Division of Economics and Business
Working Paper Series

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Working Paper 2018-03
http://econbus-papers.mines.edu/working-papers/wp201803.pdf

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April 2018

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Working Paper No. **2018-03**
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Energy efficiency, green technology and the pain of paying*

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ABSTRACT
It is well-known from the mental accounting literature that consumers would rather pay up-front for a luxury good like a vacation, but pay later for a durable good like a dishwasher. This occurs because the hedonic benefits and monetary costs enter differently in the mental accounts. But how does the mental accounting process change if the durable good saves money over time, as with an energy efficiency upgrade, or signals wealth and "green status", like a rooftop solar panel or an electric car? In this paper, we derive a mental accounting model of energy efficient and green durable investment that incorporates the consumer heterogeneity in the psychological "pain of paying". The model predicts that pain of paying attenuates the willingness to pay for status signaling and environmental protection, but increases the willingness to pay more up front in order to reduce long run energy bills. Consumers with a high pain of paying may therefore act as if they have a low discount rate when they are more accurately described as being conflicted about their intertemporal preferences. We test these predictions using a survey-based discrete choice experiment with solar and energy efficient homes, in which we measured individual subjects' susceptibility to pain of paying.

JEL **classifications: Q40, Q42, D91**
Keywords: mental accounting, pain of paying, solar, energy efficiency, green durables

*Zhappassova is corresponding author. We thank Chris Bastian, Anthony Denzer, Jon Gardzelewski, and Robert Godby. All errors are our own. The discrete choice experiment used in this paper was funded by the University of Wyoming Center for Energy Economics and Public Policy.

1. Introduction

The adoption of energy-saving durable goods has been studied widely as an intertemporal choice problem (see e.g., Hausman, 1979; Newell and Siikamaki, 2015), or in the case of conspicuous goods like hybrid cars or solar panels, as a green goods problem with benefits from warm glow and status signaling (see e.g., Bollinger and Gillingham; 2012; Sexton and Sexton, 2014; Delgado et al., 2015). In the presence of mental accounting, however, intertemporal preferences are distorted in a way that depends on how individuals perceive and psychologically account for costs and benefits over time[1]. This is a largely overlooked aspect of the adoption decision for energy-saving or green durable goods.

Nonconsumptive aspects of a decision, such as utility from the transaction itself, hedonic benefits associated with a good, and pain of paying, or the emotional discomfort from the act of spending money, are assigned to consumers' mental accounts. Although there is ample evidence of emotions impacting decision-making (Loewenstein, 2000; Schwarz, 2000; Bosman and Van Winden, 2002; Fehr and Gchter, 2002; Sanfey et al., 2003; Knutson et al., 2007; Pfister and Bhm, 2008; Coricelli et al., 2010; Cubitt et al., 2011; Jordan et al., 2015), pain of paying may be particularly important to consumer durables choices, since it acts as a proxy for opportunity costs (Prelec and Loewenstein, 1998; Loewenstein and O'Donoghue, 2006; Rick, 2013)[2]. Further, pain of paying has been shown to impact preferences for temporal cost structures. Specifically, Prelec and Loewenstein (1998) find that pain of paying affects preferences for timing of payments in a way that lines up with empirical observations. Pain of paying may therefore be important to solar panel and energy efficiency investments, which are typically characterized by a front-loaded cost structure, with high up-front investment costs, followed by potentially large future bill savings (low maintenance expenses and minimal fuel costs).

[1]Behavioral biases (e.g., status quo bias, loss and risk aversion, hyperbolic time discounting, reference dependence) may affect households decision to invest in energy efficiency and renewable energy (see Gillingham et al., 2009; Gillingham and Palmer, 2014; Frederiks et al., 2015)

[2]Pain of paying has been found to affect a range of consumer behavior, see e.g., Prelec and Loewenstein (1998), Thaler (1999), Loewenstein and ODonoghue (2006), Rick et al. (2008), Berman et al. (2016), Thunstrom et al., (2017).

Given that consumers' limited attention and cognitive ability may prevent them from consciously considering the opportunity costs of consumption, pain of paying helps consumers regulate spending, by acting as a proxy for the 'true' cost of consumption. However, there is consumer heterogeneity in pain of paying. For some, it may therefore be an imperfect proxy. Rick et al. (2008) develop a scale that identifies subgroups of people who experience either too little pain, leading to too much spending for the individual's own liking ("spendthrifts"), or too much pain, leading to too little spending ("tightwads"). People with helpful levels of pain of paying are referred to as "unconflicted".[3] Rick et al. (2011) found that spendthrifts and tightwads are indeed more unsatisfied with their own spending behavior, than are unconflicted consumers.[4]

The aim of this study is to examine how pain of paying impacts investments in renewable energy. To do so, we develop a mental accounting model that entails pain of paying. Pioneered by Richard Thaler (1980; 1985; 1990), mental accounting models incorporate the finding that consumers treat money and spending differently, depending on the source of money and type of spending. Previous studies address how investments in durable goods may be affected by mental accounting (e.g., Purohit, 1995; Okada, 2001; Shafir and Thaler, 2006; Yamamoto et al., 2008).[5] We test our model on data from a survey-based discrete choice experiment on adoption of residential solar panels and energy efficiency measures. We find that pain of paying has a significant impact on consumer decisions to invest in solar panels. Both our model and data imply that the impact of pain of paying on dynamic decisions differs from that of time discounting. Specifically, we find that consumers who feel high levels of pain of paying ("tightwads") value bill savings more than consumers who

[3]We use both Rick et al.s spendthrift scale and terminology in the following.

[4]Note that although pain of paying may correlate to self control, it is a separate construct (Rick et al., 2008; Tangney et al., 2004).

[5]Specifically, Purohit (1995) analyze trade-in decisions of old durable goods in a mental accounting model that incorporates the endowment effects. In a related study, Okada (2001) examine durable product replacement decisions in a mental accounting model that entails mental costs of retiring old products. Shafir and Thaler (2006) analyze mental accounting rules over decisions where payment and consumption are separated in time. Although they do not formalize a model, Yamamoto et al. (2008) discuss how home electricity consumption may be affected by pain of paying and mental accounting.

feel less pain ("spendthrifts"). However, tightwads are also more sensitive to upfront costs, which may deter them from adopting renewable energy, despite the long-term savings.

The main contribution of our paper lies in our findings of the impact of pain of paying on the decision to undertake investments that yield future cost savings and generate positive externalities, such as renewable energy and energy efficiency. Standard economic theory suggests time discounting also deters households from investing in energy efficient home solutions with a front-loaded cost structure. A high time discount rate means households attach a low value to future cost savings. It is therefore commonly assumed that the outcome of the intertemporal trade-off of investments in energy saving home features (solar panels, energy efficient appliances, etc) is solely affected by households (high short-term) time discount rates (e.g., Train, 1985; Hausman, 1979; Loewenstein and Prelec, 1992; Scarpa and Willis, 2010). Our results strongly propose that the intertemporal trade-off is also affected by pain of paying - a factor previously neglected in the literature on energy efficient or green durable goods. Even though the outcome of the decision by both a spendthrift and a tightwad may mimic that of a high time discounter (if the high up-front cost is sufficiently painful for the tightwad), designing policies that specifically address pain of paying may increase renewable energy adoption.

Many governments, including federal, state, and local governments in the U.S., encourage households to invest in green energy and energy efficiency, and specifically promote installation of solar panels and residential energy efficiency measures in order to reduce greenhouse gases and other pollutants, or accomplish other social or conservation objectives (EPA, 2015; European Commission, 2015; Department of Industry and Science, 2014). U.S. households consume 38 percent of total national energy use, which is more than the energy used by the entire U.S. industrial sector. Most of this energy is consumed for transportation and for heating or cooling of homes (Gardner and Stern, 2008). Substantial reductions of greenhouse gases and other pollutants can therefore be achieved from households shifting over to using renewable energy sources, such as rooftop solar panels, or from installing better insulation and appliances that reduce energy consumption.

Our results imply that policy entailing incentives to promote investments in solar panels need to consider factors beyond the net present value of the investment because households will react to the temporal cost structure itself. In other words, it matters how subsidies or tax credits are provided. The current federal U.S. residential solar investment tax credit incentivizes solar panel purchases, given that it reduces costs. However, it also means households pay the full up-front cost when purchasing the solar panel, while later receiving some of that money back, due to the tax credit. Our results imply that this particular structure of the tax incentive may, however, deter not only consumers with high discount rates, but also consumers who feel considerable pain of paying. Another common state level policy is property tax exemptions for the property value added from solar panels (e.g., Colorado, Iowa, Massachusetts, Missouri, New Mexico, New York, North Dakota, Texas, Vermont, to mention a few). The savings structure of property tax exemptions is, however, similar to that of tax credits. A subsidy (or a sales tax exemption, as implemented e.g., in Florida, Maryland) directly on price of the solar panel may be more effective in increasing demand for solar panels. Further, payment schemes (flat rate pricing) that entail no/low upfront costs, but somewhat higher monthly payments, may appeal to tightwads, depending on the exact trade-off created by their sensitivity to the up-front cost and the overall net present value of the investment.

The paper proceeds as follows. Section 2 presents a theoretical model of mental accounting in the context of energy efficiency and green durables and derives testable hypotheses. Section 3 describes the data and Section 4 discusses the empirical approach. Section 5 presents the results of the empirical analysis, and we conclude with a discussion in Section 6.

2. Model

Consider a consumer who faces a time horizon of T periods. At the beginning of the first period, the consumer pays an up front cost to buy a durable good represented by a bundle of attributes available in her choice set (as in Lancaster, 1966). To keep the exposition aligned with our empirical example we will consider the durable good to be a home and the attributes to include the energy efficiency rating, the presence or absence of green technology (energy efficient design and/or solar PV) and pollution avoided due to adoption of a particular design. The model applies to any other green or energy-saving durable good, however.

During the first and all subsequent periods, the consumer derives a per-period flow utility from using the home and enjoying its attributes, while also incurring energy costs each period. In the initial period, the consumer chooses the home design with the combination of attributes that maximize the present value of the flow utility, net of the discounted flow of energy costs and the up-front cost to purchase the home. However, the consumer's optimization is made subject to the way in which she mentally accounts for these flows over time as we describe below. The consumer's per-period flow utility from home attributes is

$$u_{ij} = \sigma_i s_j + \theta_i z_j \tag{1}$$

The indexes i and j refer to an individual and a choice respectively. The first term $\sigma_i s_j$ represents preferences over the type of technology adopted. Different technology types provide different levels of hedonic benefits. Consumers may derive utility from "conspicuous consumption", i.e., the prestige, luxury, or exclusivity that consumption of the good displays (Akerlof 1980; Cole et al., 1992, Fershtman and Weiss, 1993; Bernheim, 1994; Glazer and Konrad, 1996), or alternatively from "conspicuous conservation", i.e., the social status conferred by demonstration of one's contribution to environmental protection (Griskevicius et. al., 2010; Hards, 2013; Sexton, 2011; Korcaj et al, 2015). For example, efficiently insulated walls are less conspicuous than solar panels and may therefore provide a lower status benefit. The extent of such status utility may depend on the type of technology s_j as well as the individual consumer's preference for social status σ_i. Our model also allows the alternative interpretation that the hedonic benefit could come from the consumer's interest in technological innovation and enjoyment of the technical aspect of the attribute. For example, in a case study of homeowner motivations to adopt solar panels, Schelly (2014) found that consumers' interest in the technological innovation of the energy system played a role. These interpretations are not mutually exclusive; $\sigma_i s_j$ can also represent the status the consumer perceives from being an early adopter of a technological innovation, for example. The term $\theta_i z_j$ represents the warm glow that the consumer gets from protecting the environment by adopting an attribute bundle with greenness level z_j. The greenness of a given home design is measured in terms of pollution avoided as a result of the adoption of energy efficient or green attributes.[6]

Let p_j denote the up front price of adoption of a particular home design[7]. The cost of energy per period for a home with no solar panels or energy efficiency upgrades is given by the parameter c, while $\epsilon_j \in [0, 1]$ denotes the energy efficiency rating, or the share of baseline costs c that is incurred when bundle j is adopted[8]. The cost of energy service each period for choice j is therefore $\epsilon_j c$. The cost of energy c is the same in all periods and does not vary across choices, but the energy bills per period can differ depending on the energy efficiency rating ϵ_j.

Following Prelec and Lowenstein (1998), each episode of consumption and each episode of payment is recorded as a separate transaction in consumers' mental accounts. The experienced utility from these episodes is affected by imputed mental benefits and costs. In each consumption episode, consumers experience utility as if the good was free (u_{ij}) minus an imputed cost ($\lambda \widehat{\pi_{ij}}$) that captures the pain from memories or thoughts of payments that must be made. The imputed cost reduces the enjoyment of the consumption episode, with the parameter λ converting dollars into utility units. In each period in which flow utility is received, this mental accounting structure produces a "net utility" after subtracting mentally imputed costs of payments that are associated with the consumption

[6]The greenness level z_j is not fully captured in technology type s_j. For example, a solar panel on a home in Wyoming offsets a different amount of pollution than an equivalent panel in Oregon. In the discrete choice experiment used in our empirical setting, choice sets were designed to orthogonally vary pollution attributes, technology types, and other attributes in order to capture this, and to identify differences between σ_i and θ_i.

[7]Think of p_j as the down payment, or the increase in down payment required to finance additional attributes.

[8]In terms of our empirical setting, we can consider ϵ_j as the Home Energy Rating System (HERS) score in which $\epsilon_j = 0$ indicates a Net Zero Energy Home, and $\epsilon_j = 1$ indicates a standard home with no energy efficiency or solar upgrades.

episode. Similarly, in each payment episode the mental accounting structure produces a "net disutility" of payments that adjusts the direct disutility of payment ($\lambda\pi_{ij}$) by adding an imputed utility ($\widehat{u_{ij}}$) that consists of the memories or thoughts of enjoyment from consumption of the good that the payments afford. Each time consumers engage in a payment episode, they experience disutility from that payment that is alleviated by thoughts and memories of the enjoyment of the good. In the initial period of our model, π_{ij} contains both the up front cost p_j and the first energy bill $\epsilon_j c$, and in all subsequent periods contains only $\epsilon_j c$.

2.1. **The Consumption Experience: Net Utility of Consumption After Imputed Costs.**

Let time periods in which consumption episodes occur be indexed by b. The net utility at each consumption episode is

$$u_{ij,b} - \lambda\widehat{\pi_{ij,b}}$$

with

$$\widehat{\pi_{ij,b}} = \alpha_i \Big(\frac{u_{ij,b}}{\sum_{s \geq b} u_{ij,s}} \Big) \sum_{s \geq b} \pi_{ij,s}$$

Consumer i gets utility u_{ij} from adopting a given bundle j minus the imputed cost from the pain of payments to be made from the current time onwards. The experience of imputed costs is heterogeneous depending on the consumer's individual sensitivity to the pain of paying α_i. Much of the empirical work in this paper involves variation in α_i as we discuss in more detail below. Variation in α_i is measured by the pain of paying scale developed by Rick et al. (2008), with larger α_i indicating a "tightwad" whose imputed costs of payment excessively regulate the consumer's spending.[9] Likewise, a lower α_i indicates a "spendthrift"

[9]As mentioned in the introduction Rick et al. (2008) develop a scale that characterizes people according to their sensitivity to the pain of paying. The scale ranges from tightwads, i.e. people who experience too much pain, to spendthrifts, i.e. people who experience too little pain. Therefore the degree of tightwadism or spendthriftiness can be used interchangeably, because it indicates the location of individuals on the scale of their sensitivity to the pain of paying.

whose imputed costs are too low to regulate the consumer's spending behavior. In addition, the imputed costs at a particular consumption episode are generated by thoughts of all future payments to be made ($\sum_{s\geq b}\pi_{ij,s}$), but this disutility is also spread over, or "prorated by" the remaining consumption episodes by the prorating factor $\frac{u_{ij,b}}{\sum_{s\geq b}u_{ij,s}}$.[10] Lastly, these imputed monetary costs are converted to utility units through λ.

We make several simplifying assumptions. First, we assume that with a durable good flow benefits are the same in every period so that u_{ij} does not change across consumption episodes. Second, we assume that energy bills are constant over time. One way to think about this assumption is that consumers use their expected average energy bill in their mental accounts. Allowing energy bills to be different each period does not change the qualitative results of the model but significantly complicates the calculations. With these simplifying assumptions, the expression reduces to

$$\begin{aligned} u_{ij} - \lambda\alpha_i\Big(\frac{u_{ij}}{Tu_{ij}}\Big)(p_j + T\epsilon_j c) &= u_{ij} - \lambda\alpha_i(\frac{p_j}{T} + \epsilon_j c) \quad \text{in the initial period and} \\ u_{ij} - \lambda\alpha_i\Big(\frac{u_{ij}}{(T-s)u_{ij}}\Big)((T-s)\epsilon_j c) &= u_{ij} - \lambda\alpha_i\epsilon_j c \quad \text{in all subsequent periods.} \end{aligned}$$

The consumption experience CE_{ij} can be described as the discounted net present value of flow utility from each consumption episode, expressed as

$$CE_{ij} = \Big(u_{ij} - \lambda\alpha_i\epsilon_j c\Big)\Big(\sum_{t=0}^{T}\delta^t\Big) - \lambda\alpha_i\frac{p_j}{T} \tag{2}$$

where δ is the discount factor. This is the present value of utility net of imputed psychological costs, or pain of paying, from energy payments in each period and a single up front payment.

2.2. **The Payment Experience: Net Utility of Payment with Imputed Benefits.**

[10]Notice that the prorating factor spreads the imputed disutility of all future payments over the number of consumption episodes remaining in the life of the durable good, as the disutility of worrying about future payments is spread over the future occasions to enjoy the good. A more detailed discussion of prorating mental accounts is provided in the appendix.

The logic for the payment experience proceeds in a similar manner. Let time periods in which payment episodes occur are indexed by a. The net utility at each payment episode is

$$\widehat{u_{ij,a}} - \lambda \pi_{ij,a}$$

with

$$\widehat{u_{ij,a}} = \frac{1}{\alpha_i}\Big(\frac{\pi_{ij,a}}{\sum_{s \geq a} \pi_{ij,s}}\Big) \sum_{s \geq a} u_{ij,a}$$

Consumer i gets imputed utility $\widehat{u_{ij}}$ from thoughts of consuming bundle j in all future time periods, minus the disutility of making a payment in the current period. Here the experience of imputed benefits is inversely related to the consumer's individual sensitivity to the pain of paying α_i. We can think of α_i more generally as the individual's sensitivity to imputed utility, i.e., the extent to which they allow thoughts of future time periods to influence their enjoyment of the present.[11] This is again conceptually aligned with the scale developed by Rick et al. (2008) upon which we base the spendthrift-tightwad measure we use in the empirical section below; a tightwad with high α_i gives little weight to imputed benefits when payment occurs whereas a spendthrift with low α_i weights the imputed benefits of consumption heavily at the occasion of payment.[12] The pain of the payment during both payment and consumption episodes is therefore greater for tightwads. Lastly, as is the case in consumption episodes, the imputed benefits at a particular payment episode that are derived from expected enjoyment in all future periods ($\sum_{s \geq a} u_{ij,a}$) are prorated by the remaining payments to be made by $\Big(\frac{\pi_{ij,a}}{\sum_{s \geq a} \pi_{ij,s}}\Big)$.

[11]Prelec and Loewenstein scale the imputed benefit from consumption for each payment episode by a parameter β_i. In the context of our model we assume that the pain of paying parameter α_i and the sensitivity to hedonic benefits parameter β_i are inversely related. This implies that an individual has a certain sensitivity to the pain of paying, α_i, which governs the amount of pain she experiences in every consumption episode and the amount of hedonic benefit she experiences in every payment episode, depending on the type of the consumer. If an individual is very sensitive to pain from paying, i.e. α_i is high, then the imputed cost in every consumption episode will be higher, while the imputed benefit in every payment episode will be lower.

[12]The full scale consists of self-reported tightwaddism and self-described behavior. For space saving reasons, we only included self-reported tightwaddism in the choice experiment survey. Data from previous studies (Thunstrom et al., 2017; Thunstrom and Jones-Ritten, 2018) very strongly suggest self-reported tightwaddism highly explains the full scale, i.e., the value added by including the self-reported tightwad behavior questions in the survey would be marginal.

We again assume that u_{ij} and $\epsilon_j c$ are the same in every period. We make the further assumption that the up front cost p_j and the first energy bill $\epsilon_j c$ are separate payment episodes that both occur during the initial period. This is consistent with the timing of most energy-using durable goods purchases in which an up front payment is made at the time of purchase whereas energy costs accrue subsequently during the first period of time in which the good is used. Alternative assumptions about the timing of these first payment episodes produce the same qualitative predictions with less intuitive algebraic expressions. With these assumptions, the expression simplifies to

$$\begin{aligned} \frac{1}{\alpha_i}\frac{p_j}{p_j}Tu_{ij} + \frac{1}{\alpha_i}\frac{\epsilon_j c}{T\epsilon_j c}Tu_{ij} - \lambda(p_j + \epsilon_j c) &= \frac{T+1}{\alpha_i}u_{ij} - \lambda(p_j + \epsilon_j c) \quad \text{in the initial period and} \\ \frac{1}{\alpha_i}\frac{\epsilon_j c}{T\epsilon_j c}Tu_{ij} - \lambda\epsilon_j c &= \frac{1}{\alpha_i}u_{ij} - \lambda\epsilon_j c \quad \text{in all subsequent periods.} \end{aligned}$$

The payment experience PE_{ij} can also be described as the discounted net present value of payment disutility from each payment episode, expressed as

$$PE_{ij} = \frac{1}{\alpha_i}u_{ij}\Big(T + \sum_{t=0}^{T}\delta^t\Big) - \lambda\epsilon_j c\Big(\sum_{t=0}^{T}\delta^t\Big) - \lambda p_j \tag{3}$$

which is the disutility of the up-front payment and discounted energy costs, net of the discounted imputed benefits from each payment episode.

2.3. **Total Utility of Mental Accounts.**

Combining the payment and consumption experiences gives us the total utility from all mental accounts associated with the decision to purchase bundle j:

$$\begin{aligned} \widetilde{U_{ij}} &= CE_{ij} + PE_{ij} \\ &= \Big[\Big(u_{ij} - \lambda\alpha_i\epsilon_j c\Big)\Big(\sum_{t=0}^{T}\delta^t\Big) - \lambda\alpha_i\frac{p_j}{T}\Big] + \Big[\frac{1}{\alpha_i}u_{ij}\Big(T + \sum_{t=0}^{T}\delta^t\Big) - \lambda\epsilon_j c\Big(\sum_{t=0}^{T}\delta^t\Big) - \lambda p_j\Big] \\ &= \frac{1}{\alpha_i}\Big(T + (1+\alpha_i)\sum_{t=0}^{T}\delta^t\Big)u_{ij} - \lambda\epsilon_j c(1+\alpha_i)\sum_{t=0}^{T}\delta^t - \Big(1 + \frac{\alpha_i}{T}\Big)\lambda p_j \end{aligned} \tag{4}$$

Substituting the expression for u_{ij} into the expression for total utility $\widetilde{U_{ij}}$ gives

$$\widetilde{U_{ij}} = \frac{1}{\alpha_i}\Big(T + (1+\alpha_i)\sum_{t=0}^{T}\delta^t\Big)(\gamma_i s_j + \theta_i z_j) - \lambda\epsilon_j c(1+\alpha_i)\sum_{t=0}^{T}\delta^t - \Big(1+\frac{\alpha_i}{T}\Big)\lambda p_j \qquad (5)$$

Note that in the absence of mental accounting, we would have

$$U_{ij} = (\gamma_i s_j + \theta_i z_j)\sum_{t=0}^{T}\delta^t - \lambda\epsilon_j c\sum_{t=0}^{T}\delta^t - \lambda p_j \qquad (6)$$

Notice that as α_i grows, the disutility of up front payments and energy bills are magnified in $\widetilde{U_{ij}}$ whereas the marginal utility of attributes approach their neoclassical values. Conversely as α_i shrinks toward zero, the weight on the utility of attributes becomes magnified while the disutility of payments approach their neoclassical values. We now explore the comparative statics of how a consumer's utility changes with respect to attributes of the choice and individual characteristics in more detail.

2.4. **Comparative Statics.**

The main research question of this paper is how the pain of paying affects adoption of energy efficient and green durable goods, such as an efficient home design or solar PV technology. We first note that greater pain of paying unambiguously reduces the utility of any transaction, regardless of the relative magnitudes of up front versus per-period costs:

$$\frac{\partial\widetilde{U_{ij}}}{\partial\alpha_i} = -\frac{T + \sum_{t=0}^{T}\delta^t}{\alpha_i^2}(\gamma_i s_j + \theta_i z_j) - \lambda\epsilon_j c\sum_{t=0}^{T}\delta^t - \frac{\lambda}{T}p_j < 0 \qquad (7)$$

We can also use equation (22) to calculate how the change in choice attributes will affect the consumer's utility from adopting a particular bundle j. In general, the marginal utility of adopting bundle j with respect to a particular attribute depends on individual characteristics, such as the sensitivity to the pain of paying, α_i, the discount rate δ, the marginal utility of money λ, and the per period preference parameters for the particular attributes (γ and θ). The model implies that individual heterogeneity in sensitivity to pain of paying, i.e. the degree of tightwadism, affects decisions through the marginal utilities of the attributes.

For example, if the energy efficiency of bundle j improves (ϵ_j declines), then the utility of bundle j increases, holding other attributes equal:

$$\frac{\partial \widetilde{U_{ij}}}{\partial(-\epsilon_j)} = \lambda c(1+\alpha_i)\sum_{t=0}^{T}\delta^t > 0 \tag{8}$$

Importantly, the marginal utility of energy efficiency[13] increases with greater α_i. This implies that people with higher sensitivity to pain of paying, i.e. tightwads, value bill savings to a greater extent in their adoption decision.

For an apples-to-apples comparison, it is also instructive to compare the marginal utility of a permanent bill reduction to an equivalent reduction in the up front cost of the bundle, in the mental accounting case versus the benchmark neoclassical model without mental accounting:

$$\frac{\partial \widetilde{U_{ij}}}{\partial(-\epsilon_j c\sum_{t=0}^{T}\delta^t)} = \lambda(1+\alpha_i), \qquad \frac{\partial U_{ij}}{\partial(-\epsilon_j c\sum_{t=0}^{T}\delta^t)} = \lambda \tag{9}$$

$$\frac{\partial \widetilde{U_{ij}}}{\partial(-p_j)} = \lambda\Big(1+\frac{\alpha_i}{T}\Big), \qquad \frac{\partial U_{ij}}{\partial(-p_j)} = \lambda \tag{10}$$

In the neoclassical case, the marginal utility of a unit of discounted energy cost savings and the marginal utility of a decrease in the up front cost are both equal to the marginal utility of money (λ). In the mental accounting model, however, these marginal utilities are increasing in the sensitivity to pain of paying. Further, for *any discount rate*, consumers with high α_i value the discounted energy bill savings more than the up front cost savings. This effect makes high α_i consumers appear to be more patient when in fact they have lower utility; the imputed costs of paying $\epsilon_j c$ over time loom large in the mental accounts while the imputed costs of paying p_j are dissipated over the time horizon - an effect which is a feature of the mental accounting framework, not driven by the discount rate.

[13] This is specifically the cost savings aspect of energy efficiency and does not include any potential public goods or warm glow aspects of conserving energy.

In addition, the marginal utility of hedonic attributes (greater status or innovativeness of technology, greater pollution avoidance) decreases with the sensitivity to pain of paying α_i:

$$\frac{\partial \widetilde{U_{ij}}}{\partial s_j} = \frac{1}{\alpha_i}\Big(T + (1+\alpha_i)\sum_{t=0}^{T}\delta^t\Big)\gamma_i > 0 \tag{11}$$

$$\frac{\partial \widetilde{U_{ij}}}{\partial z_j} = \frac{1}{\alpha_i}\Big(T + (1+\alpha_i)\sum_{t=0}^{T}\delta^t\Big)\theta_i > 0 \tag{12}$$

This occurs because the pain of paying reduces the imputed benefits from the payment experience, so that the disutility of payment episodes is less alleviated by thoughts of the consumption episodes.

This analysis produces the following empirical predictions which we test in the following sections using a discrete choice survey experiment with residential solar and energy efficiency upgrades:

(1) Tightwads will be less likely to adopt bundles with conspicuous or advanced technology
(2) Tightwads will be less likely to adopt bundles with large environmental benefits
(3) Tightwads will be more likely to adopt bundles with lower up front costs and/or lower long-run energy costs, but will prefer bundles with lower long-run energy costs to those with equivalently lower (in a pure discounting sense) up front costs.

3. Empirical Approach

We empirically test the predictions of the model using data from an online discrete choice experiment with solar and energy efficient homes in order to estimate equation (22), the total utility of mental accounts. Respondents were shown a variety of home options and asked to choose between a standard model and three alternatives with various solar and energy efficiency technologies, avoided pollution damages, energy bill savings, and increased up front costs. We describe the experiment and data in more detail below. In order to proceed with empirical analysis, we apply the random utility framework to (22) by assuming that utility consists of observable factors described in $\widetilde{U_{ij}}$, and an additional component ν_{ij} that is known to the agent at the time of choice but unobservable to the researcher (Louviere et al., 2000):

$$V_{ij} = \widetilde{U_{ij}} + \nu_{ij} = \beta_i' x_j + \nu_{ij}, \tag{13}$$

where ν_{ij} is modeled as an *i.i.d.* extreme value random variable, $x_j = (s_j, z_j, \epsilon_j c, p_j)$ is the vector of attributes in bundle j (technology type, greenness, energy bill savings, and up front costs), β_i is a vector of household-specific coefficients described in (22), and V_{ij} is the total utility to person i of attribute bundle j.

On each choice occasion, individuals select the bundle j that maximizes their utility among the options in the set, i.e., choose j if:

$$\widetilde{U_{ij}} + \nu_{ij} > \widetilde{U_{ik}} + \nu_{ik} \text{ for all } k \neq j.$$

If ν_{ij} has an extreme value distribution, then we can use the conditional logit model for estimation. One limitation of the conditional logit model is that it assumes parameter homogeneity. We can see from equation (22) that heterogeneity in β_i may come from individual-specific sensitivity to the pain of paying α_i, or from heterogeneity in tastes and preferences. We recover heterogeneity in β_i from the conditional logit model by interacting each attribute in x_j with an individual-level measure of α_i that was gathered in the survey, as well as additional household covariates.

The assumption of *i.i.d.* errors across choices also results in the independence of irrelevant alternatives (IIA) property, which does not allow for flexible substitution patterns among choices. In order to avoid the IIA property and to allow parameter heterogeneity, we also estimate a mixed logit (also called random-coefficient logit) model that allows the coefficients on each attribute to vary randomly among individuals. Mixed logit allows for unrestricted substitution patterns, random taste variations and correlation in unobserved factors across choice occasions. (McFadden & Train, 2000).

A desirable feature of a mixed logit model specification is that we can define the vector of all or some coefficients to be normally distributed random variables that may be functions of individual-specific characteristics. We can use choice-specific attributes along with person-specific characteristics to test if individuals are heterogeneous in the degree with which they experience the pain from paying, and how their pain of paying affects their adoption of energy efficiency and solar technology.

The mixed logit probability can also be derived from utility-maximizing behavior over J alternatives. Let the vector of coefficients β_i in equation (13) be distributed over the decision makers in the population with density $f(\beta)$. We specify the parameter vector to be a random vector that is a function of observable individual-specific characteristics including the pain of paying measure, age, and income. The density, $f(\beta)$, is a function of parameters η that represent the mean and covariance of the β's in the population. In this setting β varies over decision makers rather than being fixed, as in a standard logit.

The decision maker knows the value of his own β_i and ν_{ij} for all j and chooses alternative j if and only if $V_{ij} > V_{ik}$ for all $j \neq k$. The researcher observes the x_j's but not β_i's or the ν_{ij}'s. If the researcher observed β_i's, then the choice probabilities would be a standard logit, since the ν_{ij}'s are *i.i.d.* extreme value. That is, the probability conditional on β_i is

$$L_{ij}(\beta_i) = \frac{exp(x_j'\beta_i)}{\sum_{j=1}^{J} exp(x_j'\beta_i)}$$

However, the researcher does not know β_i and therefore cannot condition on them. The unconditional choice probability is therefore the integral of $L_{ij}(\beta_i)$ over all possible values of β_i

$$P_{ij} = \int \frac{exp(x_j'\beta_i)}{\sum_{j=1}^{J} exp(x_j'\beta_i)} f(\beta) d\beta$$

which is the mixed logit probability.

In this setting there are two sets of parameters to be estimated: β_i and η. Parameters β_i enter the logit formula and have density $f(\beta)$. Parameters η describe this density. Using the above formula, we integrate out the β_i to obtain choice probabilities. The mixed logit choice probabilities are then functions of η (McFadden & Train, 2000). There is no closed form solution to the above integral. The probabilities are approximated through simulation of the distribution of $f(\beta|\eta)$ and maximization of the simulated log-likelihood function.

3.1. **Data and estimating equation.** The data for the analysis comes from an online discrete choice experiment reported in Gilbert et al. (2016) and Gardzelewski et al. (2017). A sample of 800 individuals from Western U.S. states who had purchased a home in the last five years or planned to purchase in the next three years was drawn from the GfK Knowledge Panel. The GfK Knowledge Panel is a representative random sample of US households recruited by GfK to take occasional surveys. Recent and expected future home buyers were selected in order to represent the relevant market as well as individuals with some familiarity with the home-buying process. Individuals were paid $20 for a completed survey.

Each choice set in the survey included four home design alternatives, from which respondents chose the option they would be most likely to purchase. Respondents were shown a photo-realistic architectural image of each alternative in the choice set. Alternatives were differentiated by technology type (s_j), pollution damages avoided (z_j), annual energy bill savings (ϵ_j), and up front costs (p_j). A "standard" version of the home with no technology upgrades, pollution or energy cost savings, or additional up front costs, was available as the outside option in every choice set. Each respondent completed eight choice tasks. Attributes were varied orthogonally across choices in the experimental design.

Technology types included solar panel options and an energy efficiency package. Solar options included traditional roof-mounted solar panels visible from the front of the home, solar panels mounted on the back of the home and not visible from the front of the home, solar panels that were architecturally integrated into the roofline, and no solar panels. The energy efficiency option was the presence or absence of a package including advanced insulation and windows.

Pollution damages avoided were presented as an annual dollar amount of social damage that would be avoided by foregone power plant emissions if the particular technology bundle was installed on the home. These ranged from \$0 to \$600 in annual avoided pollution damages. Similarly, annual energy bill savings were presented as an annual dollar amount of avoided bill expenditures ranging from \$0 to \$2400. Up front costs were described as the increase in the price of the home in order to install the particular technology bundle, and ranged from \$0 to \$30,000.

Respondents were also asked a battery of questions that reveal their attitudes toward spending in order to construct a measure of tightwadism, which acts as a proxy for the pain of paying. We used questions from the tightwad-spendthrift scale created by Rick et al. (2008). However, the full battery of questions from Rick et al. (2008) was truncated in order to allow respondents to complete the entire survey in under 20 minutes. The following two questions were used. On a scale of 1 to 6, with 1 being "strongly disagree" and 6 being "strongly agree" the individuals were asked to what extent they agree or disagree with the following statements about themselves: "I often spend money when I should not- I have trouble limiting spending" and "I often don't spend money when I should- I have trouble spending money". These questions were used to construct the measure of "tightwadism" that runs from 1 to 12, higher corresponding to more spendthriftiness/less tightwadism.

Respondents were also asked questions regarding their general preferences towards saving the environment, their perception of people who invest in energy efficiency and solar panels, individual characteristics that describe their spending habits and attitudes, and degree of patience and self-control, as well as general demographics such as age and income.

Using responses to these questions, we estimate specifications of the form

$$
\begin{aligned}
V_{ij} = \quad & \eta_1 \times Price_{ij} + \eta_2 \times Efficient_{ij} + \eta_3 \times Rear\ Solar_{ij} + \eta_4 \times Rooftop\ Solar_{ij} \\
& + \eta_5 \times Integrated\ Solar_{ij} + \eta_6 \times Bill\ Savings_{ij} + \eta_7 \times Pollution_{ij} \\
& + \eta_8 \times X_i \times Price_{ij} + \eta_9 \times X_i \times Efficient_{ij} + \eta_{10} \times X_i \times Rear\ Solar_{ij} \\
& + \eta_{11} \times X_i \times Rooftop\ Solar_{ij} + \eta_{12} \times X_i \times Integrated\ Solar_{ij} \\
& + \eta_{13} \times X_i \times Bill\ Savings_{ij} + \eta_{14} \times X_i \times Pollution_{ij} + \nu_{ij}
\end{aligned}
$$

where $Price_{ij}$ is the up front cost of the bundle. $Efficient_{ij}$, $Rear\ Solar_{ij}$, $Rooftop\ Solar_{ij}$, and $Integrated\ Solar_{ij}$ are dummy variables indicating whether a particular technology type was chosen. $Bill\ Savings_{ij}$ and $Pollution_{ij}$ are continuous variables for the amount of energy cost savings and avoided pollution damage from the chosen bundle. Each of these attributes is interacted with a vector of individual-specific covariates X_i including the pain of paying (tightwadism/spendthriftiness) scale, age, and income. Variable descriptions, descriptive statistics and expected signs of the variables are reported in Table (1).[14]

We estimate the model first using a standard conditional logit specification. Given the importance of individual heterogeneity in their sensitivity to pain of paying in adoption of energy efficient design and solar PV technology, the tightwadism/spendthriftiness data on individuals is the basis for exploring preference heterogeneity. To explore individual heterogeneity, we also segment the data into two groups on the basis of the tightwadism (spendthriftiness) index: those with a score of 6 or below, and those with a score above 6. We reestimate the conditional logit model on each of these groups. In order to further investigate parameter heterogeneity, we then estimate the model using the mixed logit specification. We allow parameters of the attributes that are found to be significant in the conditional logit model to be estimated as random parameters as a function of individuals' tightwadism/spendthriftiness. The coefficients on the remaining variables are estimated as fixed parameters.

A description of variables, summary statistics and expected signs of the coefficients can be found in Table 1

4. Results

Table 2 reports estimates from the conditional logit specification on the full sample, the tightwad subsample, and the spendthrift subsample. The regressors are jointly significant in each model, and the pseudo-R^2 for each model is between 0.14 and 0.16 indicating a

[14]Expected signs reported in the table come from the results of the theoretical model in section 2.

Table 1. Summary Statistics

Variable	Mean	Std. Dev.	N	Description	Expected Sign
Price	13.121	11.28	27680	Price in thousands of dollars	(-)
Bill Savings	1.031	0.872	27680	Annual bill savings in dollars	(+)
Pollution	0.283	0.228	27680	Annual pollution avoided in dollars of economic damage	(+)
Rear Solar	0.214	0.41	27680	Dummy for solar chosen on rear of home	(+)
Rooftop Solar	0.202	0.401	27680	Dummy for solar chosen on front of home	(+)
Integrated Solar	0.195	0.397	27680	Dummy for design-integrated solar chosen	(+)
Efficient Design	0.509	0.5	27680	Dummy for energy efficiency package chosen	(+)
Spendthrift	7.029	1.808	27296	Tightwad/spendthrift scale	none
Age	44.215	15.371	25952	Age	(?)
Income	12.888	4.252	25952	Household income categories	(?)
Spendthrift×Price	92.178	85.147	27296	The interaction of price and spendthrift variables	(+)
Spendthrift×Bill Savings	7.247	6.604	27296	The interaction of bill savings and spendthrift variables	(-)
Spendthrift×Pollution	1.988	1.732	27296	The interaction of pollution avoided and spendthrift variables	(?)
Spendthrift×Rear Solar	1.502	3.001	27296	The interaction of rear solar and spendthrift variables	(+)
Spendthrift×Rooftop Solar	1.421	2.937	27296	The interaction of rooftop solar and spendthrift variables	(+)
Spendthrift×Integrated Solar	1.375	2.901	27296	The interaction of integrated solar and spendthrift variables	(+)
Spendthrift×Efficient Design	3.579	3.743	27296	The interaction of efficient and spendthrift variables	(?)

Note: Expected signs reported in the table are derived from the results of our theoretical model. Spendthriftiness index runs from 1 to 12, higher values corresponding to more spendthriftiness/ less tightwadism. Greenness variable is measured in terms of pollution avoided as a result of adopting a given home design.

reasonable fit.[15] All interactions are mean-centered so the base coefficients can be interpreted as the coefficient for the mean respondent.

In the full sample, the coefficients on each attribute for the mean respondent are all statistically significant at the 1% level and have the expected sign. The mean respondent prefers bundles with lower up front costs, more bill savings, and more pollution avoidance, with stronger preference for a dollar in bill savings over a dollar in avoided pollution damage. All technology types increase the utility of the bundle for the mean respondent. Among technology types, the mean respondent most strongly prefers solar that cannot be seen from the front of the home and least strongly prefers an energy efficiency upgrade package, holding constant all other attributes including up front cost, bill savings, and pollution avoidance. These baseline results confirm previous analyses of this data in Gilbert et al. (2016). This specification also controls for attribute interactions with age and income, which might be correlated with the spendthrift scale interactions. We find that the hedonic technology benefits are lower for older respondents, particularly among visible technologies (rooftop and design integrated solar) and among spendthrifts. We also find that higher-income respondents have a stronger preference for bill savings (particularly among spendthrifts) and energy efficiency technologies (particularly among tightwads).

[15] Pseudo-R^2 values between 0.2 and 0.4 are considered to have a good fit for these models (Domencich & McFadden, 1975).

The prediction from section 2 that consumers with a larger pain of paying will have a stronger preference for both lower up front costs *and* lower long run energy costs is confirmed. The coefficient on the interaction of price and the spendthrift scale is positive and statistically significant in the full sample. This indicates that tightwads dislike an increase in the up front cost more than spendthrifts. In addition, the base price coefficient for the spendthrift subsample is statistically significantly larger than for the tightwad subsample. Within both subsamples, however, there is heterogeneity in the price responsiveness that can be seen in the price and spendthrift interactions, as well as the price and age interactions.

In addition, the coefficient on the interaction of bill savings with the spendthrift scale is negative and significant in the full sample, and the base bill savings coefficient is statistically significantly larger for tightwads than for spendthrifts. Again consistent with the mental accounting theory, long run bill savings are more valuable to tightwads than to spendthrifts. In other words, rather than having an easier time investing in money-saving durable good the way a rational consumer with a low discount rate would, consumers with a high pain of paying dislike both up front and long run costs. The implied discount rates are also slightly higher for spendthrifts (10.9%) than for tightwads (10.6%) which is also consistent with our prediction that tightwads will act as if they are more patient when in fact they are more conflicted.[16] However, these differences are not large.

The coefficients on pollution avoidance and technology type are also consistent with the predictions of the theory in Section 2. The empirical finding mentioned above that the technology type base coefficients are all statistically significant and positive for the mean respondent (conditional on the price, pollution avoided, and energy savings of the bundle) suggests that these technologies provide hedonic benefits beyond their effect on the household budget or their environmental impact. This hedonic benefit is larger for solar technologies than for energy efficiency, which is consistent with the idea that solar is perceived as a newer, more exciting technology. When we consider the spendthrift interactions, we see that spendthrifts value hedonic technology benefits to a greater extent than tightwads - and

[16] The implied discount rates were calculated by dividing the base price coefficient by the annual bill savings coefficient, i.e., the inverse of the willingness to pay up front for a dollar saved every year in perpetuity.

more so for the more "exciting" technology (solar). In the full sample, the coefficients on the interaction of the spendthrift scale with all of the solar adoption variables are positive and of similar magnitudes; these coefficients are statistically significant for the rear solar and design-integrated solar interactions. Similarly, the base solar attribute coefficients are larger in the spendthrift subsample than in the tightwad subsample. By comparison, the coefficient on the interaction of the spendthrift scale with the energy efficiency upgrade is an order of magnitude smaller than the other technology interactions and is not statistically significant, although the base efficiency attribute is larger in the spendthrift subsample than in the tightwad subsample.

The results are also consistent with the "warm glow" from pollution avoidance forming another hedonic benefit in the consumer's mental accounts, although this result is weaker. The coefficient on the spendthrift scale and pollution interaction is positive but not significant, and the pollution avoidance coefficient is larger in the spendthrift subsample than in the tightwad subsample.

Table 2: Conditional Logit

	Full Sample	Tightwads	Spendthrifts
Price	-0.0557***	-0.0643***	-0.0523***
	(0.00166)	(0.00303)	(0.00201)
Bill Savings	0.522***	0.609***	0.482***
	(0.0223)	(0.0403)	(0.0270)
Pollution	0.435***	0.336**	0.515***
	(0.0758)	(0.136)	(0.0921)
Rear Solar	0.439***	0.277***	0.531***
	(0.0472)	(0.0837)	(0.0575)
Rooftop Solar	0.356***	0.274***	0.404***

Continued on next page

Table 2 – continued from previous page

	Full Sample	Tightwads	Spendthrifts
	(0.0474)	(0.0841)	(0.0577)
Integrated Solar	0.311***	0.215**	0.367***
	(0.0485)	(0.0859)	(0.0591)
Efficient Design	0.215***	0.130*	0.251***
	(0.0370)	(0.0665)	(0.0448)
Spendthrift×Price	0.00256***	-0.00556*	0.00274*
	(0.000914)	(0.00303)	(0.00156)
Spendthrift×Bill Savings	-0.0261**	-0.0545	0.00516
	(0.0123)	(0.0419)	(0.0211)
Spendthrift×Pollution	0.0101	0.292**	-0.174**
	(0.0418)	(0.140)	(0.0726)
Spendthrift×Rear Solar	0.0585**	-0.0956	0.0517
	(0.0261)	(0.0861)	(0.0453)
Spendthrift×Rooftop Solar	0.0404	-0.0746	0.0657
	(0.0266)	(0.0874)	(0.0457)
Spendthrift×Integrated Solar	0.0478*	-0.0242	0.0644
	(0.0270)	(0.0888)	(0.0470)
Spendthrift×Efficient Design	0.00453	-0.0863	-0.0303
	(0.0207)	(0.0707)	(0.0351)
Age×Price	-0.0000283	0.000412**	-0.000253*
	(0.000110)	(0.000190)	(0.000136)
Age×Bill Savings	0.000200	0.000984	-0.000463
	(0.00148)	(0.00259)	(0.00182)
Age×Pollution	-0.00155	-0.0130	0.00366

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Table 2 – continued from previous page

	Full Sample	Tightwads	Spendthrifts
	(0.00500)	(0.00877)	(0.00616)
Age×Rear Solar	-0.00387	0.000193	-0.00590
	(0.00311)	(0.00538)	(0.00385)
Age×Rooftop Solar	-0.00883***	-0.00198	-0.0125***
	(0.00313)	(0.00544)	(0.00386)
Age×Integrated Solar	-0.00698**	-0.00526	-0.00818**
	(0.00319)	(0.00548)	(0.00396)
Age×Efficient Design	-0.00143	0.000922	-0.00253
	(0.00245)	(0.00422)	(0.00303)
Income×Price	-0.000310	0.000114	-0.000308
	(0.000397)	(0.000772)	(0.000468)
Income×Bill Savings	0.0196***	0.00219	0.0249***
	(0.00534)	(0.0105)	(0.00628)
Income×Pollution	-0.0203	-0.0339	-0.0175
	(0.0180)	(0.0348)	(0.0213)
Income×Rear Solar	0.00388	0.0275	-0.00420
	(0.0113)	(0.0214)	(0.0134)
Income×Rooftop Solar	-0.000428	0.0134	-0.00521
	(0.0112)	(0.0210)	(0.0134)
Income×Integrated Solar	-0.00522	0.0127	-0.0106
	(0.0116)	(0.0218)	(0.0138)
Income×Efficient Design	0.0250***	0.0701***	0.00871
	(0.00874)	(0.0168)	(0.0104)
LR	2440	932	1594

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Table 2 – continued from previous page

	Full Sample	Tightwads	Spendthrifts
p-value	0.000	0.000	0.000
pseudo-R^2	0.14	0.16	0.14
N	25,464	8,540	16,924

Note: Coefficients from the conditional logit model estimated on the full sample and on subsamples of tightwads and spendthrifts. The regressors are jointly significant in each specification. Standard errors are in parentheses with *** p<0.01, ** p<0.05, * p<0.1.

For ease of interpretation, we also report the average marginal effects from the conditional logit specifications in Table 3. These represent the average change in the probability of choosing some type of solar or energy efficiency upgrade (rather than the standard home) for a one unit change in each explanatory variable. This representation of the results confirms what was described above but offers some additional insights. We can also see from the full sample that each unit increase in the spendthrift scale is associated with almost one percentage point increase in the probability of buying a green durable good, although as mentioned earlier, within each subsample this effect moves in opposite directions suggesting that there is some nonlinearity in the relationship. It is also interesting to note that income increases the probability of adoption to a much greater degree among tightwads than among spendthrifts, which confirms the notion of pain of paying as a form of excessive attention to opportunity cost. Lastly, although age reduces the probability of adoption, this effect occurs primarily through spendthrifts.

As a robustness check, we repeat the estimation exercise using the mixed logit model, allowing the choice attribute coefficients to vary randomly. The mental accounting model presented in section 2 suggests that individuals may weigh attributes of an alternative differently in their decision to adopt a home design based on their individual pain of paying as

Table 3. Marginal Effects on Probability of Choosing a Solar or Energy Efficiency Upgrade

	Total	Tightwads	Spendthrifts
Price	-0.0125***	-0.0142***	-0.0116***
	(0.000347)	(0.000585)	(0.000429)
Bill Savings	0.117***	0.134***	0.107***
	(0.00482)	(0.00847)	(0.00584)
Pollution	0.0978***	0.0748**	0.115***
	(0.0169)	(0.0299)	(0.0204)
Rear Solar (d)	0.0987***	0.0610***	0.118***
	(0.0104)	(0.0184)	(0.0126)
Rooftop Solar (d)	0.0798***	0.0602***	0.0896***
	(0.0105)	(0.0185)	(0.0127)
Integrated Solar (d)	0.0698***	0.0473**	0.0816***
	(0.0108)	(0.0189)	(0.0130)
Efficient Design (d)	0.0478***	0.0286**	0.0556***
	(0.00825)	(0.0146)	(0.00990)
Spendthrift	0.00947***	-0.0272***	0.00338
	(0.00286)	(0.00899)	(0.00508)
Age	-0.00113***	0.000401	-0.00203***
	(0.000335)	(0.000540)	(0.000415)
Income	0.00461***	0.00846***	0.00331**
	(0.00120)	(0.00206)	(0.00146)
N	25,464	8,540	16,924

Note: Average marginal effects for the conditional logit model estimated on the full sample and on subsamples of tightwads and spendthrifts. Standard errors are in parentheses with *** p<0.01, ** p<0.05, * p<0.1. (d) stands for discrete change of dummy variable from 0 to 1.

well as other individual characteristics. Moreover, in the conditional logit results we found significant coefficient heterogeneity by age and income in addition to the spendthrift score. This suggests that attribute coefficient estimates may differ between individuals. If individual heterogeneity is present in the model, the conditional logit incorrectly constrains the parameter estimates to be fixed across individuals. For parsimony in the mixed logit specifications, we include only the age and income interactions that were statistically significant in the corresponding conditional logit model. The results are reported in Table (4).

The pattern of differences along the pain of paying dimension observed in the conditional logit results are somewhat more stark in the mixed logit results. For example, the interactions of the spendthrift scale with the price and bill savings variables in the full sample are larger in magnitude than in the conditional logit results, suggesting there may be even greater conflict in intertemporal tradeoffs. In addition, we can see from the estimated coefficient standard deviations that within each subgroup there is significant heterogeneity in preferences for up front costs versus long run savings. Within the tightwad subsample there is also significant heterogeneity in preferences for solar and energy efficiency technologies.

5. Conclusion

In this paper, we examine how the psychological pain of paying impacts investment in renewable energy. Pain of paying is essential to responsible spending decisions, as it acts as a proxy for the opportunity cost of spending (Prelec and Loewenstein, 1998; Loewenstein and O'Donoghue, 2006; Rick, 2013). Consumers experience different inherent levels of pain of paying. People who feel too much pain of paying ("tightwads") are deterred from spending, while those who feel too little pain of paying ("spendthrifts") spend too much. Previous studies show that pain of paying affects intertemporal decision-making, including preferred cost structures. Pain of paying may therefore be an important determinant of investments in energy efficiency and renewable energy, such as solar panels, characterized by high up front costs and future cost savings.

To analyze the impact of pain of paying on investments in renewable energy, we develop a theoretical mental accounting model that entails pain of paying. Our model shows that pain of paying may play a key role in renewable energy investment decisions, and generates the following main predictions. Tightwads are less likely to adopt conspicuous, or advanced, technology, compared to spendthrifts. Tightwads are also less likely to adopt home attributes that generate large environmental benefits. Both types of consumers are deterred by high up front costs, but tightwads are more sensitive to those costs than are spendthrifts. At the same time, tightwads respond more to energy cost savings over time.

Tightwads' behavior may therefore mimic that of consumers with low time discount rates, but the origin of the behavior is vastly different - tightwad behavior responds to the imputed (or emotional) costs in the mental accounts, instead of an underlying time discount rate. We use a discrete choice experiment to empirically test these theoretical results and find support for our model predictions. Our empirical model also generates additional insights. For example, our theoretical model does not specify whether certain types of imputed benefits are more likely than others to be under- or overweighted in the mental accounting process; the model does not distinguish between the warm glow of pollution avoidance, the social status associated with green signaling, or a preference for technological innovation. Empirically we find that both groups receive some utility for technology adoption and pollution avoidance, but that spendthrifts differ from tightwads most on pollution avoidance, and on the less conspicuous solar configurations (rear mounted or design integrated as opposed to front facing). This is not to say that status signaling does not play a role in green durable adoption; rather, we cannot say that tightwads underweight this source of utility relative to spendthrifts, as they do with other types of imputed benefits.

The main contribution of our analysis lies in our finding that pain of paying is important in determining consumer investment in renewable energy and energy efficiency. Standard economic theory would suggest a low time discount rate to be the only reason for consumers to place a relatively higher value on future cost savings from adoption of green durables, compared to the up front cost of the technology investment.

Our findings have important policy implications. Our results underline the importance of keeping up front costs low to incentivize all consumers, i.e., spendthrifts and tightwads alike, to adopt solar panels. Our results imply both spendthrifts and tightwads are deterred from investing in solar panels by high up front costs. Policies that reduce up front costs may be most valuable for tightwads, who are most sensitive to such costs and have a lower propensity to adopt any green durable despite their greater utility of long run savings. Income affects solar panel adoption more for tightwads than for spendthrifts. This suggests that tightwads, who are more attentive to constraints, may respond more to subsidies.

Commonly implemented policies aimed at promoting investments in renewable energy, such as tax deductions and property tax exemptions for such investments, may incentivize both spendthrifts and tightwads. The drawback of such policies, though, is that they too are affected by intertemporal trade-offs for the consumer, who need to pay the full up front cost today, while receiving the deduction (or exemption) in the future. Subsidizing the investment in the renewable energy technology at the point-of-purchase may be more effective. Many states in the U.S. have already implemented these policies, which suggests there may be scope for future research to more directly evaluate the relative impact of these policies on adoption of renewable energy technology. Other policy options aimed at reducing the technology investment are solar lease programs, or government authorities lending homeowners the money needed to cover the technology investment, over an extended period of time (Coughlin and Cory, 2009). Home owners may also be encouraged to join community based programs, where communities jointly invest in the renewable energy source and therefore benefit from economies of scale. Considering our finding of an innate hedonic benefit for the technology itself, community based programs may be most effective if they (a) facilitate individual installations at the household location rather than a single remote solar farm collectively subscribed from a distance, and (b) provide a mechanism for group bargaining with the solar provider to reduce up front costs (e.g., Bollinger et al., 2016).

Our results also imply that policies aimed at reducing high up front investment costs may be complemented by different communication strategies to spendthrifts and tightwads. Information about the technology itself, as well as its design, may incentivize spendthrifts to adopt solar panels. Tightwads, on the other hand, place lower values on the technology, but are likely to respond more to information on the future cost savings generated by the technology. Differentiating information over consumer subgroups may therefore be important in increasing adoption rates of renewable energy technology. However, our results suggest caution in how policy should attempt to induce adoption. A policy that increases adoption by leveraging spendthrifts inability to optimally regulate their spending (either purposefully or as an unintended consequence) will inefficiently allocate the burden of green durable adoption and environmental protection on those who already spend more than is optimal for them.

Appendix on Prorating of Mental Accounts

Prelec and Loewenstein proposed a mental accounting model in which each episode of consumption and payment is accompanied by imputed benefits and costs. They argue that thoughts of payment can diminish the pleasures of consumption, and the pain of making payments can be buffered by thoughts of the benefits that these payments acquire. In a double- entry mental accounting model, each consumption and payment episode is recorded as a separate transaction in consumers' mental accounts and reflects the "net" utility after subtracting the disutilty of associated payments and "net" disutility of payments after subtracting the utility of associated consumption.

Each time a consumer engages in an episode of consumption they experience utility net of the imputed cost of consumption. Imputed cost of consumption is the pain from the thoughts of associated payment for the consumption good. This pain is a real psychological burden associated with making a payment, which can be more or less salient depending on the type of purchase. Formally, we can express the experienced utility of consumption as utility from consuming a good as if it were free (u_{ij}) minus the imputed cost ($\widehat{p_{ij}}$)[17] multiplied by a payment/utility conversion parameter, λ.

$$u_{ij} - \lambda\widehat{p_{ij}}$$

Similarly, each time consumers engage in a payment episode, they experience the disutility from payment net of the imputed benefit of consumption. Imputed benefit of consumption represents the utility from thoughts of consuming a good that is being paid for. Formally, we can express the experienced disutility of making a payment as the disutility of payment if there were no associated benefits λp_j[18] buffered by the imputed benefits of the payment episode $\widehat{u_{ij}}$

[17]Notice that $\widehat{p_{ij}}$ varies across individuals and choice attributes. Imputed cost of consumption is a psychological pain of paying which is different for every individual and more or less salient for different consumption types.

[18]In this case p_j represents the cost of consumption converted to utility terms by λ, which varies across consumption types.

$$\widehat{u_{ij}} - \lambda p_j$$

The decision whether to purchase a good will depend on the sum of consumption and payment experiences as defined by above equations. Consumers' mental accounting rules determine how they allocate imputed benefits and costs over consumption and payment episodes. We adopt three mental accounting assumptions described in Prelec and Loewenstein (1998) that specify how particular costs are matched with particular benefits when consumption and payment episodes are not simultaneous and benefits of consumption extend over time.[19]

Prospective accounting assumption specifies how the benefits of consumption are affected by the timing of payments. We assume that past events are largely written off in the minds of the consumers, so their impact is essentially zero. The impact of future events is assumed to be constant across time. Therefore, when making purchases consumers care about the total sum of residual (future) utilities and payments.

When a good purchase includes multiple payment and/or consumption episodes, we need to be able to assign payments to consumption and vice versa. Prorating assumption is an amortization rule for dividing a single payment over multiple consumption episodes, or a single benefit (utility) over multiple payments. Under this assumption, consumers prorate residual payments to residual consumption, and vice versa.

Coupling assumption introduces a coefficient of conversion of payments into imputed costs and of consumption utilities into imputed benefits. The conversion coefficient reflects individuals' sensitivity to pain of paying. It dictates the degree to which consumers' pain of paying diminishes their pleasure of consumption and the degree to which consumption buffers the pain of paying.

The consumer gets utility from a bundle of attributes, and enjoys that utility today and tomorrow. Let u_{ij} represent the utility consumer i gets from a consumption bundle j today and tomorrow. Following Prelec and Loewenstein, the consumption experience is the sum

[19] When both consumption and payment are simultaneous, then consumption is the only benefit that can be imputed to the payment, and the payment is the only cost that could be imputed to consumption.

of consumption experiences at time 1 & 2 and can be expressed as

$$u_{ij} - \lambda \underbrace{\alpha_i \frac{u_{ij}}{u_{ij} + u_{ij}} \Big(p_j + \frac{2c}{\epsilon_j}\Big)}_{\widehat{p_{ij1}}} + \delta\Big(u_{ij} - \lambda \underbrace{\alpha_i \frac{u_{ij}}{u_{ij}} \frac{c}{\epsilon_j}}_{\widehat{p_{ij2}}}\Big) \tag{14}$$

At time 1, a consumer i gets utility u_{ij} from adopting a given bundle j minus the imputed cost from the pain of payments still left at time 1, i.e. the price of the bundle p_j and energy bills at time 1 and 2 ($c_e + c_e = 2c_e$), prorated over the consumption still left at time 1 (i.e. two consumption episodes), $\frac{u_{ij}}{u_{ij} + u_{ij}}$, adjusted downwards for the individual's sensitivity to the pain of paying α_i and converted to utility terms, λ. At time 2, the consumer gets utility from the bundle u_{ij} minus the pain from payments left at time 2, i.e. the energy bills at time 2, prorated over consumption left at time 2 (i.e. a single consumption episode), $\frac{u_{ij}}{u_{ij}}$, adjusted downwards for the individual's sensitivity to the pain of paying α_i, converted to utility terms λ and discounted with a discount factor δ. At time 1, there are two consumption episodes left and we are prorating the pain from the remaining payments to a single episode of consumption. At time 2, there is only one consumption episode left so prorating over one consumption episode is $\frac{u_{ij}}{u_{ij}} = 1$.

Simplifying the above expression gives us

$$u_{ij} - \lambda\alpha_i \frac{1}{2}\Big(p_j + \frac{2c}{\epsilon_j}\Big) + \delta\Big(u_{ij} - \lambda\alpha_i \frac{c}{\epsilon_j}\Big) \tag{15}$$

The payment experience is the sum of payments for the consumption bundle j, and energy bills at time 1 & 2 and can be expressed as

$$\underbrace{\frac{1}{\alpha_i}\frac{p_j}{p_j}(u_{ij} + u_{ij}) + \frac{1}{\alpha_i}\frac{c/\epsilon_j}{(c+c)/\epsilon_j}(u_{ij} + u_{ij})}_{\widehat{u_{ij1}}} - \lambda p_j - \lambda \frac{c}{\epsilon_j} + \delta\Big(\underbrace{\frac{1}{\alpha_i}\frac{c/\epsilon_j}{c/\epsilon_j} u_{ij}}_{\widehat{u_{ij2}}} - \lambda \frac{c}{\epsilon_j}\Big) \tag{16}$$

I assume that consumer i pays for bundle j in time 1, but incurs energy bills in both periods. At time 1 there are two episodes of payment: the payment for a given bundle and energy bills. The consumer pays for the bundle in full at time 1. Therefore, his imputed benefit is $\frac{1}{\alpha_i}\frac{p_j}{p_j}(u_{ij} + u_{ij})$, because he has two consumption episodes left at time 1, but pays for the

bundle in full at time 1. The second term, λp_j is the disutility from payment episode. The third term is an imputed benefit from adoption of a given design $(u_{ij} + u_{ij})$ that is prorated over two remaining payments for energy bills $\dfrac{c/\epsilon_j}{(c+c)/\epsilon_j}$ and adjusted by the sensitivity to the pain of paying $\dfrac{1}{\alpha_i}$ minus the disutility from payment for energy at time 1.[20] The fifth term is the imputed benefit from paying for energy service at time 2, u_{ij} prorated over remaining payments (i.e. one payment of the energy bill at time 2) $\dfrac{c/\epsilon_j}{c/\epsilon_j}$ minus the disutility from payment for energy bills at time 2,$\dfrac{c}{\epsilon_j}$, and discounted using a discount factor δ.
Simplifying the above expression we get

$$\frac{1}{\alpha_i}2u_{ij} - \lambda p_j + \frac{1}{\alpha_i}u_{ij} - \lambda\frac{c}{\epsilon_j} + \delta\Big(\frac{1}{\alpha_i}u_{ij} - \lambda\frac{c}{\epsilon_j}\Big) \tag{17}$$

Now combining the payment and consumption experiences will give us the total utility

$$\widetilde{U_{ij}} = u_{ij} - \lambda\alpha_i\frac{1}{2}p_j - \lambda\alpha_i\frac{c}{\epsilon_j} + \delta u_{ij} - \delta\lambda\alpha_i\frac{c}{\epsilon_j} + \frac{1}{\alpha_i}2u_{ij} - \lambda p_j + \frac{u_{ij}}{\alpha_i} - \lambda\frac{c}{\epsilon_j} + \delta\frac{1}{\alpha_i}u_{ij} - \lambda\delta\frac{c}{\epsilon_j} \tag{18}$$

Rearranging

$$\widetilde{U_{ij}} = \Big(1 + \delta + \frac{2}{\alpha_i} + \frac{1}{\alpha_i} + \delta\frac{1}{\alpha_i}\Big)u_{ij} - \lambda(\alpha_i + \delta\alpha_i + 1 + \delta)\frac{c}{\epsilon_j} - \lambda\Big(\frac{\alpha_i}{2} + 1\Big)p_j \tag{19}$$

Further simplifying

$$\widetilde{U_{ij}} = \Big(1 + \delta + \frac{3+\delta}{\alpha_i}\Big)u_{ij} - \lambda(1+\delta)(1+\alpha_i)\frac{c}{\epsilon_j} - \lambda\Big(\frac{\alpha_i}{2} + 1\Big)p_j \tag{20}$$

Substituting the expression for the utility u_{ij} into the expression for total utility $\widetilde{U_{ij}}$ gives us

$$\widetilde{U_{ij}} = \Big(1 + \delta + \frac{3+\delta}{\alpha_i}\Big)(\gamma_i s_j + \theta_i z_j) - \lambda(1+\delta)(1+\alpha_i)\frac{c}{\epsilon_j} - \lambda\Big(\frac{\alpha_i}{2} + 1\Big)p_j \tag{21}$$

[20]Prelec & Loewenstein scale the imputed benefit from consumption for each payment episode by a parameter β_i. In the context of my model I assume that the pain of paying parameter α_i and the sensitivity to hedonic benefits parameter β_i are inversely related. This implies that an individual has a certain sensitivity to the pain of paying, α_i, which governs the amount of pain he experiences in every consumption episode and the amount of hedonic benefit he experiences in every payment episode, depending on the type of the consumer. If an individual is very sensitive to pain from paying, i.e. α_i is high, then the imputed cost in every consumption episode will be higher, while the imputed benefit in every payment episode will be lower.

This expression is the total utility of consumer i adopting a consumption bundle j

$$\widetilde{U_{ij}} = (1+\delta)\gamma_i s_j + (1+\delta)\theta_i z_j + \frac{3+\delta}{\alpha_i}\gamma_i s_j + \frac{3+\delta}{\alpha_i}\theta_i z_j - \lambda(1+\delta)(\alpha_i+1)\frac{c}{\epsilon_j} - \lambda\frac{\alpha_i}{2}p_j - \lambda p_j \quad (22)$$

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Table 4. Mixed Logit

	Full Sample		Tightwads		Spendthrifts	
	β	σ	β	σ	β	σ
Price	-0.0726***	0.0582***	-0.0997***	0.0670***	-0.0671***	0.0547***
	(0.00392)	(0.00701)	(0.0119)	(0.0159)	(0.00436)	(0.00846)
Bill Savings	0.620***	0.658***	0.876***	0.887***	0.568***	0.551***
	(0.0363)	(0.0796)	(0.101)	(0.204)	(0.0390)	(0.104)
Pollution	0.793***	0.194	0.786***	1.699	0.824***	0.0548
	(0.106)	(0.706)	(0.261)	(1.052)	(0.127)	(0.533)
Rear Solar	0.626***	0.120	0.548***	0.420	0.671***	0.568*
	(0.0602)	(0.426)	(0.132)	(0.409)	(0.0759)	(0.305)
Rooftop Solar	0.523***	0.297	0.410***	1.417***	0.538***	0.352
	(0.0850)	(1.140)	(0.150)	(0.445)	(0.0744)	(0.346)
Integrated Solar	0.474***	0.154	0.460***	0.475	0.503***	0.100
	(0.0608)	(0.255)	(0.148)	(0.782)	(0.0727)	(0.328)
Efficient Design	0.308***	0.238	0.336***	1.041***	0.338***	0.0951
	(0.0462)	(0.387)	(0.108)	(0.381)	(0.0541)	(0.312)
Spendthrift×Price	0.00343***		-0.00854*		0.00327*	
	(0.00116)		(0.00467)		(0.00195)	
Spendthrift×Bill Savings	-0.0296**		-0.0868		0.00274	
	(0.0149)		(0.0615)		(0.0250)	
Spendthrift×Pollution	0.00829		0.431**		-0.203**	
	(0.0480)		(0.206)		(0.0833)	
Spendthrift×Rear Solar	0.0713**		-0.128		0.0641	
	(0.0296)		(0.117)		(0.0517)	
Spendthrift×Rooftop Solar	0.0491		-0.0794		0.0731	
	(0.0305)		(0.126)		(0.0512)	
Spendthrift×Integrated Solar	0.0525*		-0.0321		0.0731	
	(0.0306)		(0.119)		(0.0525)	
Spendthrift×Efficient Design	0.00957		-0.144		-0.0188	
	(0.0231)		(0.101)		(0.0391)	
Age×Price			0.000378		-0.000487***	
			(0.000247)		(0.000153)	
Age×Rooftop Solar	-0.00942***				-0.0118***	
	(0.00293)				(0.00350)	
Age×Integrated Solar	-0.00768***				-0.00723**	
	(0.00280)				(0.00348)	
Income×Bill Savings	0.0219***				0.0273***	
	(0.00578)				(0.00571)	
Income×Efficient Design	0.0252***		0.101***			
	(0.00941)		(0.0210)			
LR(7)	57.3		32.2		30.2	
p-value	0.000		0.000		0.000	
N	25,464		8,540		16,924	

Note: Coefficients from the mixed logit model (β), and estimated standard deviations (σ) of coefficients modeled as random. The model was estimated on the full sample and on subsamples of tightwads and spendthrifts. Age and Income interactions with attributes were included if they were statistically significant in the corresponding conditional logit model. The reported Likelihood Ratio tests pertain to the joint significance of the standard deviations on the seven random coefficients. Home attributes and price were modeled as random, and attribute interactions were modeled as fixed. All interactions are mean-centered. The model is estimated specifying the distribution around the random parameters as normal and fifty Halton draws are used for the simulated maximum likelihood procedure in STATA using the *mixlogit* command. Standard errors are in parentheses with *** p<0.01, ** p<0.05, * p<0.1.