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THEMATIC ESSAY

The Implicit Discount Rate, Information, and Investment in Energy-Efficient Appliances: A Review

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Abstract: The implicit discount rate (IDR) is a decisive factor in household investment decisions, and its modification could promote investment in energy-saving products. However, the discussion on households' IDR in developing countries is limited. In this regard, the current study aims to provide a detailed review of the IDR across various investment decisions, factors affecting its value, and policy instruments that can influence its value. The study finds that the IDR value tends to be considerably higher than market interest rates. Information and behavioural failures lead to a high IDR and under-investment in energy efficiency, which may be addressed through energy labels. However, the effectiveness of energy labels in addressing barriers and making energy-efficiency information visible to households depends on their visual presentation, time frame (annual or lifetime), units of measurement (physical or monetary), and the content of the information. The review has relevance for policymaking aimed at increasing the adoption of energy-efficient options that reduce household carbon footprints and, in turn, contribute towards realizing the net-zero emissions target.

Keywords: Implicit Discount Rate, Intertemporal choices, Investment Decision, Energy-efficient appliances, Information, Energy labels.

1. INTRODUCTION

The impetus to lower carbon dioxide (CO_2) emissions and limit global average temperatures to 1.5°C has prompted policymakers to implement several climate change mitigation measures at the household level, one of which is promoting energy efficiency (IEA 2019). Energy efficiency aims to lower emissions from burning fossil fuels, electricity generation, and energy

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use without compromising the welfare of society (IEA 2019). In this regard, energy-efficient appliances, in particular, offer considerable promise in reducing environmental externalities and internalities[1] (Gerarden, Newell, and Stavins 2015). However, households do not appear to adopt them to the warranted extent despite net financial benefits (Gerarden, Newell, and Stavins 2015; Bahinipati, Sirohi, and Rao 2022). This is understood as an "energy efficiency gap", i.e., the actual uptake of energy-efficient appliances falls short of the optimal level (Schleich *et al.* 2016). Several studies have been undertaken to investigate the potential causes of under-investment in energy-efficient appliances and have identified the use of a high implicit discount rate (IDR) as one of them (Hausman 1979; Train 1985; Jaffe and Stavins 1994; Gerarden, Newell, and Stavins 2015; Stadelmann 2017). IDR is used by an individual or a household to evaluate the trade-off between future energy savings and upfront costs when investing in an energy-saving appliance. Such an investment takes place when the present value of the product's total benefits calculated using an IDR outweighs the additional upfront costs of the initial investment. In this way, IDR is a robust parameter that captures the non-financial factors and other barriers to investment decisions and, in the process, captures a household's underlying preferences—for instance, risk, time preferences, and biases associated with intertemporal choices (Schleich *et al.* 2016).

Households tend to assign a high IDR to energy-efficiency investments, requiring them to offer a high rate of return on their upfront costs, hindering their adoption. This issue has been discussed on international platforms since the 1970s. Standard economic theory assumes that individuals are rational and apply a common discount rate equal to the market interest rate when deciding to invest in energy efficiency that would reduce lifetime costs—the sum of the upfront cost and present value of operating costs (Howarth and Sanstad 1995). However, empirical studies reveal a wide gap between the assumed discount rate and the IDR applied by the individual or household to arrive at the investment decision. This is referred to as a "discounting gap." A positive discounting gap leads to an energy-efficiency gap (Stadelmann 2017). A positive discounting gap renders energy-efficiency policies and programmes less effective than expected. It follows that identifying the factors that contribute to the IDR chosen by households can help in understanding how households value future energy savings while making decisions around energy efficiency. In turn, this can help in designing more effective energy policies.

[1] The internalities are the welfare losses households cause themselves by undervaluing energy costs relative to purchase prices (Allcott *et al.* 2014).

A high IDR has been attributed to several factors in the literature, including informational failure, behavioural biases, and market barriers, among others (Min *et al.* 2014; Schleich *et al.* 2016; Park, Woo, and Jin 2022; Silvi and Rosa 2021). Heinzle (2012) attributes the greatest impact to informational failures. To address this, full disclosure of pertinent information on the product using an energy label was suggested (Heinzle 2012). Several studies have examined the impact of different kinds of information on the uptake of energy-efficient appliances, such as energy consumption of the product (annual or lifetime, unitary or monetary, etc.), savings from the product, and CO_2 emissions (Newell and Siikamäki 2014; Min *et al.* 2014). However, debates on the type, format, and time frame of information that is most likely to increase the purchase of energy-efficient appliances remain inconclusive as of date. Further, the existing literature does not pay adequate attention to decisions at the level of households, particularly in the context of developing countries.

This survey reviews the literature on the IDR of household appliances in various countries to provide an understanding of households' intertemporal decisions and the factors that influence them. The survey also reports the discount rate ranges observed in different sectors featuring intertemporal choices. It also reviews the factors—external and internal barriers—affecting the IDR value. Among the factors, it focuses on the role of information provision with a specific emphasis on the roles that energy labels play in decisions involving the purchase of energy-efficient products. The final section discusses various forms of information provisions and their impacts on 'discounting processes.'

2. EMPIRICAL FINDINGS ON THE IDR RANGE

Discussions on IDRs peaked following the first oil crisis at the end of the 1970s. Hausman (1979), using a discrete choice model, discovered that households in the US use a 25% annual discount rate while evaluating the trade-off between the annual operating and initial purchase costs of air conditioners. He observed that households suffer from a telescopic vision, where they fail to measure the net worth of energy-using durables correctly. After Hausman's seminal work in 1979, a wide range of studies analysed consumers' investment decisions and attempted to estimate the IDR for refrigerators, air conditioners, and lighting and heating systems in different countries around the world, especially in the US (see Table 1).

Houston (1983), employing a choice model in his study on untried energy-saving durables, observed that households use a discount rate of 22%, presumably because of the risks and losses involved in the investment. Ruderman, Levine, and McMahon (1987) assessed that the IDR varies

Table 1. IDR Range for Household Appliances and Other Commodities

S. No.	Author	Study year	Country	Product category	Discount rate
1	Hausman (1979)	1976–1977	United States	Air conditioners	29% (mean); 5.1%–89%
3	Houston (1983)	1979	United States	Energy-saving durables	22% (mean); 10%–50%
4	Meier and Whittier (1983)	1977–1979	United States	Refrigerators	34%–58%
5	Ruderman, Levine, and McMahon (1987)	1972–1980	United States	Gas and oil central space heaters; room and central air conditioners; electric and gas water heaters; refrigerators and freezers	20%–800%
6	Verboven (1999)	1991–1994	Belgium, France, and Italy	Automobile sector	5%–13%
7	Newell and Siikamäki (2014)	–	United States	Water heaters	20% (mean)
8	Min *et al.* (2014)	–	United States	Light bulbs	100%–560%
9	Allcott and Wozny (2014)	1999–2008	United States	Passenger vehicles	15%
10	Cohen, Glachant, and Söderberg (2017)	2002–2007	United Kingdom	Refrigerators	11%
11	Wang and Daziano (2015)	2013	United States	Transportation	13.93%
12	Matsumoto and Omata (2017)	2013	Vietnam	Air conditioners	11.7%–312%
13	Damigos *et al.* (2021)	2017	Greece	Refrigerators	10%–60%
14	Lakić, Damigos, and Gubina (2021)	2017	Slovenia	Heating control	40% (mean)
15	Bansal *et al.* (2021)	2018	India	Two-wheelers	≤ 10%
16	Park, Woo, and Jin (2022)		South Korea	Energy-efficient appliances	21.80%–25.94%
17	Carrasco-Garcés *et al.* (2021)	2018	Chile	Efficient woodstoves	22%–87.9%

Source: Author's compilation

between 17% and 243% for appliances such as refrigerators, water heaters, and furnaces. Train (1985) reviewed several papers in his comprehensive literature survey and noted that the IDR for refrigerators ranges between 34% and 300%. However, recent studies by Cohen, Glachant, and Söderberg (2017) and Damigos *et al.* (2021) in the United Kingdom and Greece, respectively, estimate that refrigerators' discount rate varies from 10.5% to 60%, notably lower than the ranges mentioned above. Moreover, Park, Woo, and Jin (2022) find that IDRs vary from 21.8% to 25.9% for energy-efficient appliances in South Korea, implying an overestimation in the previous literature. According to Verboven (1999) and Cohen, Glachant, and Söderberg (2017), consumers' awareness of product efficiency, and reduced information gaps through the mandatory implementation of energy labels and other information disclosures, could lead to lower estimates of IDR.

For air conditioners, the IDR range varies from 3.2% (Goett 1984) to 312% (Matsumoto and Omata 2017). Using the conjoint analysis method, Min *et al.* (2014) estimate a discount rate of 100% to 560% for light bulbs in the US, insinuating that the discount rate for lower investment goods is significantly higher. On the other hand, Newell and Siikamäki (2014), using a multiple-price method, estimate an average IDR of 20% for water heating systems. Lakić, Damigos, and Gubina (2021) find a mean average 40% discount rate (see Table 1). Moreover, studies in the transport sector also observe a high variation in the IDR, further noting that the IDR is subject to market conditions in such sectors (Mau *et al.* 2008). In a detailed review of the transport and energy sectors, Haq and Weiss (2018) observe that the IDR ranges from a negative value[2] of –259% to a higher range of 764%.

The above text (and Table 1) demonstrates that a very high IDR is typically employed in various product categories. Aside from household appliances, studies in the transportation, automobile, and industrial sectors also observe that individuals place greater emphasis on initial investment costs than benefits (implied by the use of a high IDR). However, not many studies engage with the high IDR of energy-efficient household appliances in developing countries, which this survey addresses.

2 Negative discount rates imply that consumers invest in energy-saving technologies even when the energy savings realised may be insufficient to cover the cost of the initial purchase (Heinzle *et al.* 2012).

3. FACTORS INFLUENCING THE IDR

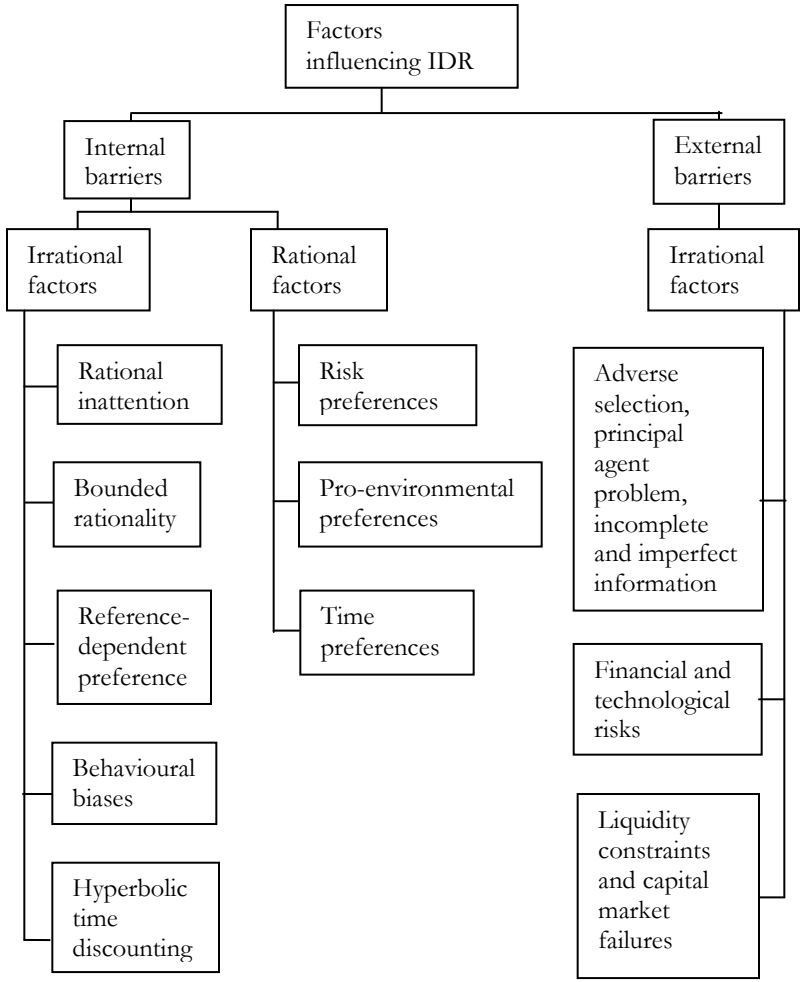
Identifying the factors that contribute to a high IDR is crucial for framing policies to steer resources towards energy-saving products with a significant impact. Towards this end, we have attempted to list all the factors from the energy-efficiency investments and behavioural economics literature that influence the purchase of energy-efficient products, with the premise that they affect IDR values. In fact, Jaffe and Stavins (1994, 806) state that "a high IDR is more of an expression of energy efficiency paradox"—whereby lesser adoption of energy-efficient products implies a higher IDR. Following the classification of Schleich *et al.* (2016) and Cattaneo (2019), we have divided the factors into two categories: (1) internal barriers and (2) external barriers. Figure 1 presents factors that belong to these two barriers. It also introduces an additional category of factors that influence the IDR, namely, irrational and rational factors.[3] Using the two categories, we aim to clarify what factors may contribute to households making privately suboptimal or optimal purchase decisions..

3.1. External Barriers

Gerarden, Newell, and Stavins (2015), Schleich *et al.* (2016), and Cattaneo (2019) have identified the external barriers that mostly originate from market and institutional settings. These studies conclude that households' discounting behaviour is negatively affected when they face liquidity constraints due to a lack of access to financial markets or when they borrow money at exorbitant interest rates. Epper, Fehr-Duda, and Schubert (2011) estimate that discount rates for liquidity-constrained customers are 40% greater than those for unconstrained customers in a temporal financial trade-off. It was also observed that technological risks associated with uncertainty regarding actual versus planned energy savings, fluctuating fuel prices, and the irreversibility of investments contribute to a high IDR (Schleich *et al.* 2016; Cattaneo 2019). In addition, inefficient functioning of capital markets, high-risk premiums, lack of capital, high debt leverage, and

3 Irrational factors cause households to make purchase decisions that do not maximize their experience utility or that are in their best self-interest. Behavioural decisions and the settings of purchase decisions contribute to such suboptimal outcomes. These factors result in a high IDR and cause households to buy appliances with a lower efficiency. On the other side, a high IDR is also caused by rational factors, but it does not indicate privately non-optimal and irrational behaviours. Households might, for example, deliberately use discount rates that are higher than risk-adjusted market interest rates because of their time and risk preferences. Although these behaviours result in a high IDR, they maximize their private utility (Stadelmann 2017).

Figure 1: An Overview of the Factors Influencing the IDR



Source: Author's compilation

political turmoil in developing nations lead to a high IDR (Hausman 1979; Train 1985; Sutherland 2003; Schleich *et al.* 2016).

It was observed that the benefits of energy-efficient investments are not fully revealed to households because of multiple information asymmetries (Giraudet 2020). Adverse selection and principal-agent problems are the two constituents of such asymmetries. The adverse selection problem appears when the seller of the product fails to deliver credible information (e.g., regarding the efficiency of the product and its advantages) to buyers

(Gillingham and Palmer 2014). As a result, this may lead to the use of a high IDR, and the consumer selects less energy-efficient appliances. On the other hand, the principal-agent problem arises between the landlord and tenants. Landlords intentionally invest in inefficient products because it is the tenants who will realise the efficient product's benefits, while they will remain uncompensated. Empirical findings reveal that only owner-occupied houses are equipped with energy-efficient appliances and insulation measures (Gillingham, Newell, and Palmer 2009; Ameli and Brandt 2015). Bhattacharya and Copper (2010) also find that information and agency problems are among the primary barriers to energy-efficient appliance adoption in India.

Symmetric information problems,[1] such as imperfect and incomplete information, have been identified as the primary impediments to investment in energy-efficient products, due to the action of a high IDR (Newell and Siikamäki 2014; Giraudet 2020). Examples include uncertainty about energy prices and climate conditions, infrequent energy consumption billing, lack of periodic energy audits, and insufficient or partial disclosure of product attributes. Usually, households lack knowledge of the actual energy usage of different appliances and are incapable of mentally computing the annual/lifetime monetary expenses of appliances (Giraudet 2020). Given this, when information on the costs and savings associated with alternatives are insufficient, asymmetric, or challenging to obtain at the time of purchase, energy efficiency becomes an unobservable characteristic for households when purchasing appliances. Further, information failure accentuates several behavioural aspects such as bounded rationality, inattention, and myopia, and in the process, heightens uncertainty about the product's benefits. For example, Min *et al.* (2019) observed that the absence of annual operating cost information makes the product's efficiency unattractive and caused an IDR of 560% for CFL (compact fluorescent lamp) bulbs. In short, information failure, cognitive restrictions, and myopia lead consumers to overlook usage cost differences and excessively focus on upfront costs, reflecting a higher IDR (Sutherland 2003; Cohen, Glachant, and Söderberg 2017; Stadelmann 2017).

[1] Giraduet (2018) mentions that incomplete and imperfect information fall under symmetric information; however, these problems are often mistaken for information asymmetries. Adverse selection or principal-agent problems, on the other hand, are examples of information asymmetry.

3.2. Internal Barriers

Internal barriers to decisions to invest in energy-efficient products include behavioural biases and individual preferences. First, energy-efficiency investment decisions rest on the "pure time preferences" of households (Schleich *et al.* 2016). The time preferences of households manifest their innate preferences and tell us how they value the future in relation to the present (Epper, Fehr-Duda, and Schubert 2011). According to rational choice theory, the time preferences of households are captured by the discount rate of individuals, which is a positive constant number and measures their extent of patience (or impatience). This implies that patient individuals will use a lower IDR and place a higher value on future benefits. Empirical studies by Newell and Siikamäki (2014) and Liebermann and Ungar (1997) find that households with patience are more likely to wait for future benefits, use a lower IDR, and invest in energy-efficient water heaters.

However, energy-efficient appliances are non-liquid assets that involve the risk of losing money if additional investment costs are not repaid from future energy savings. Further, they are subject to uncertainty due to a lack of knowledge about future energy prices, which tends to drive impatience regarding future benefits (Chernoff 1983; Hassett and Metcalf 1993). Therefore, an impatient household will have a time preference and might purchase an energy-efficient appliance only if offered a high premium. A high premium is nothing but a reflection of the use of a high IDR. Thus, high time preferences lead to a higher IDR. In such cases, households can be provided direct incentives to change their cost-effectiveness calculations in favour of energy-efficient appliances.

Since energy-efficient appliances are non-liquid assets and carry a risk of losing money if investments are not repaid by future energy savings (Hassett and Metcalf 1993), such uncertainty surrounding potential energy cost savings increases the risk quotient of energy-efficient investments. As a result, risk-averse individuals have a lower likelihood of spending money on energy-saving appliances (Fischbacher, Schudy, and Teyssier 2021). Studies by Qiu, Colson, and Grebitus (2014) and He *et al.* (2019) also confirm that risk-aversive households and farmers do not prefer buying energy-efficient appliances. This implies that greater risk aversion leads to a high IDR, affecting investments in energy-efficient products. However, there has been no specific research on the relationship between the IDR and risk aversiveness for energy-efficient appliances (Schleich *et al.* 2016). Only one empirical study (Qiu, Wang, and Wang 2015) focuses on industries and shows that risk-aversive firms apply a higher discount rate of about 42% for energy-efficiency projects. A high IDR may become less pronounced in

purchasing decisions if households demonstrate environmental concerns, the literature suggests. An environmentally conscious family attaches more value to environmental improvements due to energy savings, which positively affects energy-efficient investments and steers energy-saving habits (Schleich *et al.* 2016). This implies that such households favour outcomes advantageous to the environment over immediate monetary benefits in a trade-off between high upfront costs and addressing environmental concerns. Thus, a pro-environmental preference positively influences the IDR and may lead to a lower IDR.

The value of the IDR and the decision to invest in energy-efficient products are also influenced by several behavioural matters such as bounded rationality, rational inattention, the status quo bias, and the loss aversion bias. Bounded rationality refers to when a household fails to process data and undertake calculations due to their limited cognitive capacity and time, resulting in less optimal choices. As a result, they rely on mental shortcuts or heuristics to simplify their calculation process (Simon 1990; see Biswal, Singh and Bahinipati 2022). For example, households, due to their limited cognitive capacity, prioritize the purchasing price rather than calculating annual operating costs, or total lifetime costs, when buying energy-efficient appliances and impose internalities on themselves (Gillingham and Palmer 2014; Gerarden, Newell, and Stavins 2015). Even when the opportunity costs of time and effort to conduct a cost-benefit analysis of appliances become high, households make decisions based on the salient upfront costs of appliances while 'rationally' ignoring shrouded price attributes, i.e., the higher running energy costs (Stadelmann 2017). This is referred to as a rational inattention problem, where households may prefer to act or remain uninformed rather than incur the costs of becoming perfectly informed (Sallee 2014). Due to these biases, households weigh purchase costs more than future benefits, implying the use of a high IDR.

Information complexity also leads to biases such as the status quo bias and loss aversion, reducing households' ability to compare alternatives (efficient versus inefficient) and making choices more unpredictable (Samuelson and Zeckhauser 1988; Heutel 2019; He *et al.* 2019). In prospect theory, Kahneman and Tversky (1979) noted that individuals do not evaluate outcomes in absolute terms but relative to a point of reference, which they termed 'reference dependence preference.' This means that individuals give more weight to losses than gains—also known as the loss aversion phenomenon—where "losses loom larger than gains" (see Biswal, Singh and Bahinipati 2022). Concerning energy-efficient appliances, the possibility of a loss—due to uncertainty regarding future electricity prices and the actual improved performance of energy-efficient products—compels

households to weigh negative payoffs heavily and prevents them from investing in efficient appliances notwithstanding the positive net benefits (Gillingham and Palmer 2014; Heutel 2019). A large-scale study by Schleich *et al.* (2016) in European countries supports the hypothesis that loss-aversive individuals with experience using energy-inefficient appliances are less inclined to adopt energy-efficient appliances because of possible losses. Thus, reference-dependent preferences lead to the problem of loss aversion, which causes households to underestimate future savings from efficient appliances by using a high IDR (Ortoleva 2010; Schleich *et al.* 2016).

Empirical findings reveal that 'present-biased individuals' assign more weight to the payoff that is closer in time than what will incur in the distant future, i.e., they use a higher IDR and refrain from purchasing energy-efficient refrigerators (Allcott and Wozny 2014; Cohen, Glachant, and Söderberg 2017). In other words, the difference between the initial price (immediate costs) of efficient and less efficient/inefficient products is weighed more heavily than the difference in future energy operating costs (delayed benefits). This is also called 'hyperbolic discounting,' where the discount rate declines sharply over time (Stadelmann 2017). An empirical study by Fuerst and Singh (2018) on investment in energy-efficient appliances in India confirms that patient and less present-biased individuals are more likely to invest in them. This implies that the time preferences of households and the IDR are crucial in investment decisions pertaining to energy-efficient products. This needs further research and discussion.

4. ROLE OF INFORMATION IN REDUCING THE ENERGY-EFFICIENCY GAP

Information instruments are widely popular and used across countries to overcome informational and behavioural barriers. One such information instrument is energy labelling, which communicates information graphically using linear scales, bars, dials, or stars. It facilitates product comparisons and reduces transaction costs and uncertainties so that households can understand products' benefits (Stadelmann and Schubert 2018). Many studies have examined the effect of providing physical versus monetary units. In contrast, others have looked at the impact of providing information at different time scales when communicating running operating costs information (for example, monthly, annual, five-year, ten-year, and lifecycle costs) for energy-efficient appliances adoption (Heinzle 2012; Min *et al.* 2014; Newell and Siikamäki 2014; Jain, Rao, and Patwardhan 2018; Stadelmann and Schubert 2018; Damigos *et al.* 2021). These studies

observed that monetary information increases consumers' willingness to pay, i.e., it supports higher purchase prices and addresses the over-discounting problem. However, regarding time length, some studies favour annual over lifetime operating costs (Jain, Rao, and Patwardhan 2018; Damigos *et al.* 2021). Nevertheless, the most effective time frame for disclosing information is still being explored.

Further, empirical evidence indicates that the nature of information and the communication context enhances the impact of information provision (Delmas, Montes-Sancho, and Shimshack 2010). Information presented in terms of the opportunity costs of choosing less energy-efficient appliances, and listing a range of expected energy savings percentages, can significantly reduce the over-discounting problem and lessen the deterring effects of uncertainties on risk-aversive and present-biased consumers (Qiu, Colson, and Grebitus 2014; Silvi and Rosa 2021). Moreover, social comparison–based and environment-related information are also found to be more promising in increasing energy-efficient appliance investments than technical information or encouraging savings (Ferraro and Price 2013). It follows that disclosure of such information through labels, along with energy costs information, influences households' decision to make energy-efficient investments.

As it is well known, in intertemporal choices, information availability and how information is conveyed (through appropriate framing) influence individuals' discount rates for future costs and benefits (Loewenstein and Thaler 1989). In this regard, improving how information is represented on labels will make electricity consumption information more visible to consumers and reduce their cognitive load. Additional information is required to address various biases and promote energy-efficient appliance purchases. However, research in this regard has received little scholarly attention in developing countries.

5. CONCLUSION

Understanding household preferences and purchasing decisions is vital in encouraging energy-efficient appliance investments. Many studies on the energy-efficiency gap find that households underestimate the future energy savings from energy-efficient appliances and make their purchasing decisions based on mere price comparisons. This indicates how households implicitly apply a high IDR in their purchasing decisions. The literature review demonstrates the high IDR applied by decision-makers for various product categories in different countries, which is significantly greater than

the market interest rate. However, a close look at the literature on IDR reveals that estimations of IDR are mainly confined to developed nations. Only a limited discussion has taken place regarding how households in developing countries value the future benefits of energy-efficient investments. This survey covered multiple facets of the IDR. By assessing the factors affecting the value of the IDR, it finds that information failure significantly affects households' valuations of energy savings from energy-efficient appliances. It also covered the influence of behavioural factors like present-biased preferences, inattention, bounded rationality, and myopia, which make it difficult for households to compare the prices and operating costs of efficient and inefficient appliances.

The literature reveals that instruments such as energy labels that convey relevant information regarding energy consumption and the product's efficiency may encourage households to decide in favour of optimal choices. The literature review related to information provision for various household appliances shows that monetary annual energy costs information is more effective in driving purchases. Additionally, it finds that a better visual presentation of information simplifies household decision-making and promotes the purchase of energy-efficient appliances. It is, however, unrealistic to believe that informational instruments will alone eliminate the problem of limited attention, myopia, and short-sightedness. Therefore, it is equally important that policymakers consider the intuitive decision-making of individuals and design incentives such as energy taxes and subsidies along with information provision to address the high IDR problem and increase the adoption of energy-efficient appliances.

Ethics Statement: This statement is not applicable to us as it is review paper and we have not taken any ethical approvals to write this manuscript.

Data Availability Statement: This is a review paper. Information was collected from the previous published studies.

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