy savings. It is only when information is given in real-time (real time feedback) or includes higher involvement interventions (e.g., home energy audits) that energy conservation is triggered over the span of monitored experimental periods.

In addition, study participants actually increased their energy usage when provided information on monetary savings or monetary incentives (payments or rate changes). One potential explanation for these increases is the so-called "licensing effect" where participants may learn that their expenditures and/or potential savings are small, and they may feel entitled to benefits from energy use because they are paying for it. Overall, the strong focus of current policies on providing additional pricing information is not necessarily warranted based on our study. Rather, it indicates that non-price triggers for behavior change also merit consideration when building future conservation programs.

Although much prior research on energy conservation behavior has focused on pecuniary aspects, one limitation of this approach is that financial benefits from saving energy are often quite small (Wolak, 2011). The average monthly residential electricity bill is \$110 (EIA, 2010), so saving 5% energy translates to little more than \$5 saved per month. This provides little incentive to conservation behavior given the potential impact on comfort or convenience. Furthermore, a rational actor model of electricity use behaviors, where individuals are utility maximizing and are primarily motivated by self-interest, neglects the pro-social behaviors that people often engage in (Penner et al. (2005), Verplanken and Holland (2002)). Providing financial incentives may crowd out such prosocial motivation (Bénabou and Tirole, 2005) and this could in fact explain the observed increase energy usage in over thirty years of experimental field studies dating back to the 1970s. Bowles (2008) describes several conditions under which explicit financial incentives may be counterproductive, because self-interest and prosocial motives are not separable, but interact. According to him when incentives were framed as a transaction in terms of a market exchange, they "all but extinguished the subjects' ethical predispositions," without succeeding to "enforce the social optimum." Incentives may also evoke control aversion in individuals, who react exactly opposite to the incentives' intent (see also: reactance theory, Brehm, 1966). Overall, psychological perspectives on incentives predict that financial incentives are effective only under specific circumstances, and sometimes can be counterproductive.

Comparative feedback in the form of norms did not prove to be a significant driver of conservation behavior. As we indicated, one possibility for this finding might be the smaller size of the majority of the studies using this information strategy. Another possibility might be the delivery of the comparative feedback. For example, it is possible that comparative feedback is more effective when delivered in real time but no study in our sample includes real time comparative feedback. Variation in the type of metrics or comparison group might also be important. For example, a recent study found that privately disclosed information about a consumer own (relative) energy use was less effective than when such information was publicly disclosed (Delmas and Lessem, 2012), allowing conservation to act as a signal of "green" virtue.

Finally, the study provides insights into methodological challenges prevalent in this field. Many of the reviewed studies suffer from methodological problems. They involve small samples (e.g., Gronhoj and Thogersen, 2011; Ueno et al., 2006), short time periods (e.g. Petersen et al. (2007)), and low level of granularity (i.e. providing overall electricity usage without appliance level information, see for example Alcott, 2011; Becker et al., 2010; Wolak, 2011). A surprisingly large number of studies do not have control groups or do not take baseline measurements prior to reporting changes in consumption. Additionally, many studies also do not account for the impacts of weather characteristics over time or demographics, jeopardizing the reliability of estimates. The estimation methods themselves could also be improved, by adopting more rigorous statistical approaches for time series analysis that can include de-seasonalizing trends in the data or employing difference-in-difference estimation. While we controlled for these methodological factors in the meta-analysis to the best of our ability, future studies in this field should pay careful attention to these aspects to contribute to building a more solid basis of experimental evidence.

Based on our finding, the minimum recommended set of controls for experimental field studies should include:

- Dedicated control group, where subjects are monitored in-situ, but receive no treatment
- Weather controls (i.e. heating and cooling degree days or hours (see Day and Karayiannis, 1998))

- Demographic and household level controls
- Randomization (or pseudo-randomization for opt-in studies)

Randomization appears to be well understood in this literature, so the fourth item is less of an issue in the experimental literature. However, the set of all controls above is non-obvious and forms the basis of methodological issues uncovered in this review, as very few studies incorporate all of the above elements in the experimental research design.

The present study is limited in several regards. As mentioned above, the methodological shortcomings of the included case studies cast some doubt on the reliability of the reported effect sizes. A second limitation of this study is that strategies can differ in additional characteristics that are not tested in this study. For example, conservation strategies may have different levels of intensity. Participating in an energy audit requires greater involvement and time commitment than reading a tip sheet on how to conserve electricity. Studies also differ in the tailoring of the information given. Strategies can be generic (e.g., generalized energy savings tips) or tailored to the participant (e.g., appliance-specific energy-use feedback). For example, audits are custom-tailored to the particular needs of the participant. Finally, the comparison of individual information strategies suffers from confounding effects. There are very few studies that apply only one strategy per experimental group, making it difficult to identify the additional variability explained by a single strategy.

6. Conclusion

In this article, we provide a comparison of the quantitative evidence on behavioral strategies targeting energy usage across various literatures in behavioral psychology, economics and related fields. This study represents the most comprehensive review of experimental energy conservation studies to date. We find an overall treatment effect of 7.4% energy conservation across all experimental studies. Based on these results, we conclude that despite heterogeneous treatment effects, non-monetary, information-based strategies can be effective at reducing overall energy usage in controlled experimental studies. This is an important finding, because it suggests that information and education programs targeting conservation through behavioral change should be considered alongside with efforts to reduce energy consumption through technological improvements. As the advent of new technologies such as smart meters reduces the cost of feedback and increases the quality and reliability of information provided, policy makers would be well-served to shift some means to these high-impact, relatively low-cost information programs, which can result in real savings.

While this meta-analysis suggests that information strategies induce energy conservation, it is less clear which strategies work best, in part because many experiments simultaneously use more than one strategy leading to confounding issues and also because of the lack of methodological sophistication of some of the studies. To better identify the winning strategies, additional experiments are needed. Such experiments should learn from the previous literature by following a few guiding principles with regard to the methodological rigor. Sound experiments in energy conservation should use dedicated control groups, take sufficient baseline measurements and control for weather and demographic characteristics. It is also advisable to isolate individual strategies to assess their added value. The field could also benefit from studies of longer duration and larger sample size. With the continuing deployment of smart meters across the world, there are new and exciting opportunities to test information-based strategies for energy conservation. Providing information to encourage energy

savings has enormous potential, but it is critical to carry out this research in a methodologically rigorous.

Acknowledgment

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Appendix A1

List of papers included in meta-analysis.

Aigner, Lillard	1984	Journal of Business and Economic Statistics, 2(1) 21–39
Alahmad, Wheeler, et al.	2012	IEEE Transactions on Industrial Electronics, 59(4) 2002–2013
Alcott	2011	Journal of Public Economics, 95, 1082–1095
Ayres, Raseman, Shih	2009	NBER Working Paper No. 15386 Sep 2009
Battalio, Kagel, et al.	1979	The Review of Economics and Statistics 61(2), 180–189
Becker	1978	Journal of Applied Psychology, 63 (4), 428–433
Becker, Cumming, et al.	2010	Journal of Applied Behavior Analysis, 43 (2), 327–331
Bittle, Valesano, et al.	1979	Behavior Modification, 3(2), 187–202
Bittle, Valesano, Thaler	1980	Journal of Applied Social Psychology, 10(1), 20–31
Brandon, Lewis	1999	Journal of Environmental Psychology, 19, 75–85
Costa, Kahn	2010	NBER Working Paper No. 15939 May 2010
Craig, McCann	1978	Journal of Consumer Research, 5 (2), 82–88
Geelen, Keyson, Boess, Brezet	2012	Journal of Design Research, 10(1/2), 102–120
Gleerup, Larsen et al.	2010	The Energy Journal 31 (3) 113–132
Gonzales, Aronson, Costanzo	1988	Journal of Applied Social Psychology 18(12) 1049–1066
Gronhoj, Thogersen	2011	International Journal of Consumer Studies 35, 138–145
Gustafsson, Bang	2009	Computers in Entertainment, 7(4), 2009
Hayes, Cone	1981	Journal of Applied Behavior Analysis, 14, 81–88
Hayes, Cone	1977	Journal of Applied Behavior Analysis, 10(3) 425–435
Hutton, Mauser, et al.	1986	Journal of Consumer Research, 13, 327–336
Kantola, Syme, et al.	1984	Journal of Applied Psychology 69 (3), 416–421
Katzev, Johnson	1983	Journal of Economic Psychology, 3, 267–284
Katzev, Johnson	1984	Journal of Applied Social Psychology 14, 12–27
Katzev, Cooper, Fisher	1980	Journal of Environmental Systems, 10(3), 215–227

Kua, Wong 2012 Energy Policy 47, 49–56
 Lifson, Miedema 1980 Energy 6, 403–408
 Matsukawa 2004 The Energy Journal, 25 (1) 1–17
 McClelland, Belsten 1979 Journal of Environmental Systems, 9(1), 29–38
 McMakin, Malone, et al. 2002 Environment and Behavior, 34(6), 848–863
 Midden, Meter, Weenig, Zieverink 1983 Journal of Economic Psychology, 3 (1) 65–86
 Nielsen 1993 Energy Policy 21(11), 1133–1144
 Ouyang, Hokao 2009 Energy and Buildings, 41(7) 711–720
 Pallak and Cummings 1976 Personality and Social Psychology Bulletin, 2(1) 27–30
 Palmer, Lloyd, Lloyd 1977 Journal of Applied Behavior Analysis, 10(4) 665–671
 Peschiera, Taylor 2012 Energy and Buildings 49, 584–590
 Peschiera, Taylor, Siegel 2010 Energy and Buildings, 42(8) 1329–1336
 Petersen, Shunturov, et.al. 2007 Intl. Journal of Sustainability in Higher Education 8(1) 16–33
 Reiss, White 2008 RAND Journal of Economics, 39(3), 636–663
 Schultz, Nolan, et al. 2007 Psychological Science 18(5), 429
 Seligman, Darley 1977 Journal of Applied Psychology, 62 (4), 363–368
 Seligman, Darley, Becker 1978 Energy and Buildings 1(3), 325–337
 Sexton, Brown Johnson et al. 1987 Journal of Consumer Research, 14, 55–62
 Slavin, Wodarski, Blackburn 1981 Journal of Applied Behavior Analysis, 14(3), 357–363
 Staats, Harland, et al. 2004 Environment and Behavior, 36(3), 341–367
 Torriti 2012 Energy 44, 576–583
 Ueno, Sano et al. 2006 Applied Energy 83(2), 166–183
 van Dam, Bakker, van Hal 2010 Building Research and Information, 38(5) 458–469
 Vassileva, Odlare, Wallin, Dahlquist 2012 Applied Energy 93, 572–582
 Wenders, Taylor 1976 Bell Journal of Economics 7(2) 531–552
 Wilhite and Ling 1995 Energy and Buildings 22(2), 145–155
 Winett, Hatcher, et al. 1982 Journal of Applied Behavior Analysis 15(3), 381
 Winett, Kagel, et al. 1978 Journal of Applied Psychology, 63 (1), 73–80
 Winett, Leckliter, et al. 1985 Journal of Applied Behavior Analysis, 18, 33–44
 Winett, Love, Kidd 1982 Journal of Environmental Systems, 12(1), 61–70
 Winett, Neale, et al. 1979 Journal of Applied Behavior Analysis, 12(2), 173–184
 Winett, Nietzel 1975 American Journal of Community Psychology, (3)2 123–133

Behavior Modification
 Bell Journal of Economics
 Building Research and Information
 Computers in Entertainment Energy
 Energy and Buildings
 Energy Policy
 Environment and Behavior
 IEEE Transactions on Industrial Electronics
 International Journal of Consumer Studies
 International Journal of Sustainability in Higher Education
 Journal of Applied Behavior Analysis
 Journal of Applied Psychology
 Journal of Applied Social Psychology
 Journal of Business and Economic Statistics
 Journal of Consumer Research
 Journal of Design Research
 Journal of Economic Psychology
 Journal of Environmental Psychology
 Journal of Environmental Systems
 Journal of Public Economics
 NBER Working Paper
 Personality and Social Psychology Bulletin
 Psychological Science
 RAND Journal of Economics
 Resource and Energy Economics
 The Energy Journal
 The Review of Economics and Statistics

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Appendix A2

List of journals included in the meta-analysis.

American Journal of Community Psychology
 Applied Energy

- Day, A.R., Karayiannis, T.G., 1998. Degree-days: comparison of calculation methods. *Building Services Engineering Research and Technology* 19 (7), 7–13.
- Delmas, M.A., Montes, M., Shimshack, J., 2010. Mandatory information disclosure policy: evidence from the electric utility industry. *Economic Inquiry* 48 (2), 483–492.
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