Front. Eng. Manag. 2023, 10(3): 540–545
https://doi.org/10.1007/s42524-023-0264-2

COMMENTS

Boqiang LIN, Huanyu JIA

Nudging sustainable consumption of residential energy use: A behavioral economics perspective

1 Introduction

How to achieve economic development while minimizing the negative impact on the environment is the challenge faced by policy makers. *CO_2 emissions in 2022*, released by the International Energy Agency in March 2023, showed that global energy-related CO_2 emissions increased by 0.9% or 321 million tons to a record high of over 36.8 billion tons in 2022. Carbon emissions from the residential sector in developed countries account for 40%–50% of total domestic emissions. Emerging and developing countries such as China, Brazil, and India, account for 60% of global final energy demand currently and are expected to increase that share by 5% by 2030. As these countries experience economic growth and rising living standards, the energy consumption and carbon emissions of their residential sector will continue to climb. Thus, nudging sustainable consumption of residential energy use is crucial and urgent.

Energy efficiency improvements are one of the most rapid, cost-effective means of reducing carbon emissions. Governments worldwide have placed much effort into enhancing energy efficiency, and progress has been made. In the UK, for example, total residential energy consumption fell by 15% from 2000 to 2019 despite an increase of 500 million m^2 of building area, owing to a 29% increase in overall building energy efficiency. Nonetheless, scholars generally agree that the energy-saving effects of energy efficiency policies have not been fully realized (Allcott and Kessler, 2019). Why is this? What kind of policies should be designed to bridge the gap? Do policies that are feasible and effective for developing countries exist?

Gillingham and Palmer (2014) held that policies based on traditional economics usually rely on macro-level fiscal policies such as price controls, new energy subsidies, environmental regulations, taxes, and fees. Such policies do not pay enough attention to micro consumers and their decision-making characteristics, and they play a limited role in explaining and addressing behavioral failures. Moreover, due to the rebound effect, the energy efficiency gains from technological advances can be partially or fully offset by increased demand. Therefore, promoting behavior changes in residential energy consumption is urgently needed.

Different from standard economics, behavioral economics studies the joint influence of economic and psychological factors on human behavior, arguing that consumers exhibit limited rationality, limited willpower, limited self-interest, and conformity. These assumptions enable more realistic models, which helps better understand and predict the behavior of energy consumers.

More importantly, the existence of behavioral irrationality enables implementing nudge strategies. Behavioral economics researchers have proposed several low-cost, effective nudge strategies such as labeling energy efficiency, reshaping choice architecture, providing information feedback, and setting green default options. These strategies intervene and correct consumer behavior in a predictable manner, without compromising energy consumers' freedom of choice and without substantially altering economic incentives, thus providing a useful complement to standard economics and important references for energy efficiency policy making.

Received Mar. 25, 2023; revised May 18, 2023; accepted May 31, 2023

Boqiang LIN (✉)
School of Management, China Institute for Studies in Energy Policy, Xiamen University, Xiamen 361005, China; Innovation Laboratory for Sciences and Technologies of Energy Materials of Fujian Province (IKKEM), Xiamen 361005, China
E-mail: bqlin@xmu.edu.cn

Huanyu JIA
School of Management, China Institute for Studies in Energy Policy, Xiamen University, Xiamen 361005, China

This work was supported by the National Natural Science Foundation of China (Grant No. 72133003), and Science and Technology Projects of Innovation Laboratory for Sciences and Technologies of Energy Materials of Fujian Province (IKKEM) (Grant No. RD2020060101).

2 Sustainable consumption: Concepts and the status quo

Sustainable consumption, also known as green consumption and low-carbon consumption, broadly refers to the win–win situation of achieving improved quality of life and lower carbon emissions. Promoting sustainable consumption is an important way to balance carbon neutrality goals and economic development (Chalal et al., 2020). It not only reduces carbon emissions at the consumption end but also pushes the supply side to switch to clean, circular production, thus facilitating industrial restructuring and upgrading (Zhou et al., 2022). For energy consumers, some examples of shifts toward sustainability include purchasing more energy-efficient technologies, purchasing or producing renewable energy, reducing energy consumption overall and during specific times of high demand, and changing consumption patterns to fit the time period when low-carbon energy is generated (Wolske et al., 2020).

Many developed country governments have been aware of the importance of sustainable consumption and have taken positive action, but developing countries have paid far less attention to it. Another report, *Energy Efficiency 2022*, released by the International Energy Agency in December 2022, noted that governments in the developed world attach great importance to changes in consumer behavior, targeting "behavior change campaigns" as a critical way to lower energy demand rapidly. Since 2022, at least 10 European governments have launched campaigns aimed at changing energy behavior and raising energy saving awareness, but the efforts of developing countries in this respect are not sufficient.

This paper is motivated by the fact that academics and policy makers presently place far less emphasis on consumer behavioral preferences and nudge strategies for promoting sustainable energy consumption, which are put forward by behavior economists and might be an efficient, feasible solution, especially for developing countries. For these countries, the greatest opportunities for future energy efficiency improvements will occur. Undoubtedly, a shift in energy consumer behavior toward sustainability is imperative.

3 Insights from behavioral economics

Standard economics (i.e., neoclassical economics, traditional economics, and mainstream economics) assumes consumers are perfectly rational. The broad term "rational person" refers to a person who can rank choices and whose decisions are inherently consistent. This assumption ensures human decisions can be mathematized, and a utility function is introduced on this basis. The narrow meaning of "rational person" comes from neoclassical economics, which believes people have well-defined, stable preferences; have access to all information; have perfect information processing ability; care only about their absolute interests; can maximize expected utility and find optimal solutions; have unlimited willpower to execute plans strictly; and can accurately determine the probability of uncertain events.

In reality, the "rational person" assumption appears demanding. Consumers exhibit behaviors that deviate from these assumptions. These deviations are called behavioral anomalies (or behavioral failures). One may not always be able to determine the optimal solution. Even if the optimal solution is found, one may not necessarily select it. For example, even if one knows that turning the air conditioner to 26 degrees helps save energy, maintaining this temperature can be difficult. Moreover, even if one is aware that buying energy-efficient products leads to higher energy savings in the future, resisting the lure of cheaper non-energy-efficient products can be challenging. In addition, people are not always interest-oriented but have complex social preferences. In one-time interactions, people care about others, are willing to help others, and seek fairness, justice, honesty, and trust. People are also biased in their judgment of the probability of events, displaying gambler's bias and hot hand bias. Moreover, many behaviors cannot be explained by classical models. For example, the expected utility model, the workhorse model for studying decisions that include risk, cannot simultaneously explain why people are extremely risk averse in small-scale gambling but only moderately risk averse in large-scale gambling. The exponential discounting model, a common model for studying intertemporal decisions, cannot simultaneously account for the inconsistency between human preferences in short-term and long-term decisions, the self-control problem when people cannot execute their plans, and the fact that people care about things that may happen in the distant future.

Energy Efficiency 2022 indicates that about half of household energy expenditure is spent on housing, primarily heating, cooling, and cooking, and the other half is spent on transportation. The difference in operating costs between the most efficient and the least efficient homes or cars can often be 40%–75%. This result means heating the same area or to travel the same distance can cost some consumers two or even three times more. Improving energy efficiency is so important that governments have invested a great deal of resources and designed many policies to promote product efficiency. However, on the consumption side, the diffusion of energy-efficient products is not as fast as expected. The failure of consumers to make all investments in energy-efficient products with positive net present value is known as the "energy efficiency gap". Standard economics has difficulty explaining its existence. If consumers are considered rational, they should realize

that investing in energy-efficient products is the right choice.

Behavioral economics begins by exploring whether the "rational person" assumption is fully realistic, and studies how human psychological factors affect economic behavior and how it systematically deviates from the "rational person" assumption. In the domain of energy choices, researchers have explored the questions of "which aspects energy consumers show limited rationality", "why energy consumers behave irrationally", and "how irrational behavior leads to energy efficiency gaps and energy waste" (Gillingham and Palmer, 2014; Gillingham et al., 2018). Specifically, the presence of behavioral regularities such as heuristics, present bias, loss aversion, and status quo bias may lead to higher observed energy consumption than the level that would satisfy consumer utility maximization.

(1) Suboptimal decision heuristics. The cognitive ability of energy consumers is limited. Sometimes they are unable to conduct a comprehensive, objective cost–benefit analysis, and they simplify decisions, which triggers suboptimal decisions. Heuristic thinking describes the phenomenon of people simplifying decisions with the help of heuristics. When faced with complex quantitative relationships, people use the linearity heuristic, which treats the relationship between variables as linear. For example, when vehicle fuel efficiency is expressed in miles per gallon, a linear relationship between fuel consumption and fuel efficiency is often incorrectly assumed, thereby underestimating the energy savings and emission reductions when retiring less fuel efficient vehicles (Larrick and Soll, 2008). Consumers also depend on the salience of information to accelerate their decisions while ignoring other less salient but equally important factors of products considered, exhibiting salience bias. This tendency often leads consumers to ignore the energy efficiency attributes of products. The availability heuristic is also often used. People may overestimate the energy consumption of large appliances frequently operated and easily thought of in daily life and underestimate the energy consumption of appliances that are not frequently operated, leading to biases in their energy consumption judgments. The affect heuristic and trust heuristic can influence investment behavior in home energy technologies or products as well. People may opt to invest in new energy, and engage in insulation and energy retrofit projects out of trust in institutions or government (Stern, 1992). Consumer preferences are also shaped by the way decision options are described and presented, showing a framing effect. Consumers are willing to buy "fuel efficient" vehicles but not "good fuel economy" vehicles (Turrentine and Kurani, 2007).

(2) Loss aversion. Energy consumers are also characterized by limited willpower. People sometimes make choices that do not meet long-term interests. Consumers are reluctant to adopt new energy technologies and time-of-use tariff policies despite knowing that they may bring higher energy cost savings. These phenomena are explained well by prospect theory proposed by behavioral economists. This theory suggests people do not care about their absolute gains but compare their gains with a reference point. People feel losses relative to a reference point are more relevant than gains. For example, when deciding whether to purchase a more fuel-efficient vehicle, consumers are likely to be uncertain about future fuel prices, actual energy efficiency improvements, and how much they drive their car. In such case, loss averse consumers are more reluctant to take on potential losses than they are to gain the benefits (Greene et al., 2009). For the adoption of time-of-use tariffs, loss averse individuals are more concerned about the increased cost of energy use due to their inability to avoid peak periods than they are about the energy savings gained from usage during low-carbon energy generation periods. Loss aversion leads to status quo bias that discourages consumers from making changes to the status quo, even when the costs of doing so are low and the benefits are likely to be realized. Loss aversion is a stable psychological mechanism that permeates all aspects of people's behavior, creating excessive risk aversion and reluctance to trade when a loss is possible.

(3) Present bias. When people make intertemporal decisions, they may overstate the present utility, a phenomenon known as present bias (also known as time-inconsistent preferences, or self-control problems). This phenomenon causes people to become more impatient when making intertemporal choices involving the present and to irrationally overspend, under-save, procrastinate, and fail to stick to their plans. Sophisticated decision makers can recognize the problem through past experience and develop the need for self-restraint, seeking self-limiting mechanisms to mitigate problems. This behavior explains why some products traditionally seen as restricting the flexibility of consumer choice, such as self-limiting savings products, attract some market demand. The existence of present bias can cause consumers to fail to pay high upfront costs for future energy savings when investing in energy efficiency and presents an implicit discount rate far higher than the current interest rate. Present bias leads to an underestimation of the net present value of energy-saving products and hinders their promotion.

(4) Social interaction. In addition to consumers' own psychological factors that can lead to behavioral anomalies, the influence of reference groups on individual preferences cannot be ignored. Social interaction describes the conformity of individual behavior to the group. Social norms known as the "majority choice (descriptive norms) or majority-approved choice (injunctive norms)" produce a peer effect, where individuals exhibit conformity behavior when they feel group pressure to maintain interpersonal relationships and gain a sense of identity (Schultz et al., 2007). Peer effects are a sufficiently

important factor in the diffusion of new energy technologies to influence decision making and often outweigh other factors such as income or education level. Empirical researchers have found that social interactions can promote public low-carbon behavior, the investment in solar photovoltaic systems, and home energy retrofit measures (Wolske et al., 2020).

4 Nudging people's energy use towards sustainability: Current strategies

Most traditional policies are based on the "rational person" assumption, and generally not much need exists for policy intervention because the market corrects the bias in individual decisions. Consumers' own experience over time also reduces biases. Policy interventions require considerable costs to change people's behavior. In practice, however, consumers do not have many opportunities to learn about many important decisions, such as the purchase of expensive household appliances and cars. Despite opportunities to correct bias through learning, consequences may occur when they first make a biased decision. At the same time, new entrants to the market are constant, and consumers' irrational behavior deserves equal attention.

Behavioral economists hold that because people in reality do not behave perfectly, changing the choice architecture may lead to different decisions. Intervention is needed in certain situations. Gillingham et al. (2018) considered that if behavioral failures lead to systematic biases in energy efficiency decisions, then they clearly lead to energy efficiency gaps and incentivize policies to play a role in correcting the biases. Thaler and Sunstein (2009) further proposed nudge theory, which proposes people are enabled to make better choices by intervening transparently in the decision environment while ensuring freedom of choice. Nudging is often known for its low cost, high efficiency, invisibility, and strong operability. It does not affect the decisions of rational people, gives people freedom of choice, and helps those with behavioral biases to improve their decisions. Therefore, it is also called behaviorally informed policy and libertarian paternalism. Gillingham et al. (2018) believed nudge programs are often the most cost effective.

Exploiting behavioral biases, Western scholars have designed a series of nudge strategies that intervene in the energy decision-making environment to improve household energy efficiency, and they have empirically evaluated the actual effects of certain programs. A fairly consistent finding is that these policies are effective in bridging the energy efficiency gap and fostering sustainable consumption.

Considering the behavioral characteristics of energy consumers using heuristics to simplify decision making, researchers have found that introducing energy labels, increasing the salience of energy efficiency information, and vividly expressing product energy consumption information in the form of figures and illustrations can effectively raise consumers' attention to energy efficiency information and promote decision changes. If the energy savings of different energy efficiency levels are conspicuously identified, the implicit discounting rate can be substantially reduced (Min et al., 2014; Newell and Siikamäki, 2015). The in-home-display, which shows electricity consumption in real time, has a remarkable effect on reducing energy consumption by increasing the salience (Jessoe and Rapson, 2014). Translating vehicle fuel economy information into fuel costs and carbon emissions also helps mitigate the lack of salience of energy efficiency attributes (Johnson et al., 2012). In addition, consumers exhibit an anchoring effect by agreeing to the default option rather than making changes due to status quo bias and simplistic decision-making tendencies. Setting the choice of green electricity and installing smart meters as default options are also highly effective interventions (Pichert and Katsikopoulos, 2008; Ölander and Thøgersen, 2014). Gonzales et al. (1988) applied loss aversion and framing effects and found that describing information in terms of losses better motivates consumers' loss aversion and promotes home energy efficiency retrofits. Making social norms visible through the mailing of electricity bills (or gas consumption bills) of reference groups is also an effective way to intervene in energy use behavior and make households conscious of energy savings (Allcott, 2011). New energy technologies with visibility and salience in the community, such as solar water heaters, rooftop photovoltaic equipment, new energy vehicles, and clean cooking appliances, can create a proliferating, leading effect through the peer effect (Miller and Mobarak, 2015; Rode and Weber, 2016; Pettifor et al., 2017).

5 Conclusions and directions for future research

Shifting energy consumption patterns toward sustainability is an issue of widespread concern. Within the academia, an increasingly prominent focus of energy research is on understanding consumers' energy choices and developing intervention strategies to induce a switch to more sustainable ways of consumption in the future (Wolske et al., 2020).

However, scholars and governments in developing countries have primarily concentrated their attention on macro fiscal policies and energy conservation propaganda, ignoring the irrational behavioral characteristics of consumers and resulting in the limited effect of current energy-saving policies.

Behavioral Anomalies			
Bounded Rationality		**Bounded Willpower**	**Bounded Self-interest**
Suboptimal decision heuristics	Loss aversion	Present bias	Peer effect
Salience bias	Reference-dependent preferences	Time-inconsistent preferences	Descriptive norms
Framing effect, Default effect	Status-quo bias	Self-control problem	Injunctive norms
Nudge Strategies			
Increasing the salience of energy efficiency information; Setting green default	Describing information in terms of losses; Setting deadlines for incentives	Providing low-interest loans for energy efficiency retrofits; Emphasizing present benefit	Making social norms visible through the mailing of electricity bills; Increasing the salience of new energy technologies

Fig. 1 Summary of behavior anomalies and nudge strategies for future research.

As a strategy to promote changes in people's energy-related behavioral decisions, nudging based on behavioral economics plays a positive role in Western countries. Notwithstanding, whether behavioral anomalies exist in developing countries and the effectiveness of nudge strategies in driving consumers' energy choices toward sustainability are largely unknown. Related studies are scarce, and these gaps need to be filled by future research.

Finally, some specific research directions are suggested, which is shown in Fig. 1. In the case of Chinese consumers living in collectivist cultural contexts, the behavior of others may easily influence their own. Peer effect is likely substantial, which means the effect of public policy to save energy or drive green consumption can be amplified if reasonably utilized. Moreover, some widely adopted nudge strategy in the West such as providing timely information feedback (e.g., real-time household energy bills and comparisons with neighbors), setting green default (e.g., default use of green electricity and installation of smart meters), and leveraging framing effect (e.g., to boost time-of-use tariff adoption), have not been noticed by researchers. Furthermore, perceived behavior control, which refers to a person's belief toward access to necessary opportunities or resources to perform a certain behavior, is likely to influence people's energy-related decisions and has not been given much attention by behavior economics studies.

Competing Interests The authors declare that they have no competing interests.

References

Allcott H (2011). Social norms and energy conservation. Journal of Public Economics, 95(9–10): 1082–1095

Allcott H, Kessler J B (2019). The welfare effects of nudges: A case study of energy use social comparisons. American Economic Journal. Applied Economics, 11(1): 236–276

Chalal M L, Medjdoub B, Bezai N, Shrahily R (2020). Big data to support sustainable urban energy planning: The EvoEnergy project. Frontiers of Engineering Management, 7(2): 287–300

Gillingham K, Keyes A, Palmer K (2018). Advances in evaluating energy efficiency policies and programs. Annual Review of Resource Economics, 10(1): 511–532

Gillingham K, Palmer K (2014). Bridging the energy efficiency gap: Policy insights from economic theory and empirical evidence. Review of Environmental Economics and Policy, 8(1): 18–38

Gonzales M H, Aronson E, Costanzo M A (1988). Using social cognition and persuasion to promote energy conservation: A quasi, experiment 1. Journal of Applied Social Psychology, 18(12): 1049–1066

Greene D L, German J, Delucchi M A (2009). Fuel economy: The case for market failure. In: Cannon J, Sperling D, eds. Reducing Climate Impacts in the Transportation Sector. Dordrecht: Springer, 181–205

Jessoe K, Rapson D (2014). Knowledge is (less) power: Experimental evidence from residential energy use. American Economic Review, 104(4): 1417–1438

Johnson E J, Shu S B, Dellaert B G, Fox C, Goldstein D G, Häubl G, Larrick R P, Payne J W, Peters E, Schkade D, Wansink B, Weber E U (2012). Beyond nudges: Tools of a choice architecture. Marketing Letters, 23(2): 487–504

Larrick R P, Soll J B (2008). The MPG illusion. Science, 320(5883): 1593–1594

Miller G, Mobarak A M (2015). Learning about new technologies through social networks: Experimental evidence on nontraditional stoves in Bangladesh. Marketing Science, 34(4): 480–499

Min J, Azevedo I L, Michalek J, de Bruin W B (2014). Labeling energy cost on light bulbs lowers implicit discount rates. Ecological Economics, 97: 42–50

Newell R G, Siikamäki J (2015). Individual time preferences and energy efficiency. American Economic Review, 105(5): 196–200

Ölander F, Thøgersen J (2014). Informing versus nudging in environmental policy. Journal of Consumer Policy, 37(3): 341–356

Pettifor H, Wilson C, Axsen J, Abrahamse W, Anable J (2017). Social influence in the global diffusion of alternative fuel vehicles: A meta-analysis. Journal of Transport Geography, 62: 247–261

Pichert D, Katsikopoulos K V (2008). Green defaults: Information presentation and pro-environmental behaviour. Journal of Environmental Psychology, 28(1): 63–73

Rode J, Weber A (2016). Does localized imitation drive technology adoption? A case study on rooftop photovoltaic systems in Germany. Journal of Environmental Economics and Management,

78: 38–48

Schultz P W, Nolan J M, Cialdini R B, Goldstein N J, Griskevicius V (2007). The constructive, destructive, and reconstructive power of social norms. Psychological Science, 18(5): 429–434

Stern P C (1992). What psychology knows about energy conservation. American Psychologist, 47(10): 1224–1232

Thaler R H, Sunstein C R (2009). Nudge: Improving Decisions about Health, Wealth, and Happiness. Berkeley, CA: Penguin Publishing Group

Turrentine T S, Kurani K S (2007). Car buyers and fuel economy? Energy Policy, 35(2): 1213–1223

Wolske K S, Gillingham K T, Schultz P W (2020). Peer influence on household energy behaviours. Nature Energy, 5(3): 202–212

Zhou P, Gao S, Lv Y, Zhao G (2022). Energy transition management towards a low-carbon world. Frontiers of Engineering Management, 9(3): 499–503