

Research Article

Estimating the implicit discount rate for new technology adoption of wood-burning stoves

Moisés Carrasco-Garcés^{a,c,*}, Felipe Vásquez-Lavín^{b,c,d}, Roberto D. Ponce Oliva^{b,c}, Francisco Diaz Pincheira^a, Manuel Barrientos^e

^a Departamento de Gestión Empresarial, Universidad de Concepción, Los Ángeles, Chile

^b School of Economics and Business, Universidad Del Desarrollo, Concepción, Chile

^c Center of Applied Ecology and Sustainability (CAPEs), ANID PIA/BASAL FB0002, Pontificia Universidad Católica de Chile, Santiago, Chile

^d Center for Climate Change and Resilience (CR2), Chile

^e Department of Economics, Universidad de Concepción, Chile, Chile

ARTICLE INFO

JEL classification:

QQ4

Q51

Keywords:

Efficient energy technologies

Implicit discount rate

Stated preferences

Intertemporal choice

Energy regulation

ABSTRACT

In the last decade, there have been several initiatives to incentivize Efficient Energy Technologies (EET) to reduce air pollution caused by wood-burning in developing countries. More efficient woodstoves can improve health, reduce family expenditures, CO₂ emissions, and forest degradation. Despite these benefits, there is low level of adoption of EETs. This paper contributed to the literature in three ways. First, it estimates the implicit discount rate (IDR) used by individuals to decide whether to adopt EET using exponential and hyperbolic specifications. Second, it includes sociodemographic characteristics in the definition of the IDR. Third, it evaluates how the adoption curve changes by different policy designs. Since the interest rate is part of the policy design, comparing the interest rate and the IDR is relevant to increasing adoption. Our monthly estimated IDR is between 1.7% and 5.4% with a significant overlap with market interest rate. The IDR is affected by the perception of the future economic situation, trust in environmental authorities, happiness, and gender. We found that using an interest rate lower than the IDR increases the probability of adoption significantly. An understanding of the effects of copayments, payment frequencies, and difference between interest rates and IDR is needed to maximize adoption.

1. Introduction

Understanding adoption decisions on Efficient Energy Technologies (EET) and people's response to economic incentives, such as technology adoption subsidies, are essential to reach environmental goals such as climate change mitigation and air pollution reduction. Within the households' energy mix, wood-burning is globally relevant as approximately half of the population in developing countries use solid biomass for cooking and heating (IEA, 2014).

In the last decade, there has been a substantial effort to incentivize the use of more efficient and less-polluting woodstoves in many developing countries aiming to reduce air pollution (indoor and outdoor) from wood-burning (Carvalho et al., 2018; Gómez et al., 2014; Lewis and Pattanayak, 2012; Savolahti et al., 2019a, 2019b). Adopting wood-based EETs provides both private and social benefits, these include the improvement in health and thermal comfort (Balsa et al.,

2016; Chafe et al., 2014; Conibear et al., 2018; Lee et al., 2003; Lim et al., 2012; Palma et al., 2019), reduction in family expenditures due to lower demand of firewood (Beltramo and Levine, 2013; Miller and Mobarak, 2013; Poortinga et al., 2018; Trotta, 2018), less native forest degradation, and decreasing in CO₂ emissions (Arnold et al., 2003, 2006; Bhattacharya and Salam, 2002; Davidar et al., 2010; Ouedraogo, 2006; Shackleton et al., 2005; Twine et al., 2003; Zein-Elabdin, 1997).

Despite these benefits, many households are not willing to adopt wood-based EETs. Lewis and Pattanayak (2012) claimed that some households are unwilling to invest in these technologies because they do not know or value their benefits. Recent studies have shown that households may be less likely to adopt new technologies for reasons such as financial restrictions or risk aversion (Olsthoorn et al., 2019). For instance, Gómez et al. (2014) showed that households significantly increase their adoption rate when they have access to credits that allow them to pay in at least 12 installments. Despite the relevance of

* Corresponding author. Departamento de Gestión Empresarial, Universidad de Concepción, Los Ángeles, Chile.

E-mail address: mocarrasco@udec.cl (M. Carrasco-Garcés).

analyzing the intertemporal preferences, there is limited evidence from existing literature about this issue for wood-based EETs. This paper contributes to filling this gap by considering the intertemporal implications in adopting efficient woodstoves (Beltramo and Levine, 2013; Damigos et al., 2021; Lewis and Pattanayak, 2012; Olsthoorn et al., 2019; Schleich et al., 2016, 2019).

Comparing the benefits and costs of different payment schedules available for people can affect their decision to adopt EETs. Adopting new technologies may involve short-term costs that need to be compared with long-term benefits. The cost is mainly associated with financing the technology in an initial period while the benefits (such as a reduction in family expenditures), are distributed over the technology's lifespan (Allcott and Greenstone, 2012; Amasino et al., 2019; Blasch et al., 2019; Bulley et al., 2016; Carson and Roth Tran, 2009; Frederick et al., 2002; Lempert et al., 2015; Peters and D'Esposito, 2016; Richards and Green, 2015; Zhao et al., 2019).

Economists framed individuals' intertemporal choices as if individuals use a *discounting factor* mechanism to bring to the present flows of costs or benefits that will occur in the future. This discounting factor depends on the individual's *implicit discount rate* (IDR) that generally represents how individuals value the future compared to the present.

Within the energy technology adoption field, Schleich et al. (2016) pointed out that the IDRs reflect the "barriers to energy efficiency" and are therefore related to an individual's risk aversion, financial restrictions, and other sociodemographic characteristics (see also Cattaneo (2019)). The higher the IDR, the lower the present value of future benefits and the lower the likelihood that an individual adopts the EET if most of the benefits occur in the future while costs are immediate.

However, this does not capture the whole picture regarding the policies used to promote EET. Most programs for EET adoption include different payment horizons to take household financial restrictions into account, aiming to increase the probability of adopting technologies as in Gómez et al. (2014). The literature on discounting in environmental, transportation, and energy economics use variations in the frequency of payments to estimate both the IDR and the willingness to pay (WTP) for a good (Bond et al., 2009; Kovacs and Larson, 2008; Meyer, 2013; Vasquez-Lavín et al., 2019b). Knowing the IDR can help the design of public policy regarding the frequency and specific amounts of payments to increase the probability of adoption.

Some policies for EET adoption also include a "credit" for the families that accept the technological change of stoves to reduce air pollution (Gómez et al., 2014). This credit has an interest rate negotiated between the provider of the new stove and the government (sometimes, it is the same government that provides the credit and therefore decides the interest rate). In other words, the interest rate is a central component of the policy design. The interest rate, the total cost of the stove, and the frequency of payments will affect the monthly amount payable by families. Therefore, comparing the interest rate and the IDR is relevant to increasing the new technology's adoption.

This paper uses Stated Preferences (SP) method to estimate the IDR associated with a program promoting EET adoptions, specifically efficient woodstove technologies, in Southern Chile. We explicitly include sociodemographic characteristics in the definition of the IDR and use both exponential and hyperbolic specifications. Furthermore, we evaluate the implications of the estimated IDR in designing policies aimed at incentivizing the adoption of efficient woodstove technologies. That is, we assess how different payment schemes (frequency and amount of money to pay in each installment), together with the different interest rates used by policymakers, affect the adoption curve of new technologies. To the best of our knowledge, our econometric specification, which allows us to estimate the IDR when people choose among multiple

technology alternatives, has not been discussed in the literature.

The SP method allows us to estimate the adoption curve for efficient stoves directly, determine the IDR, and include explanatory variables in the discount rate definition. SP has faced several critics, including the problem of embedding effect, hypothetical bias, warm glow effects, and mental accounting (Carson, 2012; Diamond et al., 1993; Hausman, 2012; Kahneman and Knetsch, 1992; Thaler, 1985). Nevertheless, it is the only methodology that provides enough flexibility to accommodate attributes of the goods that are not observed in the market and allows us to evaluate differences in the levels of those attributes, different payment schemes, and to do ex-ante policy evaluations (Bateman et al., 2001, 2002; Champ et al., 2003; Schläpfer et al., 2004). With the SP method, individuals choose among a series of hypothetical choice situations according to their preferences and restrictions. Commonly used SP techniques are Contingent Valuation (CV) and Choice Experiment (CE). The former presents two options (a status quo and a modified situation), while the latter offers more options that differ in the levels of the attributes (Fifer et al., 2014; Holmes et al., 2017; Louviere et al., 2008; Meenakshi et al., 2012). Both methodologies allow the estimation of the WTP or the willingness to accept (WTA) changes in the provision of a good or service. The estimated model will enable us to assess the change in the probability of technology adoption after an increase or decrease in an attribute, such as price or subsidy (Train, 2009).

The use of a constant discount rate implies that perceived net benefits in the distant future are marginally considered in the evaluation of a present policy (Dasgupta, 2008; Gollier and Weitzman, 2010; Goulder and Williams, 2012; Karp, 2005; Karp and Tsur, 2011; Schneider et al., 2012). However, there has been a debate about the rationality of this assumption in the context of environmental program assessments whose impacts extend over a long period, such as those intended to reduce climate change severity account (Frederick et al., 2002). A time-decreasing discount rate associated with hyperbolic discounting can take this factor into account (Chapman, 1996; Frederick et al., 2002; Thaler, 1991). With the hyperbolic discount, IDRs decrease with time, which favors future benefit flows when bringing them to present value (Stadelmann, 2017).

Previous literature on adopting efficient woodstoves has focused on the impact of sociodemographic variables such as income, age, education level, and other household characteristics on the likelihood of adoption, disregarding the IDR's role. Some authors showed that family income increases the probability of adopting efficient stoves (Boso et al., 2019; Gómez et al., 2017). Evidence regarding the impact of age is mixed; Boso et al. (2019) found that age increases the probability of participating in the adoption program, whereas Mahapatra and Gustavsson (2008) suggested that older adults have fewer incentives to adopt. Higher education levels are associated with more significant adoption rates of efficient stoves (García-Maroto et al., 2015).

There is vast literature estimating the IDR in environmental economics (Grammatikopoulou et al., 2020; Lew, 2018; Vásquez-Lavín et al., 2021; Vasquez-Lavín et al., 2019b), risk analysis (value of statistical life) (Andersson et al., 2013), transportation (Wang and Daziano, 2015), experimental economics (Attema and Versteegh, 2013; Newell and Siikamäki, 2014; Viscusi and Moore, 1989), and in the general field of clean technology adoption (Haq and Weiss, 2018; Stadelmann, 2017). Nevertheless, we only found one article estimating IDRs for efficient woodstove adoption. This finding is surprising since most of the programs that incentivize these technologies include different payment horizons to increase the probability of adoption. The only paper that evaluates this issue is Gómez et al. (2014), which used a CV experiment to assess the adoption of EET using different payment schemes (a single payment, 12 or 24 monthly payments) and obtained an IDR of 9.8% for

the 12-month analysis and a negative discount rate for the 24-month case.

In other environmental economics areas, the literature on discounting also used SP methods to estimate both the IDR and the WTP using variation in the frequency of payments. Most studies estimate the IDR outside the valuation exercise (Howard et al., 2021; Kovacs and Larson, 2008; Lew, 2018; Wang and Daziano, 2015). Fewer and more recent studies used an endogenous approach that takes advantage of the variation in the payment frequency across samples to jointly estimate the WTP and the IDR (Bond et al., 2009; Howard et al., 2021; Kim and Haab, 2009; Kovacs and Larson, 2008; Meyer, 2013; Vasquez-Lavín et al., 2019b).

Research on EET adoption has focused on durable goods (refrigerators, automobiles, heating systems). Stadelmann (2017) and Haq and Weiss (2018) presented a review of the main IDR found in this literature. The IDR shows high variability between categories of goods and within the same category. For example, in the case of goods such as refrigerators (Gately, 1980; Revelt and Train, 1998), the IDR ranges from 39% to 300%, while for automobiles (Allcott and Wozny, 2014; Train, 1985), it ranges from 2% to 45%. On heating systems (Hausman, 1979; Jaccard and Dennis, 2006), IDRs range from 2% to 36%. A hybrid study by Newell and Siikamäki (2014) used an experimental setting and CE to study the effectiveness of energy efficiency labels on household decisions. They estimated an average individual discount rate of 19%. While previous literature focused on electricity-based heating systems, our paper focuses on firewood as an energy source for a more efficient heating system.

The IDRs found in this study ranged from 1.7% to 5.4% monthly (between 22% and 87.9% annually). These rates are lower than those found in the literature and very close to the interest rate for bank and non-bank loans in the Chilean context (see appendix A in the appendices and Vasquez-Lavín et al. (2019b)). Among the determinants of these discount rates are sociodemographic characteristics. Our results suggest that maximizing the likelihood of adoption requires understanding the difference between the (market) interest rate and the IDR. Using an interest rate lower than the IDR significantly increases the probability of adoption because people would be willing to take long-term commitments.

2. Methodology

2.1. Context of firewood and energy policies in Chile

In Chile, firewood use for heating systems varies between 57.8% and 99.3% of households depending on latitude (Reyes et al., 2018). This energy source can be up to five times cheaper than alternative sources, such as liquefied petroleum gas, kerosene, and electricity (Schueftan and González, 2013). Firewood is the primary source of particulate matter emissions in south-central Chile, leading to a severe air pollution problem (CDT, 2015). Around 40% of the PM₁₀, PM_{2.5}, and CO₂ emissions come from residential wood burning, according to the 2005–2015 report from the Pollutant Release and Transfer Register (PRTR). The concentration limits for PM₁₀ and PM_{2.5} defined by the World Health Organization (WHO) are systematically exceeded in Chile (Molina et al., 2017), affecting approximately 10 million people and causing about 3400 deaths related to air pollution per year (Ostro et al., 1996; Oyarzún, 2010; Sanhueza et al., 2006; World Health Organization, 2016).

Regulating the firewood market is difficult as it is mainly informal, with thousands of small- and medium-sized producers who allocate time to this activity in the agricultural off-season (Reyes et al., 2015). While 90% of firewood purchases in southern Chile occur in informal market transactions, some evidence shows that customers are willing to move towards a more formal scheme (Vásquez Lavín et al., 2020).

To address urban air pollution, Chile implemented a policy to subsidize EETs for heating and cooking. This policy is accompanied by regulations that restrict the use of firewood, define the maximum level

of moisture on firewood, subsidize the improvement of household insulation, and initiate educational campaigns on the use and combustion of firewood (Gómez et al., 2017; Vásquez-Lavín et al., 2020). Gómez et al. (2014) showed that adopting the new EET is very low despite its multiple benefits. Furthermore, Air Pollution Management Plans (APMP) implemented by the authority have been criticized as focusing heavily on replacing firewood as a heating source without considering the socio-economic dimensions of the problem (Mobarak et al., 2012; Reyes et al., 2019; Schueftan et al., 2016; Vásquez-Lavín et al., 2020).¹

2.2. Experimental design

The city of Los Angeles (Chile) was declared an *air pollution saturated zone*, a legal status that mandates policymakers to reduce air pollution in the area. At least ten cities in south-central Chile are considered saturated zones, with more than 70% of its population affected. Each saturated zone needs to have an APMP implemented by the authority, and one of the central policies included in those plans is the replacement of wood stoves. Since the program consists of a subsidy, households need to afford part of the cost of the new technology. Therefore, policymakers are interested in estimating the adoption curve as a function of the copayment (the price of the new stove minus the subsidy), allowing for the definition of the optimal sponsorship level. It should be noted that the environmental authority or policymakers assign the subsidy; therefore, it is not a decision variable on the part of families.

During November and December 2018, we interviewed (face to face) 310 households on their heating systems in Los Angeles, Chile. We randomly choose a house (with evidence of having a stove) in the selected blocks. The survey aims to evaluate the city's inhabitants perceptions about a replacement program that would replace their old woodstoves with newer, more efficient technology. They could accept or reject this change; if they accept, they would have to pay a part of the cost. They faced three questions that differ in payment schedules: single payment, 12-month payment, and 24-month payment. In each of these alternatives, the monthly amount they would have to pay also changes. Two treatments were done in this study. In treatment I, all 310 households faced each of the three alternatives independently and therefore did not have the option of choosing among all three. This treatment is a classical CV survey with three valuation questions. The order of the questions and values for each payment schedule were randomly assigned to the households. In treatment II, using a subsample of 120 families, the respondents had the opportunity to choose one of the payment schedules. This treatment includes four options: a nonpurchase alternative plus the three payment schedules. This exercise requires respondents to compare their WTP with the schedule offered and choose the most convenient one. This decision is typical in any private market for durable goods in which consumers must compare their WTP with the payment to be made and choose the more convenient schedule based on the amount to be paid and the payment periods.

The copayments required in the surveys were designed using two

¹ While there are other policies besides the stove exchange programs, such as household insulation projects and certified firewood programs, we focus on the former. For readers interested in a comparison of these policies see: Jorquera, H., Barraza, F., Heyer, J., Valdivia, G., Schiappacasse, L.N., Montoya, L.D., 2018. Indoor PM 2.5 in an urban zone with heavy wood smoke pollution: The case of Temuco, Chile. *Environmental pollution* 236, 477–487. Schueftan, A., González, A.D., 2015. Proposals to enhance thermal efficiency programs and air pollution control in south-central Chile. *Energy Policy* 79, 48–57. Ortega, V., Reyes, R., Schueftan, A., González, A., Rojas, F., 2016. Contaminación atmosférica: Atacando el síntoma, no la enfermedad. Análisis de los sistemas de calefacción residencial y los programas de descontaminación atmosférica en la Región de Los Ríos. *Bosques, Energía y Sociedad* 3, 1–24. and Vásquez Lavín, F., Barrientos, M., Castillo, Á., Herrera, I., Ponce Oliva, R.D., 2020. Firewood certification programs: Key attributes and policy implications. *Energy Policy* 137.

sources of information. First, the policy design allows us to subsidize at most 80% of the total cost, which was \$280,000 CLP (approximately 500 USD) and a copayment of \$70,000 CLP (around 130 USD, first column first row of Table 1) and a minimum subsidy of 20% (copayment of approximately 500 USD), this copayment is randomized through the bids offered to respondents. Second, we used the responses of a pilot study that utilized an open-ended elicitation format. To define the bid vector, we followed an optimal design methodology suggested by Cooper (1993) for the single payment case. The bids were randomly assigned among the interviewees. For the 12-month and 24-month cases, we selected rounded values representing similar loans given by commercial retail companies in the country.

The survey included three sections. Section A asks questions of general interest, such as those regarding interviewees' heating and fuel systems. Section B explains the policy for stove replacements using visual aids of the new stoves. It also develops the hypothetical market and asks the valuation question. Interviewees faced the following valuation context:

Let me tell you about the Atmospheric Decontamination Plan for the city of Los Angeles. This plan has already been approved and is currently under review by the Comptroller General of the Republic. It considers a replacement program of 6,000 stoves that uses firewood in the next ten years. The idea is to ask households for their voluntary enrollment in this program. The government will partially subsidize the cost of the new stove. That is why we are consulting with families like yours about preferences regarding several program alternatives. Your answers will help authorities in the implementation and design of this program.

The equipment to be delivered costs \$350,000 in the market without a subsidy. It will reduce firewood consumption by 35% and the emission of particulate matter by 50%. The equipment has an approximate life span of 20 years.

It is currently unknown how much people will have to pay for the new equipment, nor how many people will be willing to participate in the program,

$$\begin{aligned}
 Pr\{y_i = 0\} &= Pr\{V_n(WTP_i) < V_i(B_i)\} \\
 &= Pr\left\{ (X_i\beta + \sigma\varepsilon_i) \cdot \left(\frac{1+r}{r}\right) \left(1 - \frac{1}{(1+r)^{n_i}}\right) < B_i \left(\frac{1+r}{r}\right) \left(1 - \frac{1}{(1+r)^{t_i}}\right) \right\} \\
 &= Pr\left\{ \varepsilon_i < -\frac{X_i\beta}{\sigma} + \frac{B_i}{\sigma} \frac{\delta(r, t_i)}{\delta(r, n_i)} \right\}
 \end{aligned} \tag{2}$$

but it is estimated that the cost for households can be between \$A_L and \$A_U. This is equivalent to a subsidy from the State between \$S_L and \$S_U.²

Now, I will present the three alternatives to participating in the program; they differ in terms of the amount of money that needs to be paid and in the payment frequencies. The order of presentation is random. Please consider these three questions individually. Considering the reduction in the use of firewood and in the monthly budget of your home:

If, after receiving the subsidy, the cost for your family were \$Y for Z monthly payments, would you participate in this program?

In treatment II, a subset of 120 households was also allowed to choose between the three alternatives. Finally, Section C contains the interviewees' socio-economic characteristics and information on other relevant covariates to explain people's decisions, WTP, and IDR. Although Blasch et al. (2019) suggest evaluating the investment literacy in the purchase of energy-efficient appliances to capture the participant's ability to think in the present value of future energy costs, it does

² Since this policy has been implemented in several cities in the country, we had to include this "uncertainty" to avoid perceptions of bias among interviewees that were offered different deals. In this way we avoid political controversies.

not apply in this context. In our framework, individuals do not need to engage in complex present value calculations (Egan et al., 2015), they just need to compare changes in the monthly payments and the number of periods.

2.3. Econometric approach for the intertemporal choice model with multiple options

It is possible to estimate the IDR taking advantage of the variability of the payment schemes by jointly estimating the WTP, as suggested by Bond et al. (2009) and Vásquez-Lavín et al. (2021). If we assumed a finite horizon, the present value of the benefits would be determined by

$V_n(WTP_i) = WTP_i \left(\frac{1+r}{r}\right) \left(1 - \frac{1}{(1+r)^n}\right)$, where n represents the time in which the benefits are distributed, and r is the IDR. The cost is the present value of the finite stream of payments $V_t(B_i) = B_i \left(\frac{1+r}{r}\right) \left(1 - \frac{1}{(1+r)^t}\right)$, where t represents the period the payment must be made (1, 12, and 24). Let's consider that an individual could either accept or reject the payment. The household agrees with the payment as long as the benefits of adopting energy-efficient technology are greater than or equal to adoption costs. We denote a positive response (yes) using the indicator $y_i = 1$ and $y_i = 0$ otherwise. Therefore, the decision can be represented as follows:

$$y_i = \begin{cases} 1 & \text{if } V_n(WTP_i) \geq V_t(B_i) \\ 0 & \text{in any other case} \end{cases} \tag{1}$$

Following Bond et al. (2009), the benefits for an individual i is $WTP_i = X_i\beta + \sigma\varepsilon_i$ where $\varepsilon_i \sim N(0, 1)$. Therefore, the probability of observing a negative response to a required amount of B_i^t can be written as follows:

In this case, t_i is known and corresponds to the period in which each payment schedule is offered to the interviewees, n_i is known and corresponds to the expected useful life of efficient energy technology, but r is unknown.

In equation (2), the IDR is embedded in the formulation of the discount factor $\delta(r, t_j)$ and $\delta(r, n_j)$. The main feature of our approach is that the IDR is estimated "endogenously" following Bond et al. (2009). That is, r is a parameter to be estimated in the econometric process. Within this approach, there are two options: 1) estimate r as a single parameter or 2) Define r as a function of explanatory variables, that is:

Table 1
Frequency of Bids for different payment schedules (CLP \$).

Single	Frequency	12 months	Frequency	24 months	Frequency
70,000	46	10,000	20	8000	20
150,000	80	12,000	9	9000	10
210,000	111	15,000	96	10,000	132
280,000	73	20,000	115	12,000	52
-		25,000	70	15,000	96

Bids were randomly assigned among interviewees. We sort them in the table for a better representation.

$$r_i = \alpha_0 + \alpha_1 \cdot x_{i1} + \alpha_2 \cdot x_{i2} + \dots + \alpha_k \cdot x_{ik} \quad (3)$$

This option allows us to know which sociodemographic determine the IDR and to capture heterogeneity among individuals. This issue has received less attention in the literature. [Schleich et al. \(2016\)](#) pointed out that a wide range of factors may explain the underlying IDRs, such as financial restrictions, institutional aspects, and status quo bias.

The first treatment does not allow individuals to choose among the three payment schedules. Nevertheless, in many countries, including Chile, real market decisions regarding technology investment enable individuals to select one payment schedule. To take this fact into account, we applied treatment II, in which some individuals have the opportunity to choose among them. This approach requires a different econometric analysis. Consider that people may choose among different payment schedules specified by an amount B_i^j , and a time horizon for the payment, where j represents the payment horizon (1, 12, or 24). The alternatives are the following: 1) non-payment ($B_i^0 = 0$), 2) a single payment of B_i^1 , 3) the payment of B_i^{12} for 12 months, and 4) the payment for 24 months of B_i^{24} . If the individual decides to pay the B_i^j payment scheme, it implies that the present value of the benefits (PVWTP) is greater than the present value of the B_i^j scheme payment. Without loss of generality and to bound the WTP from above, we assume that since the individual rejected the other alternatives, then his/her PVWTP is lower than the next larger present value (upper bound) of the schedule denoted by B_i^l , where $l \neq j$.

We have enough information to determine the upper bound because all individuals faced treatment I in which they accept or reject the three options. We also have information on the yes/no answers for all payment schemes. Approximately 76% of the respondents who chose the single payment rejected at least one of the other payment schemes (12-month and 24-month payment scheme). Among those who chose the 12-month scheme, they also declined at least one of the other schemes by approximately 76%. Among those who chose the 24-month scheme, about 55% rejected at least one of the remaining payment schemes. With this information, we established the upper limits for the model for choosing multiple payment schemes.

The probability of choosing the calendar B_i^j , will be denoted by:

$$\begin{aligned} Pr\{y_{nj} = 1\} &= Pr\{V_j(B_i^j) \leq V_n(WTP_i) < V_l(B_i^l)\} \\ &= Pr\left\{-\frac{X_i\beta}{\sigma} + \frac{B_i^j \delta(r, t_j)}{\sigma \delta(r, n_i)} \leq \varepsilon_i < -\frac{X_i\beta}{\sigma} + \frac{B_i^l \delta(r, t_l)}{\sigma \delta(r, n_i)}\right\} \\ &= \frac{B_i^l \delta(r, t_l)}{\sigma \delta(r, n_i)} - \frac{X_i\beta}{\sigma} \\ &= \int \phi(Z) dZ \\ &= \frac{B_i^j \delta(r, t_j)}{\sigma \delta(r, n_i)} - \frac{X_i\beta}{\sigma} \end{aligned}$$

$$Pr\{y_{nj} = 1\} = \Phi\left(\frac{B_i^j \delta(r, t_j)}{\sigma \delta(r, n_i)} - \frac{X_i\beta}{\sigma}\right) - \Phi\left(\frac{B_i^l \delta(r, t_l)}{\sigma \delta(r, n_i)} - \frac{X_i\beta}{\sigma}\right)$$

The likelihood function is given by:

$$\log L = \sum_1^N \ln \left[\Phi\left(\frac{B_i^j \delta(r, t_j)}{\sigma \delta(r, n_i)} - \frac{X_i\beta}{\sigma}\right) - \Phi\left(\frac{B_i^l \delta(r, t_l)}{\sigma \delta(r, n_i)} - \frac{X_i\beta}{\sigma}\right) \right] \quad (4)$$

in which $\Phi(\cdot)$ is the c. d.f. of a normal distribution, $\delta(r, n_i) \equiv \left(1 - \frac{1}{(1+r)^{n_i}}\right)$ and $\delta(r, t_j) \equiv \left(1 - \frac{1}{(1+r)^{t_j}}\right)$. In case we do not bound the WTP from above, the probability in equation (4) would be $1 -$

$$\Phi\left(\frac{B_i^l \delta(r, t_l)}{\sigma \delta(r, n_i)} - \frac{X_i\beta}{\sigma}\right)$$

Because different individuals have different discount rates, the order of the present value of different payment alternatives will vary among individuals and change with the discount rate. For instance, suppose an individual is asked to choose among the three payment schedules: a) 100

USD paying once, b) 21.42 USD paying for 12 months, and c) 17.14 USD paying for 24 months and a non-purchase alternative (not accepting any payment schedule). If $r < 0.12$ and the individual chooses option b, then the order of the present values would be $V_{12}(B_i^{12}) \leq V_n(WTP_i) < V_{24}(B_i^{24})$ (see [Figure B1](#) in the appendices). But if $r > 0.248$, the order of the present values will change $V_{24}(B_i^{24}) < V_{12}(B_i^{12}) \leq V_n(WTP_i)$. These results are considered in each iteration of the maximum likelihood estimation process. Notice that our assumption regarding the upper bound of the WTP is relevant only in the first case because, in the second, we will not have an upper bound unless the individual also rejects the single payment option.

3. Results

The yes/no answers for the payment schemes and respective bids are presented in [Table 2](#) for the single, 12-month, and 24-month options. We observe that the probability of a yes response is decreasing with the bid in all cases. In the single payment option, the range of probability is adequate for a CV experiment as it ranges from 93% to 25%, as would be expected given the optimal design approach used ([Alberini, 1995](#)). Notice that we did not get a probability lower than 25% because the subsidy design did not allow a copayment above 80% of the total cost. Furthermore, the frequency of yes answers for the 12-month payments is higher than the one for 24-month payments; this result is in line with [Gómez et al. \(2017\)](#). Note that the highest 12-month payment (\$25,000 CLP) has the same probability of yes answer as the cheapest 24-month payment (\$8000 CLP), indicating that individuals prefer shorter contracts. This fact significantly affects the probability of adoption, covering the upper half of the distribution in the 12-month case and the lower half in the 24-month case.

Future CV applications should consider separate optimal design approaches for different payment schedules to cover an acceptable portion of the adoption curve (between 15% and 85% as suggested by [Kanninen \(1995\)](#) and [Alberini \(1995\)](#)). The simple approach followed in this paper is "naïve" in the sense that the present value of the costs is not the only relevant information for an optimal design of bids when considering different payment frequencies. We could not foresee these results before doing the experiment, but as our learning from this application shows, people have strong preferences for some payment schedules that need to be considered in the optimal design of the experiment.

Out of 310 respondents, 241 chose at least one option while only 69 rejected all options in treatment I, while 114 chose one option and only 6 rejected all of them in treatment II. [Table 3](#) shows that 63.5% of the respondents accepted the 12-month payment in treatment I, 36.4% accepted the 24-month payment, and 55% accepted the single payment. Treatment II shows that 58 (48%) out of 120 chose the single payment, 45 (37.5%) the 12-month and 11 (9.1%) the 24-month option.

For the WTP estimation, we include income and gender as explanatory variables. *Income*³ is the income range that best describes the average monthly household income before taxes. The percentage of families with an income lower than \$900,000 CLP (approximately 1700 USD) is 61%. The variable *gender* is a dummy variable taking the value 1 for men (33%) and 0 for women (67%). [Gómez et al. \(2014\)](#) obtain a similar percentage of participation of men (39%) and women (61%) within the same context. This could be due to cultural issues where a high percentage of women are present in homes during the day, which enables their participation. We included other variables, such as education and firewood consumption, in the regression, but they were not statistically significant.

In the definition of the IDR, we included *rfinancial*, which is a categorical

³ The level of household income is divided into deciles (75000, 225000, 375000, 525000, 750000, 1050000, 1350000, 1750000, 2250000, and 3000000).

Table 2
Acceptance percentage to the payment scheme (CLP \$).

Single payment	12-month payment		24-month payment	
	No	Yes	No	Yes
70,000	7%	93%	10,000	5%
150,000	24%	76%	12,000	11%
210,000	54%	46%	15,000	23%
280,000	75%	25%	20,000	47%
			25,000	50%

Table 3
Choice responses for each payment schedule.

	Treatment I		Treatment II	
	No	Yes	No	Yes
Single Payment	137	173	62	58
Payment 12 months	113	197	75	45
Payment 24 months	197	113	109	11

variable representing respondents' perceptions of their economic situations in the next five years, going from much better (*rfinancial* = 1) to much worse (*rfinancial* = 5), compared with their current situations. About 46% believe that their financial situation will remain the same, 2.4% believe that it will be much worse, and 9.6% believe that it will be much better. We also included the variable *rtrust* that indicates the level of trust in the environmental authority going from *rtrust* = 1 for a lot of trust to *rtrust* = 4 for a lot of distrust. Around 77.9% declared having much or some distrust in the environmental authority. Both *rfinancial* and *rtrust* have been used in other studies (Gómez et al., 2014) but as explanatory variables in adoption in a CV context. Unlike these studies, we follow the line proposed in the review presented by Schleich et al. (2016), who identifies factors such as financial restrictions, institutional aspects, and status quo bias as determinants of the IDRs.

The last covariate considered in this study is subjective well-being, measured as the respondents' perception of their happiness (*rhappy*). This covariate ranges from not very happy (*rhappy* = 1) to very happy (*rhappy* = 7). The notion of including this variable is to provide evidence on hedonic subjective wellbeing and IDRs. The median level of happiness was 6, while the average was 5.9, which we consider high happiness levels.

To assess whether respondents discount their preferences hyperbolically or exponentially, we calculated the discount rate for each payment schedule (12 months and 24 months). This analysis assumes that if the interviewees discounted their preferences exponentially, the rate for both periods should be constant over time. On the contrary, if the discount rate decreased, the appropriate discount is the hyperbolic discount. Using this approach, the discount rate for the 12-month payment was equivalent to approximately 5%, while it was approximately 1% for the 24-month payment scheme. We used a one-sided mean comparison test to evaluate the null hypothesis of equal discount rates between both samples against the alternative hypothesis of decreasing discount rates. We conclude that the discount rate decreases over time, so the use of a hyperbolic discount would be more appropriate.

The estimation of the WTP and IDR for the different treatments are presented in Table 4, considering a life span of 20 years for the woodstove. Income is positive and statistically significant in all models, while gender is only significant in the hyperbolic model for treatment I. The variables included in the definition of the discount rate (financial status, trust, happiness, gender)⁴ are statistically significant in all models, except in the exponential case (treatment I). Gender is statistically significant only in the

⁴ In the analysis, we included socioeconomic variables such as age (average 48 years), level of education (35% complete high school and 35% complete university) and consumption of firewood in the last year (1582 average wood chips per household). In addition to a dummy variable that indicates whether the individuals are willing to participate in helping to solve the pollution problem (85% said yes) and a dummy variable indicating whether the air pollution problem is important for individuals (98% said yes). None of them was statistically significant through the models.

Table 4
Results of the intertemporal choice model for multiple options (dep. variable is WTP).

	Treatment I		Treatment II	
	Exponential discount	Hyperbolic discount ^a	Exponential discount	Hyperbolic discount
Constant	0.0236*** (0.0086)	0.0071 (0.0045)	0.0601*** (0.0096)	0.0248*** (0.0030)
Income	0.0012** (0.0005)	0.0030*** (0.0008)	0.0030* (0.0017)	0.0021*** (0.0005)
Gender	-0.0058 (0.0063)	0.0127* (0.0066)	-0.0024 (0.0067)	-0.0034 (0.0022)
Variables in the definition of the IDR				
r_Constant	0.0144** (0.0069)	-0.0346*** (0.0000)	0.0487*** (0.0008)	0.0613*** (0.0036)
r_financial	-0.0003 (0.0004)	-0.0053*** (0.0000)	-0.0053*** (0.0012)	-0.0075*** (0.0021)
r_trust	0.0002 (0.0004)	-0.0025*** (0.0000)	-0.0036*** (0.0013)	-0.0047*** (0.0017)
r_happy	-0.0002 (0.0004)	0.0126*** (0.0000)	0.0040*** (0.0005)	0.0043*** (0.0006)
r_gender	-0.0037 (0.0036)	0.0232 (0.0159)	0.0054 (0.0041)	0.0057** (0.0026)
Sigma	0.0150*** (0.0047)	0.0312*** (0.0040)	0.0207*** (0.0019)	0.0081*** (0.0007)
N	930	930	120	120
Log-likelihood	572.8	613.2	178.6	190.7
WTP (US dollars)	5.3559	5.2591	14.6306	6.7265
WTP Std. Err (US dollars)	1.92	0.95	0.611	0.24
WTP P-Value	0.003	0.000	0.000	0.000
PV-WTP(US dollars)	365.7	495.8	323.5	328.5
IDR	0.0144	0.0177	0.0474	0.0549
IDR Std. Err	0.0069	0.0000	0.0015	0.0016
IDR P-Value	0.036	0.000	0.000	0.000

***p < 0.01, **p < 0.05, *p < 0.1. ^a For further specification of the hyperbolic model, see appendix B in the appendices section.

hyperbolic model (treatment II).

Some novel results are given by the variables included in the definition of the IDR. It is important to distinguish the two implications of these results. First, changes in the IDR affect the probability of adopting the technology, *ceteris paribus*. For a given payment scheme (single, 12, or 24 months) and a horizon of 20 years of benefits for the stove, the larger the IDR, the lower the probability of adoption. This is very much an expected result. Nevertheless, what is not very well documented in the literature is that the decrease in the probability of adoption could vary among the different payment schemes (time and values) because a higher (lower) discount rate will affect not only the benefits but also the present value of the costs for the 12- or 24-month schemes. Therefore, a second effect is that different IDR levels will affect the desirability of the payment scheme themselves. The net effect will depend on whether the design of the payments was made with an interest rate lower or higher than the IDR.

Therefore, if respondents expect a worse financial future situation, the IDR decreases. This will have two implications. First, a lower IDR increases the desirability of the adoption since the long-term benefits

will have a higher weight in the present. However, at the same time, future costs will also have more relevance in the present value, which implies that people will less likely commit to payments in the future, increasing the desirability of the single payment over the 12-24-month options. The same analysis is applied to trust (*rtrust*) since it also has a negative and statistically significant effect on the IDR.

People's distrust on the authorities will have a lower IDR, increasing the probability of adoption but reducing the likelihood of committing to future payments. The former result is unexpected since the literature suggested that institutional barriers in the form of distrust on authorities prevent the adoption of EETs by an increase in the IDRs (Anderhub et al., 2001; Damigos et al., 2021; Schleich et al., 2016). To the best of our knowledge, this is the first attempt to include these variables in determining the IDR, making the comparison of our results that of previous literature's difficult. Happiness is statistically significant and positive, meaning that an increase in happiness increases the IDR. This measure of hedonic happiness shows that there is more attachment to goods that deliver pleasure in the short term, not wanting to wait for long-term benefits, such as adopting EET. Finally, *rgender* is statistically significant and positive, only for treatment II and hyperbolic discount.

Fig. 1 shows the effect of different explanatory variables on the IDR, and the probability of adopting different payment schedules. In Panel A, we set the explanatory variables to their extreme values so that the IDR is the lowest (i.e., *rfinancial* = 5, *rtrust* = 4, *rhappy* = 1). The predicted probability of adoption decreases significantly for longer payment schedules. In Panel B, the explanatory variables take the extreme values that allow the highest IDR (i.e., *rfinancial* = 1, *rtrust* = 1, *rhappy* = 7). In this case, the predicted probability of adoption increases for longer payment schedules and becomes higher than for the single payment. The worse the respondents consider their future financial situation to be, the greater the distrust of the environmental authority, and the less happy they feel, the lower the probability of adopting long-term payment schedules.

In summary, while an increase (decrease) in the IDR makes all adoption curves shift downward (upward), meaning less likely to adopt, it also decreases (increases) the relative desirability of using a single payment option. It has important implications in the probability of adoption depending on the difference between the interest rate and the IDR, as we show below.

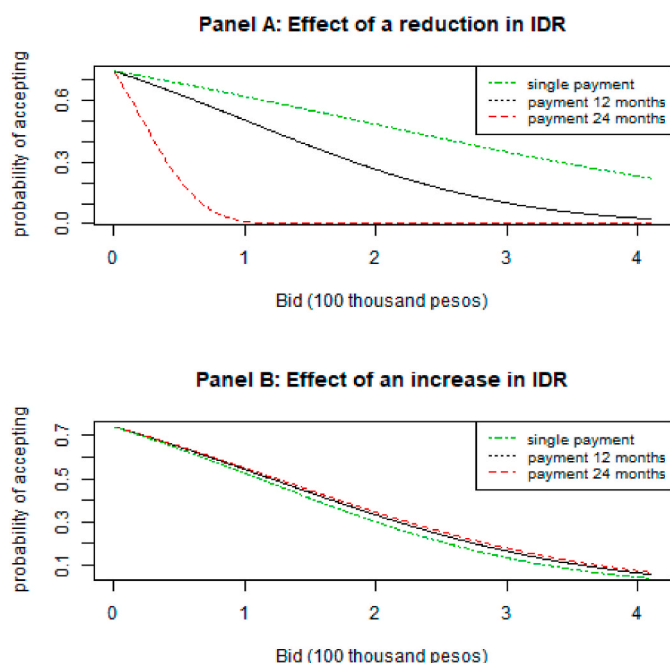


Fig. 1. Effect of IDR over the probability of accepting.

When we analyze the monthly WTP in treatment I, there are no significant differences between exponential and hyperbolic models, but the use of a hyperbolic discount generates a higher present value of about 130 USD. This is because the hyperbolic discount has a smaller impact on benefits over time. When we look at treatment II, the WTP of the exponential discount is significantly higher than the hyperbolic discount, but when calculating the present value, it is the same for both discounts.

The IDRs found in this study ranged from 1.7% to 5.4% monthly (between 22% and 87.9% annually), depending on the model specified. These rates are lower than those found in the literature and very close to the interest rate for bank and non-bank loans in the Chilean context (see appendix A in appendices section). In the literature, there are a few estimations of IDRs in the context of EET. Haq and Weiss (2018) show that the IDRs range between -259% and 764% for different groups of technologies such as thermal insulation, space heating, and water heating in a recent and comprehensive review. In the heating area, in which our study would classify, the average discount rates are between 7% and 102%. Our results are entirely inside that interval.

In the environmental economics literature, Vásquez-Lavín et al. (2021) conduct a literature review founding four ranges for the IDR: Above 500% (Bond et al., 2009; Echeverría et al., 1995; Myers et al., 2017), between 100% and 350% (Egan et al., 2015; Lew, 2018; Vásquez-Lavín et al., 2019a; Wang and He, 2018), values between 50% and 100% (Egan et al., 2015) and a few studies with rates below 50% (Howard et al., 2021). Additionally, they report around 20 studies in the transportation literature using SP (Wang and Daziano, 2015). The discount rates in these studies are between 2% and 102% (Hess et al., 2012; Musti and Kockelman, 2011). Finally, experimental economics studies report IDR ranging from 0% to 5.747%, with a significant variability (Andreoni et al., 2015; Andreoni and Sprenger, 2012; Cheung, 2019; McDonald et al., 2017). Our findings are very plausible and consistent with the literature.

4. Conclusion and policy implications

To show the implications of our results on the policy design of loans for EET adoption, we evaluate how the probability of adoption changes as copayment increases (lower subsidy). We do this by using different assumptions on the interest rate used in the loan offered to families for new technologies. We use the results from the hyperbolic discount and consider three scenarios as shown in Fig. 2: 1) The interest rate of the schemes is equal to the IDRs (Panel A); 2) An interest rate twice the size of the IDR, that is, 3.4% (Panel B); and 3) an interest rate is lower than IDR (close to zero) (Panel C). We recall that policymakers may choose to finance between a maximum of 80% of the total cost (\$280,000 CLP subsidy and a \$70,000 CLP copayment; approximately US\$130) and a minimum of 20% (\$280,000 CLP copayment; approximately US\$500). The copayments are shown on the x-axis, where the unit of measurement is 100000 Chilean pesos, approximately 180 dollars.

For the maximum 80% subsidy, the probability of adoption is around 66% for all schemes, assuming that the discount rate is equal to the IDR (Panel A). More interestingly, households would feel indifferent between payment schemes (single, 12-month, and 24-month) because the present value of all the alternatives would be approximately the same.

When the interest rate is higher than the IDRs (Panel B), the probability of adoption is the same (66%) for the single payment but, for the 80% subsidy, it decreases to 65%, and 64% for 12-month and 24-month payment schedule respectively. On the contrary, when the interest rate is lower than the IDRs (Panel C) there is an increase in the adoption to 67%, and 68%, for the 12-month, and 24-month payment schedules, respectively. Notice that the highest level of adoption would almost be 68% if authorities offer the possibility of paying in 24 months. If the only option is a single payment, the level of adoption would only be 66%.

For the minimum 20% subsidy, the probability of adoption reaches approximately 37% for all payment schemes (Panel A). By using an

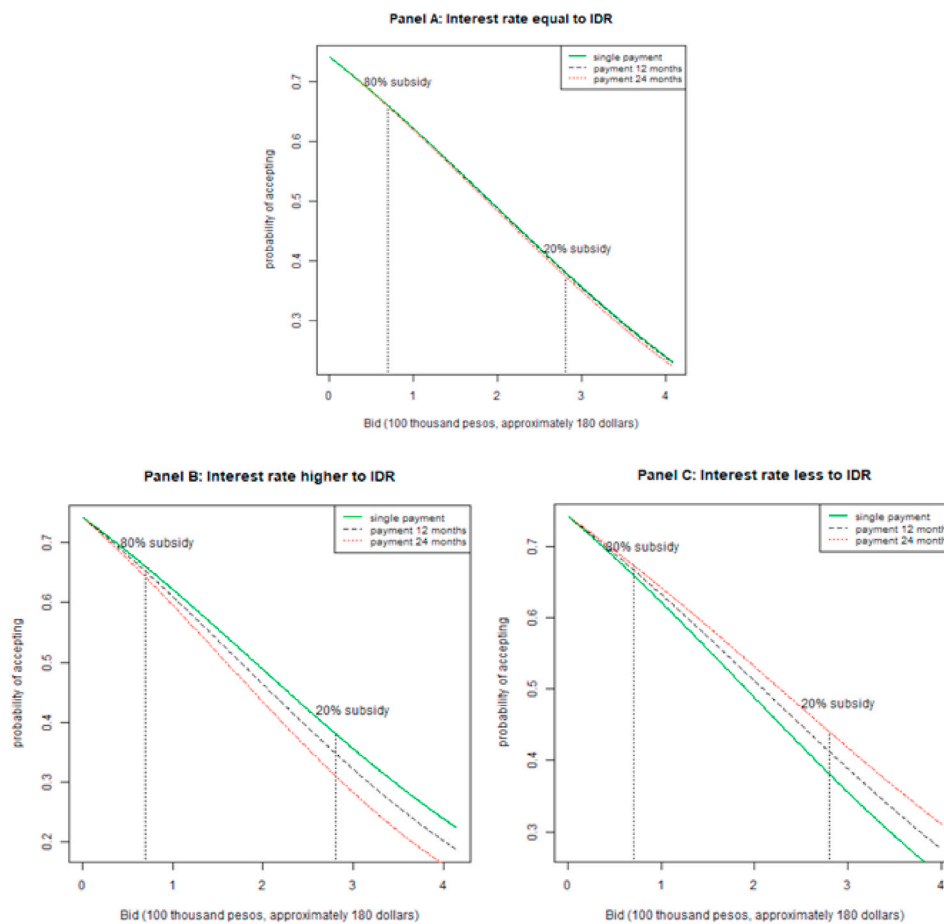


Fig. 2. Adoption probability for different bids and interest rates.

interest rate higher than the IDR (Panel B), the probability of adoption remains the same for the single payment, while it decreases to 33% and 29% for the 12- and 24-month payment schedules, respectively. When we analyze the case of the lowest interest rate at IDRs (close to 0, Panel C), the probability of adoption increases for all payment schemes to 38%, 41%, and 44% for the single payment, 12-month, and 24-month payment schemes, respectively. Therefore, when the interest rate is higher than the IDR, the single payment dominates the other two options, whereas the 12-month scheme dominates the 24-month alternative. The order is reversed when the IDR is higher than the interest rate.

We performed Kolmogorov-Smirnov tests to evaluate differences in the probability distribution for both cases (interest rate higher or lower than the IDR). Results show significant differences in probability distributions between single and 24-month payments (p -value < 0.001) for both cases. When the interest rate is higher than the IDR, the probability distribution for a 12-month payment is significantly higher than a 24-month payment (p -value = 0.065). In contrast, the difference between single and 12-month payments is not statistically significant (p -value = 0.11). When the interest rate is lower than the IDR, the probability distribution for a 12-month payment is significantly higher than a single payment (p -value = 0.09, while the difference between 12-month payment and 24-month payment is not statistically significant). Hence, if policymakers want to maximize the probability of adoption, they should bear in mind that different adoption levels will be obtained depending on copayments, frequency of payments, and the difference between interest rates defined for the policy design and the IDR. This result has not been explicitly addressed in previous literature (Haq and Weiss, 2018; Schleich et al., 2016; Stadelmann, 2017).

The adoption of efficient technologies for heating homes is an important alternative to reduce the use of firewood and has a positive

impact on air quality affecting the health and welfare of families (Cohen et al., 2017; Gómez et al., 2017; Reyes et al., 2019; Schueftan et al., 2016). Nevertheless, low levels of adoption by families emphasize the importance of knowing how households could be affected by different policy designs could increase the adoption of efficient energy technologies. Investment decisions are complex and mainly influenced by barriers to entry, individual factors, and personal context. Improving the understanding of these factors is essential for the proper design of interventions for specific household groups.

This article uses a model of intertemporal choice to explain the adoption decisions of a more efficient heating system by families from Los Angeles, Chile. A CV survey was carried out, where we were able to estimate both the WTP and their IDR. The IDRs found in this study ranged from 1.7% to 5.4%, depending on the model specified (between 22% and 87.9% annually).⁵ These rates are lower than those found in the literature (Vasquez-Lavín et al., 2019b) and very close to the interest rate for bank and non-bank loans in the Chilean context (appendix A). Among the determinants of these discount rates are sociodemographic characteristics, aspects related to preferences, and the institutional and financial context in which families live. For instance, the more pessimistic the expectations about the future financial situation of the families are, the lower the IDR. Therefore people would prefer payment options closer in time, reducing the probability of adoption because people would not want to take extended-time loans. The same effect has a higher distrust in environmental authorities.

Particularly, there is little evidence on how levels of perceived subjective wellbeing could affect financial decisions and IDRs (Kennedy,

⁵ $r_{\text{annual}} = (1 + r\%)^{12} - 1$.

2020; Zia et al., 2017). Our evidence suggests that better levels of happiness (measured as hedonic wellbeing) increase IDRs, raising the probability of technology adoption since people would be more likely to take loans of 12 or 24 months. However, all these effects will be conditioned by the differences between the interest rate and the IDR.

Additionally, our results suggest that having different payment schemes encourages the adoption of efficient woodstoves. A program that seeks to improve adoption should provide a flexible payment scheme where families can choose the calendar to pay. These findings reveal a series of policy implications. First, the design of policies to incentivize efficient technologies should consider flexibility in payment schedules. Credit restrictions discourage adoption, especially for low-income households. The income is relevant in the WTP by families; therefore, incentives should be targeted according to sociodemographic measures such as income. But more importantly, maximizing the likelihood of adoption requires understanding the impact of the difference between the interest rate and the IDR and how different explanatory variables affect this IDR.

Despite its implications, the novelty of this approach entails limitations, such as the optimal design of the experiment. In future research, different preferences for payment schedules should be included in the optimal design of the investigation.

Funding

Center of Applied Ecology and Sustainability (CAPES), ANID PIA/BASAL FB0002, Finances data analysis and interpretation of results.

CRediT authorship contribution statement

Moisés Carrasco-Garcés: Conceptualization, Methodology, Software, Writing – original draft, Formal analysis. **Felipe Vásquez-Lavín:** Conceptualization, Writing – review & editing, Validation. **Roberto D. Ponce Oliva:** Writing – review & editing, Investigation, Visualization, Investigation, Funding acquisition. **Francisco Diaz Pincheira:** Conceptualization, Data curation, Resources, Writing – review & editing. **Manuel Barrientos:** Software, Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendices. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.enpol.2021.112407>.

References

- Alberini, A., 1995. Optimal designs for discrete choice contingent valuation surveys: single-bound, double-bound, and bivariate models. *J. Environ. Econ. Manag.* 28, 287–306.
- Allcott, H., Greenstone, M., 2012. Is there an energy efficiency gap? *J. Econ. Perspect.* 26, 3–28.
- Allcott, H., Wozny, N., 2014. Gasoline prices, fuel economy, and the energy paradox. *Rev. Econ. Stat.* 96, 779–795.
- Amasino, D.R., Sullivan, N.J., Kranton, R.E., Huettel, S.A., 2019. Amount and time exert independent influences on intertemporal choice. *Nature human behaviour* 3, 383–392.
- Anderhub, V., Güth, W., Gneezy, U., Sonsino, D., 2001. On the interaction of risk and time preferences: an experimental study. *Ger. Econ. Rev.* 2, 239–253.
- Andersson, H., Hammitt, J.K., Lindberg, G., Sundström, K., 2013. Willingness to pay and sensitivity to time framing: a theoretical analysis and an application on car safety. *Environ. Resour. Econ.* 56, 437–456.
- Andreoni, J., Kuhn, M.A., Sprenger, C., 2015. Measuring time preferences: a comparison of experimental methods. *J. Econ. Behav. Organ.* 116, 451–464.
- Andreoni, J., Sprenger, C., 2012. Estimating time preferences from convex budgets. *Am. Econ. Rev.* 102, 3333–3356.
- Arnold, J.M., Köhlin, G., Persson, R., 2006. Woodfuels, livelihoods, and policy interventions: changing perspectives. *World Dev.* 34, 596–611.
- Arnold, M., Köhlin, G., Persson, R., Shepherd, G., 2003. Fuelwood Revisited: What has changed in the last decade?, Vol. 37. CIFOR, Bogor.
- Attema, A.E., Versteegh, M.M., 2013. Would you rather be ill now, or later? *Health Econ.* 22, 1496–1506.
- Balsa, A.I., Caffera, M., Bloomfield, J., 2016. Exposures to particulate matter from the eruptions of the Puyehue volcano and birth outcomes in Montevideo, Uruguay. *Environ. Health Perspect.* 124, 1816–1822.
- Bateman, I.J., Carson, R.T., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Ozdemiroglu, E., 2002. *Economic Valuation with Stated Preference Techniques: a Manual. Economic Valuation with Stated Preference Techniques: a Manual.*
- Bateman, I.J., Willis, K.G., Arrow, K.J., 2001. *Valuing Environmental Preferences: Theory and Practice of the Contingent Valuation Method in the US, EU, and Developing Countries.* Oxford University Press, pp. 5–6.
- Beltramo, T., Levine, D.L., 2013. The effect of solar ovens on fuel use, emissions and health: results from a randomised controlled trial. *J. Dev. Effect.* 5, 178–207.
- Bhattacharya, S., Salam, P.A., 2002. Low greenhouse gas biomass options for cooking in the developing countries. *Biomass Bioenergy* 22, 305–317.
- Blasch, J., Filippini, M., Kumar, N., 2019. Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances. *Resour. Energy Econ.* 56, 39–58.
- Bond, C.A., Cullen, K.G., Larson, D.M., 2009. Joint estimation of discount rates and willingness to pay for public goods. *Ecol. Econ.* 68, 2751–2759.
- Boso, A., Oltra, C., Hofflinger, A., 2019. Participation in a programme for assisted replacement of wood-burning stoves in Chile: the role of sociodemographic factors, evaluation of air quality and risk perception. *Energy Pol.* 129, 1220–1226.
- Bulley, A., Henry, J., Suddendorf, T., 2016. Prospect and the present moment: the role of episodic foresight in intertemporal choices between immediate and delayed rewards. *Rev. Gen. Psychol.* 20, 29–47.
- Carson, R.T., 2012. Contingent valuation: a practical alternative when prices aren't available. *J. Econ. Perspect.* 26, 27–42.
- Carson, R.T., Roth Tran, B., 2009. *Discounting Behavior and Environmental Decisions.* Educational Publishing Foundation.
- Carvalho, R.L., Vicente, E.D., Tarelho, L.A., Jensen, O.M., 2018. Wood stove combustion air retrofits: a low cost way to increase energy savings in dwellings. *Energy Build.* 164, 140–152.
- Cattaneo, C., 2019. Internal and external barriers to energy efficiency: which role for policy interventions? *Energy efficiency* 12, 1293–1311.
- CDT, 2015. *Medición del consumo nacional de leña y otros combustibles sólidos derivados de la madera.*
- Chafe, Z.A., Brauer, M., Klimont, Z., Van Dingenen, R., Mehta, S., Rao, S., Riahi, K., Dentener, F., Smith, K.R., 2014. Household cooking with solid fuels contributes to ambient PM_{2.5} air pollution and the burden of disease. *Environ. Health Perspect.* 122, 1314.
- Champ, P.A., Boyle, K.J., Brown, T.C., 2003. *A Primer on Nonmarket Valuation.* Kluwer Academic Publishers.
- Chapman, G.B., 1996. Temporal discounting and utility for health and money. *J. Exp. Psychol. Learn. Mem. Cognit.* 22, 771.
- Cheung, S.L., 2019. Eliciting utility curvature in time preference. *Exp. Econ.* 1–33.
- Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *Lancet* 389, 1907–1918.
- Conibear, L., Butt, E.W., Knot, C., Arnold, S.R., Spracklen, D.V., 2018. Residential energy use emissions dominate health impacts from exposure to ambient particulate matter in India. *Nat. Commun.* 9, 617.
- Cooper, J.C., 1993. Optimal bid selection for dichotomous choice contingent valuation surveys. *J. Environ. Econ. Manag.* 24, 25–40.
- Damigos, D., Kontogianni, A., Tourkolias, C., Skourtos, M., 2021. Dissecting subjective discount rates and investment literacy for energy-efficient investments. *Energy Efficiency* 14, 1–20.
- Dasgupta, P., 2008. Discounting climate change. *J. Risk Uncertain.* 37, 141–169.
- Davidar, P., Sahoo, S., Mammen, P.C., Acharya, P., Puyravaud, J.-P., Arjunan, M., Garrigues, J.P., Roessingh, K., 2010. Assessing the extent and causes of forest degradation in India: where do we stand? *Biol. Conserv.* 143, 2937–2944.
- Diamond, P., Hausman, J., Leonard, G., Denning, M., 1993. Does Contingent Valuation Measure Preferences? Experimental Evidence. A critical assessment, Contingent valuation, p. 41.
- Echeverría, J., Hanrahan, M., Solórzano, R., 1995. Valuation of non-priced amenities provided by the biological resources within the monteverde cloud forest preserve, Costa Rica. *Ecol. Econ.* 13, 43–52.
- Egan, K.J., Corrigan, J.R., Dwyer, D.F., 2015. Three reasons to use annual payments in contingent valuation surveys: convergent validity, discount rates, and mental accounting. *J. Environ. Econ. Manag.* 72, 123–136.
- Fifer, S., Rose, J., Greaves, S., 2014. Hypothetical bias in Stated Choice Experiments: is it a problem? And if so, how do we deal with it? *Transport. Res. Pol. Pract.* 61, 164–177.
- Frederick, S., Loewenstein, G., O'donoghue, T., 2002. Time discounting and time preference: a critical review. *J. Econ. Lit.* 40, 351–401.

- García-Maroto, I., García-Maraver, A., Muñoz-Leiva, F., Zamorano, M., 2015. Consumer knowledge, information sources used and predisposition towards the adoption of wood pellets in domestic heating systems. *Renew. Sustain. Energy Rev.* 43, 207–215.
- Gately, D., 1980. Individual discount rates and the purchase and utilization of energy-using durables: Comment. *Bell J. Econ.* 11, 373–374.
- Gollier, C., Weitzman, M.L., 2010. How should the distant future be discounted when discount rates are uncertain? *Econ. Lett.* 107, 350–353.
- Gómez, W., Chávez, C., Salgado, H., Vásquez, F., 2017. Lessons from a pilot program to induce stove replacements in Chile: design, implementation and evaluation. *Environ. Res. Lett.* 12, 115001.
- Gómez, W., Salgado, H., Vásquez, F., Chávez, C., 2014. Using stated preference methods to design cost-effective subsidy programs to induce technology adoption: an application to a stove program in southern Chile. *J. Environ. Manag.* 132, 346–357.
- Goulder, L.H., Williams, R.C., 2012. The choice of discount rate for climate change policy evaluation. *Climate Change Economics* 3, 1250024.
- Grammatikopoulou, I., Artell, J., Hjerppe, T., Pouta, E., 2020. A mire of discount rates: delaying conservation payment schedules in a choice experiment. *Environ. Resour. Econ.* 1–25.
- Haq, G., Weiss, M., 2018. Time preference and consumer discount rates—insights for accelerating the adoption of efficient energy and transport technologies. *Technol. Forecast. Soc. Change* 137, 76–88.
- Hausman, J.A., 1979. Individual discount rates and the purchase and utilization of energy-using durables. *Bell J. Econ.* 33–54.
- Hausman, J.A., 2012. Contingent valuation: from dubious to hopeless. *J. Econ. Perspect.* 43–56.
- Hess, S., Fowler, M., Adler, T., Bahreini, A., 2012. A joint model for vehicle type and fuel type choice: evidence from a cross-nested logit study. *Transportation* 39, 593–625.
- Holmes, T.P., Adamowicz, W.L., Carlsson, F., 2017. *Choice Experiments, A Primer on Nonmarket Valuation*. Springer, pp. 133–186.
- Howard, G., Whitehead, J.C., Hochard, J., 2021. Estimating discount rates using referendum-style choice experiments: an analysis of multiple methodologies. *J. Environ. Econ. Manag.* 105, 102399.
- IEA, 2014. *World Energy Outlook 2014*. International Energy Agency.
- Jaccard, M., Dennis, M., 2006. Estimating home energy decision parameters for a hybrid energy—economy policy model. *Environ. Model. Assess.* 11, 91–100.
- Jorquera, H., Barraza, F., Heyer, J., Valdivia, G., Schiappacasse, L.N., Montoya, L.D., 2018. Indoor PM 2.5 in an urban zone with heavy wood smoke pollution: the case of Temuco, Chile. *Environ. Pollut.* 236, 477–487.
- Kahneman, D., Knetsch, J.L., 1992. Valuing public goods: the purchase of moral satisfaction. *J. Environ. Econ. Manag.* 22, 57–70.
- Kanninen, B.J., 1995. Bias in discrete response contingent valuation. *J. Environ. Econ. Manag.* 28, 114–125.
- Karp, L., 2005. Global warming and hyperbolic discounting. *J. Publ. Econ.* 89, 261–282.
- Karp, L., Tsur, Y., 2011. Time perspective and climate change policy. *J. Environ. Econ. Manag.* 62, 1–14.
- Kennedy, J., 2020. Subjective wellbeing and the discount rate. *J. Happiness Stud.* 21, 635–658.
- Kim, S.-I., Haab, T.C., 2009. Temporal insensitivity of willingness to pay and implied discount rates. *Resour. Energy Econ.* 31, 89–102.
- Kovacs, K.F., Larson, D.M., 2008. Identifying individual discount rates and valuing public open space with stated-preference models. *Land Econ.* 84, 209–224.
- Lee, B.E., Ha, E.H., Park, H.S., Kim, Y.J., Hong, Y.C., Kim, H., Lee, J.T., 2003. Exposure to air pollution during different gestational phases contributes to risks of low birth weight. *Hum. Reprod.* 18, 638–643.
- Lempert, K.M., Glimcher, P.W., Phelps, E.A., 2015. Emotional arousal and discount rate in intertemporal choice are reference dependent. *J. Exp. Psychol. Gen.* 144, 366.
- Lew, D.K., 2018. Discounting future payments in stated preference choice experiments. *Resour. Energy Econ.* 54, 150–164.
- Lewis, J.J., Pattanayak, S.K., 2012. Who adopts improved fuels and cookstoves? A systematic review. *Environ. Health Perspect.* 120, 637–645.
- Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., AlMazroa, M. A., Amann, M., Anderson, H.R., Andrews, K.G., 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 380, 2224–2260.
- Louviere, J.J., Street, D., Burgess, L., Wasi, N., Islam, T., Marley, A.A., 2008. Modeling the choices of individual decision-makers by combining efficient choice experiment designs with extra preference information. *Journal of choice modelling* 1, 128–164.
- Mahapatra, K., Gustavsson, L., 2008. Innovative approaches to domestic heating: homeowners' perceptions and factors influencing their choice of heating system. *Int. J. Consum. Stud.* 32, 75–87.
- McDonald, R., Chilton, S., Jones-Lee, M., Metcalf, H., 2017. Evidence of variable discount rates and non-standard discounting in mortality risk valuation. *J. Environ. Econ. Manag.* 82, 152–167.
- Meenakshi, J., Banerji, A., Manyong, V., Tomlins, K., Mittal, N., Hamukwala, P., 2012. Using a discrete choice experiment to elicit the demand for a nutritious food: willingness-to-pay for orange maize in rural Zambia. *J. Health Econ.* 31, 62–71.
- Meyer, A., 2013. Intertemporal valuation of river restoration. *Environ. Resour. Econ.* 54, 41–61.
- Miller, G., Mobarak, A.M., 2013. Gender Differences in Preferences, Intra-household Externalities, and Low Demand for Improved Cookstoves. National Bureau of Economic Research.
- Mobarak, A.M., Dwivedi, P., Bailis, R., Hildemann, L., Miller, G., 2012. Low demand for nontraditional cookstove technologies. *Proc. Natl. Acad. Sci. Unit. States Am.* 109, 10815–10820.
- Molina, C., Toro, R., Manzano, C., Leiva-Guzmán, M.A., 2017. Particulate matter in urban areas of south-central Chile exceeds air quality standards. *Air Quality, Atmosphere & Health* 10, 653–667.
- Musti, S., Kockelman, K.M., 2011. Evolution of the household vehicle fleet: anticipating fleet composition, PHEV adoption and GHG emissions in Austin, Texas. *Transport. Res. Pol. Pract.* 45, 707–720.
- Myers, K., Parsons, G., Train, K., 2017. Inadequate response to frequency of payments in contingent valuation of environmental goods. *Contingent Valuation of Environmental Goods*. Edward Elgar Publishing, Inc., Massachusetts, Estados Unidos da América, pp. 43–57.
- Newell, R.G., Siikamäki, J., 2014. Nudging energy efficiency behavior: the role of information labels. *Journal of the Association of Environmental and Resource Economists* 1, 555–598.
- Olsthoorn, M., Schleich, J., Faure, C., 2019. Exploring the diffusion of low-energy houses: an empirical study in the European Union. *Energy Pol.* 129, 1382–1393.
- Ortega, V., Reyes, R., Schueftan, A., González, A., Rojas, F., 2016. Contaminación atmosférica: Atacando el síntoma, no la enfermedad. Análisis de los sistemas de calefacción residencial y los programas de descontaminación atmosférica en la Región de Los Ríos. *Bosques. Energía y Sociedad* 3, 1–24.
- Ostro, B., Sanchez, J.M., Aranda, C., Eskeland, G.S., 1996. Air pollution and mortality: results from a study of Santiago, Chile. *J. Expo. Anal. Environ. Epidemiol.* 6, 97–114.
- Ouedraogo, B., 2006. Household energy preferences for cooking in urban Ouagadougou, Burkina Faso. *Energy Pol.* 34, 3787–3795.
- Oyarzún, M., 2010. Contaminación aérea y sus efectos en la salud. *Rev. Chil. Enferm. Respir.* 26, 16–25.
- Palma, A., Petrunyk, I., Vuri, D., 2019. Air Pollution during Pregnancy and Birth Outcomes in Italy. CEIS Working Paper 464.
- Peters, J., D'Esposito, M., 2016. Effects of medial orbitofrontal cortex lesions on self-control in intertemporal choice. *Curr. Biol.* 26, 2625–2628.
- Poortinga, W., Jiang, S., Grey, C., Tweed, C., 2018. Impacts of energy-efficiency investments on internal conditions in low-income households. *Build. Res. Inf.* 46, 653–667.
- Revelt, D., Train, K., 1998. Mixed logit with repeated choices: households' choices of appliance efficiency level. *Rev. Econ. Stat.* 80, 647–657.
- Reyes, R., Nelson, H., Navarro, F., Retes, C., 2015. The firewood dilemma: human health in a broader context of well-being in Chile. *Energy for Sustainable Development* 28, 75–87.
- Reyes, R., Nelson, H., Zerriffi, H., 2018. Firewood: cause or consequence? Underlying drivers of firewood production in the South of Chile. *Energy for Sustainable Development* 42, 97–108.
- Reyes, R., Schueftan, A., Ruiz, C., González, A.D., 2019. Controlling air pollution in a context of high energy poverty levels in southern Chile: clean air but colder houses? *Energy Pol.* 124, 301–311.
- Richards, T.J., Green, G.P., 2015. Environmental choices and hyperbolic discounting: an experimental analysis. *Environ. Resour. Econ.* 62, 83–103.
- Sanhueza, P., Vargas, C., Mellado, P., 2006. Impacto de la contaminación del aire por PM10 sobre la mortalidad diaria en Temuco. *Rev. Med. Chile* 134, 754–761.
- Savolahti, M., Karvosenoja, N., Soimakallio, S., Kupiainen, K., Tissari, J., Paunu, V.-V., 2019a. Near-term climate impacts of Finnish residential wood combustion. *Energy Pol.* 133, 110837.
- Savolahti, M., Lehtomäki, H., Karvosenoja, N., Paunu, V.-V., Korhonen, A., Kukkonen, J., Kupiainen, K., Kangas, L., Karppinen, A., Hänninen, O., 2019b. Residential wood combustion in Finland: PM2.5 emissions and health impacts with and without abatement measures. *Int. J. Environ. Res. Publ. Health* 16, 2920.
- Schläpfer, F., Roschewitz, A., Hanley, N., 2004. Validation of stated preferences for public goods: a comparison of contingent valuation survey response and voting behaviour. *Ecol. Econ.* 51, 1–16.
- Schleich, J., Gassmann, X., Faure, C., Meissner, T., 2016. Making the implicit explicit: a look inside the implicit discount rate. *Energy Pol.* 97, 321–331.
- Schleich, J., Gassmann, X., Meissner, T., Faure, C., 2019. A large-scale test of the effects of time discounting, risk aversion, loss aversion, and present bias on household adoption of energy-efficient technologies. *Energy Econ.* 80, 377–393.
- Schneider, M.T., Traeger, C.P., Winkler, R., 2012. Trading off generations: equity, discounting, and climate change. *Eur. Econ. Rev.* 56, 1621–1644.
- Schueftan, A., González, A.D., 2013. Reduction of firewood consumption by households in south-central Chile associated with energy efficiency programs. *Energy Pol.* 63, 823–832.
- Schueftan, A., González, A.D., 2015. Proposals to enhance thermal efficiency programs and air pollution control in south-central Chile. *Energy Pol.* 79, 48–57.
- Schueftan, A., Sommerhoff, J., González, A.D., 2016. Firewood demand and energy policy in south-central Chile. *Energy for Sustainable Development* 33, 26–35.
- Shackleton, C., Guthrie, G., Main, R., 2005. Estimating the potential role of commercial over-harvesting in resource viability: a case study of five useful tree species in South Africa. *Land Degrad. Dev.* 16, 273–286.
- Stadelmann, M., 2017. Mind the gap? Critically reviewing the energy efficiency gap with empirical evidence. *Energy research & social science* 27, 117–128.
- Thaler, R., 1985. Mental accounting and consumer choice. *Market. Sci.* 4, 199–214.
- Thaler, R.H., 1991. Some empirical evidence on dynamic inconsistency. *Quasi rational economics* 1, 127–136.
- Train, K., 1985. Discount rates in consumers' energy-related decisions: a review of the literature. *Energy* 10, 1243–1253.
- Train, K.E., 2009. *Discrete Choice Methods with Simulation*. Cambridge university press.
- Trotta, G., 2018. The determinants of energy efficient retrofit investments in the English residential sector. *Energy Pol.* 120, 175–182.

- Twine, W., Moshe, D., Netshiluvhi, T., Siphugu, V., 2003. Consumption and direct-use values of savanna bio-resources used by rural households in Mamefja, a semi-arid area of Limpopo province, South Africa. *South Afr. J. Sci.* 99, 467–473.
- Vásquez-Lavín, F., Barrientos, M., Castillo, Á., Herrera, I., Oliva, R.D.P., 2020. Firewood certification programs: Key attributes and policy implications. *Energy Pol.* 137, 111160.
- Vásquez-Lavín, F., Carrasco, M., Barrientos, M., Gelcich, S., Oliva, R.D.P., 2021. Estimating discount rates for environmental goods: are People's responses inadequate to frequency of payments? *J. Environ. Econ. Manag.* 107, 102446.
- Vasquez-Lavín, F., Oliva, R.D.P., Hernández, J.I., Gelcich, S., Carrasco, M., Quiroga, M., 2019a. Exploring dual discount rates for ecosystem services: evidence from a marine protected area network. *Resour. Energy Econ.* 55, 63–80.
- Vasquez-Lavín, F., Ponce, R., Hernández, J., Gelcich, S., Carrasco, M., Quiroga, M., 2019b. Exploring dual discount rates for ecosystem services: evidence from a marine protected area network. *Resour. Energy Econ.* 55, 63–80.
- Vásquez Lavín, F., Barrientos, M., Castillo, Á., Herrera, I., Ponce Oliva, R.D., 2020. Firewood certification programs: Key attributes and policy implications. *Energy Pol.* 137.
- Viscusi, W.K., Moore, M.J., 1989. Rates of time preference and valuations of the duration of life. *J. Publ. Econ.* 38, 297–317.
- Wang, C., Daziano, R.A., 2015. On the problem of measuring discount rates in intertemporal transportation choices. *Transportation* 42, 1019–1038.
- Wang, H., He, J., 2018. Implicit individual discount rate in China: a contingent valuation study. *J. Environ. Manag.* 210, 51–70.
- World Health Organization, 2016. *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*.
- Zein-Elabdin, E.O., 1997. Improved stoves in sub-saharan africa: the case of the Sudan. *Energy Econ.* 19, 465–475.
- Zhao, W.J., Diederich, A., Trueblood, J.S., Bhatia, S., 2019. Automatic biases in intertemporal choice. *Psychonomic Bull. Rev.* 26, 661–668.
- Zia, L., Ilyas Sindhu, M., Haider Hashmi, S., 2017. Testing overconfidence bias in Pakistani stock market. *Cogent Economics & Finance* 5, 1289656.