Zwick Center for Food and Resource Policy
Working Paper No. 7

Re-Evaluating the Role of Energy Efficiency Standards: A Time-Consistent Behavioral Economics Approach

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December 2011

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We are grateful for the helpful comments and suggestions made by Ian Parry, Charles Mason, Richard Carson, and seminar participants at the Inaugural AERE Conference in Seattle and the 13th Colorado University Environmental and Resource Economics Workshop.

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Abstract

The economic models that prescribe Pigovian taxation as the first-best means of reducing energy-related externalities and argue that taxes are superior to energy efficiency standards are typically based on the neoclassical model of rational consumer choice. Yet, observed consumer behavior with regards to energy use and the purchase of energy-using durable goods is generally thought to be far from efficient, giving rise to the concept of the "energy-efficiency gap." In this paper, we present a welfare analysis of Pigovian taxes and energy efficiency standards that is based on an alternative, time-consistent behavioral model. We adapt the model of temptation and self-control of Gul and Pesendorfer (2001, 2004) to the context of the purchase of energy-using durable goods. Our results suggest that (i) temptation or self-control might be a contributing factor in explaining the energy-efficiency gap, (ii) standards might be used as a commitment device to address inefficiencies in consumer choice that stem from temptation, and (iii) in the presence of temptation, a policy that combines standards with a Pigovian tax can yield higher social welfare than a Pigovian tax alone.

Journal of Economic Literature Classification: D03, Q48**,** Q58

Keywords: behavioral economics; temptation; self-control; time-consistent preferences; energy-efficiency gap; energy efficiency standards; Pigovian taxes

1. Introduction

The importance of reducing energy use has been widely acknowledged, as a means for both meeting future energy needs and addressing environmental problems. Economists have long argued that the first-best policy for reducing the externalities that result from energy use is a Pigovian tax. Yet, historically, the U.S. and many other countries have relied heavily on energy or fuel efficiency standards to reduce energy use. Examples include energy efficiency standards for appliances and the U.S. Corporate Average Fuel Economy (CAFE) standards[1] for automobiles. Recently, Section 321 of the U.S. Energy Independence and Security Act (EISA) of 2007 established a minimum efficiency standard for light bulbs, which will be phased in between 2012 and 2014. This standard will effectively result in eliminating most incandescent bulbs (i.e. the low-efficiency product) from the market. A similar outcome would ensue in other appliance markets if participation in the Energy Star program[2] became mandatory.

While widely used, energy efficiency standards have also been widely criticized by economists as being inefficient. Among recent papers, Linares and Labandeira (2010) and Parry *et al.* (2010) discuss the advantages of implementing energy taxes over efficiency standards. Arguments against the use of standards include the existence of a "rebound effect"[3] and the inefficiency induced when a uniform standard is imposed on heterogeneous consumers (Hausman and Joskow 1982).

The economic models that prescribe Pigovian taxation as the first-best means of reducing energy-related externalities and argue that taxes are superior to energy efficiency standards are typically based on the neoclassical model of rational consumer choice, which assumes that, when faced with proper price signals, consumers will make efficient choices. Yet, observed consumer behavior with regards to energy use and the purchase of energy-using durable goods is generally thought to be far from efficient, giving rise to the concept of the "energy-efficiency gap." In particular, individuals appear to exhibit excessively high discount rates when purchasing energy-using durable products. Studies have estimated implied discount rates ranging from 25% for air conditioners to 300% for refrigerators.[4] Even the lower bound of these estimates is well above the interest rates in the economy.

There is a large body of literature that seeks to explain this puzzling behavior and evaluate its implications for public policy design. Carson and Tran (2009) and Gillingham *et al.* (2009) provide extensive reviews of possible causes for the energy-efficiency gap, ranging from market failures (energy market failures, innovation market failures, liquidity constraints, and information problems) to hidden adoption costs. Hausman and Joskow (1982) point out that due to heterogeneity, a given technology that is found to be efficient for the average user may not be optimal for some consumers. Davis (2010) presents empirical support for the role of the "landlord-tenant problem": lack of incentive for landlords to purchase efficient appliances when their tenants pay the utility bill.

While the above explanations for the energy-efficiency gap rest upon the rational consumer assumption, some researchers have argued instead that individual rationality is bounded and that agents discount the near future more heavily than the distant future. Evidence of such behavior has been found in a wide range of contexts, including credit card take-up (Ausubel 1999) and life-cycle savings (Laibson *et al.* 2007).[5] In a context relevant to our study, McManus (2007), Fan and Rubin (2009), and Allcott and Wozny (2010) find evidence that consumers substantially undervalue future fuel costs at the time of automobile purchase.[6]

Laibson (1997) formally models such behavior through preferences that exhibit hyperbolic discounting.[7] The hyperbolic discounting framework can explain purchase patterns in energy markets where consumers seem to exhibit present bias and undervalue future gains from energy-efficient products. However, in this context hyperbolic discounting preferences generally imply time inconsistency (Heutel 2011).[8] In each period, the agent can be viewed as a separate "self" choosing *current* behavior to maximize *current* preferences. Thus, the agent's preferences differ across periods.

Recently, based on evidence of behavioral anomalies, some authors have sought to analyze policies to reduce energy use in the presence of "internalities" (Fischer *et al.* 2007, Allcott *et al.* 2011, Heutel 2011), a term introduced by Herrnstein *et al*. (1993). With internalities, consumer behavior does not conform to standard rationality assumptions, implying that consumers make choices that impose costs on themselves (e.g., Gruber and Koszegi 2001). However, time inconsistency and internalities generally raise concerns about the interpretation of welfare analyses based on the revealed preference approach.

In this paper, we present a welfare analysis of Pigovian taxes and energy efficiency standards that draws on an alternative behavioral model of time-consistent preferences developed by Gul and Pesendorfer (2001, 2004). The key notion in the Gul-Pesendorfer model relates to temptation and self-control. Empirical tests of this model have found statistical evidence supporting the presence of temptation (Ameriks *et al.* 2007, Huang *et al.* 2007). More generally, the existing evidence shows that individuals experience self-control problems due to their tendency to pursue instantaneous gratification (O'Donoghue and Rabin 2001). Examples can be found in a variety of contexts, such as consumption of "vice" products (e.g. cigarettes, unhealthy food) (Wertenbroch 1998), aversion to medical checkups (Trope and Fishbach 2000), and difficulties in resisting school parties (Zhang *et al.* 2010). While some people may overcome this temptation and in the process incur a certain self-control cost, there are others who succumb to it and make decisions that could be *ex-ante* inefficient.

The behavioral implication of temptation is that consumers may actually prefer to restrict their choices so as to avoid the temptation that short-term gains create in some contexts. For example, illiquid assets (e.g. housing, IRAs, etc.) and social security serve to reduce the temptation of immediate consumption (Gul and Pesendorfer 2004). Alternatively, some people achieve commitment through self-imposed restrictions: e.g. rationing one's purchase of tempting goods even when they are sold with quantity discounts (Wertenbroch 1998), avoiding visits to restaurants offering unhealthy food (Gul and Pesendorfer 2001), or self-imposing earlier deadlines than necessary for class assignments (Ariely and Wertenbroch 2002).[9] Such instances of self-imposed restrictions can have important policy implications.[10]

In this paper, we adapt the Gul-Pesendorfer model to depict the purchase decision in the markets for energy-using durable goods, where a less energy-efficient product with a low purchase price appears "tempting," in spite of its relatively high use costs that will be incurred in the future. We argue that this model can present another possible cause contributing to the energy-efficiency gap while at the same time allowing for time consistency and hence a clear interpretation of the welfare impacts of alternative policies. Furthermore, the preference for choice restriction that some consumers exhibit in the Gul-Pesendorfer framework may have significant implications with regards to using energy efficiency standards as a policy instrument in this market. Energy efficiency standards that, for example, eliminate the possibility and hence the temptation to buy cheap but energy-inefficient goods could actually be beneficial, *ceteris paribus*. Of course, this gain must be weighed against losses that can arise from heterogeneity. In the presence of heterogeneity, the purchase of cheap but energy-inefficient goods is sometimes efficient (e.g., for low use consumers), implying that, *ceteris paribus*, the elimination of this option generates a welfare loss. In our model, we incorporate heterogeneity in use and identify the potential tradeoff that arises.

We consider two policy roles for efficiency standards: as substitutes for taxes and as their complements. Our analysis provides conditions under which a Pigovian tax alone does not yield a first-best outcome, and a combined policy comprised of a Pigovian tax and an efficiency standard (which we model as a ban on an inefficient product) would result in greater social welfare. This suggests a potentially important role for energy efficiency standards. Thus, while most of the existing literature tends to analyze Pigovian taxes and efficiency standards as substitutes (e.g. CAFE standards vs. gasoline taxes), our results provide support for treating these two policies as complements that should be used in combination. While we are not the first to suggest a complementary role for taxes and standards,[11] to our knowledge we are the first to suggest that (i) temptation or self-control might be a contributing factor in explaining the energy-efficiency gap, (ii) standards might be used as a commitment device to address inefficiencies in consumer choice that stem from temptation, and (iii) in the presence of temptation, a policy that combines standards with a Pigovian tax can yield higher social welfare than a Pigovian tax alone.

The rest of the paper is structured as follows. Section 2 reviews the Gul-Pesendorfer model and its behavioral and policy implications. Section 3 presents an adaptation of the Gul-Pesendorfer model to the context of the purchase of energy-using products. Section 4 examines consumer choices in the absence of policy intervention, and Section 5 describes the first-best choices. Section 6 analyzes the welfare implications of three different policy scenarios: an energy tax, an energy efficiency standard, and a combination of the two. Section 7 extends the model by introducing heterogeneity in self-control costs. Section 8 discusses the relevance of our findings and presents some recommendations for future research.

2. A Model of Time-Consistent Preferences

Gul and Pesendorfer (2001) set up an axiomatic framework to represent time-consistent preferences over choice sets in the presence of temptation or lack of self-control. The key axiom in the Gul-Pesendorfer model, *Set Betweenness*, captures the notion that the presence of a tempting alternative in the choice set reduces individual well-being, compared to a case in which this alternative is absent from the set. Let x and y be two possible choices, with y being the tempting alternative. Then, Set Betweenness implies that $\{x\} \succsim \{x, y\} \succsim \{y\}$, where $\succsim$ denotes the agent's preferences over choice sets. In other words, the consumer weakly prefers the restricted choice set $\{x\}$ to the choice set $\{x, y\}$ that involves the tempting alternative. Formally, these preferences over sets can be represented by a function W defined as follows: the agent weakly prefers set S_1 over set S_2 if and only if $W(S_1) \geq W(S_2)$, where

$$W(S) = \max_{z \in S}\{u(z) + v(z)\} - \max_{z \in S} v(z), \tag{1}$$

for some functions u and v.[12] In the above specification, function u represents the agent's "commitment utility," i.e. her ranking over singleton sets containing only one possible choice option and hence no temptation. Thus, the preference ranking $\{x\} \succsim \{y\}$ is represented by $u(x) \geq u(y)$. The function v is the agent's "temptation utility," where $v(y) > v(x)$ if y is the tempting alternative. When S consists of a single option, e.g. $S = \{x\}$, then $W(S) = u(x)$. However, once we add a tempting option to the choice set, i.e. $S = \{x, y\}$, then $W(S)$ depends on whether or not the individual will give into temptation. When presented with the choice set $\{x, y\}$, the agent chooses the option z^* that maximizes $u(z) + v(z)$. If $z^* = y$, the agent gives into temptation and $W(S)=u(y)$. If $z^*=x$, she exercises self-control and resists temptation, but in doing so incurs a "self-control cost" given by $v(y)-v(x)$, which is always non-negative. In this case, $W(S)=u(x)-[v(y)-v(x)]$.

The behavioral implication of this framework is that people would exhibit a preference for commitment in order to avoid being confronted with the tempting alternative. As discussed in the introduction, there exists ample evidence indicating the use of commitment devices in real life. In this framework, policy intervention that eliminates the tempting alternative from the consumer's choice set is analogous to a commitment device and can be welfare-improving.

While the above model is static, the Gul-Pesendorfer model can also be set in a multi-period framework. Assume that, when the agent chooses z in period t, she only faces temptation in the current period and receives a future payoff Ω_{t+1} conditional on her choice of z. We can then specify the dynamic version of (1) as follows:

$$W_t(S_t)=\max_{z_t\in S_t}\{u_t(z_t)+v_t(z_t)+\delta\Omega_{t+1}(z_t)\}-\max_{z_t\in S_t}v_t(z_t), \quad t\geq 1. \tag{2}$$

In this setting, $u_t + \delta\Omega_{t+1}$ represents the present discounted value of the "commitment utility" of the period t choice, and v_t is the "temptation utility" in period t.[13]

As discussed by Gul and Pesendorfer (2001, 2004) and Miao (2008), a key property of the model is that, when applied to a multi-period framework, the agent's preferences do not change between periods, i.e. preferences are time-consistent. The agent makes consistent choices over time, which can be mapped directly to her preferences. Thus, a standard welfare analysis can be conducted using the revealed preference approach: if the agent is willing to choose a particular policy over other policies, this policy must give her at least as much welfare as the other alternatives. In contrast, behavioral models with time-inconsistent preferences feature consumer choices that are not consistent across different periods. As a result, it is difficult to develop a universal welfare criterion for comparing alternative policies in those frameworks.

3. A Time-Consistent Model of Markets for Energy-Using Durable Goods

A fundamental insight of Gul and Pesendorfer (2001, 2004), utilized by Miao (2008), is that individuals find immediate rewards tempting. This could happen in markets for energy-using durables, where consumers tend to buy inefficient products with low purchase prices even when over the product lifespan the efficient product entails lower total (purchase and operating) discounted costs. We extend the Gul-Pesendorfer model to depict the purchase of energy-using products viewing immediate "payoff" as the price paid for a product and future "payoff" as the use benefits net of use costs. Our framework could be used to describe any market for energy-using durables that features a dichotomy between high- and low-efficiency products (e.g. light bulbs, air conditioners, heaters, computers, TVs, cars, etc.), in which the more efficient products have relatively higher purchase prices.

The model features two periods: in period 1, consumers make a purchase, and in period 2, they decide how much to use the purchased product.[14] In the absence of regulation, the purchase choice set contains two choices: a high-efficiency (*H*) and a low-efficiency (*L*) product.[15] The high-efficiency product has a higher purchase price ($P_H > P_L$), but uses less energy per unit of use ($x_H < x_L$). In the first period, the agent who purchases product $j \in \{H, L\}$ pays price P_j. In period 2, she chooses the amount h that the product is used.

Each consumer is characterized by a (θ, λ) combination, where θ is a characteristic affecting the benefits of use and λ is a characteristic representing the extent to which the consumer is tempted by the low purchase price. We assume that θ is continuously distributed over the segment $[\underline{\theta},\overline{\theta}]$ with distribution $f(\theta)$, and λ is distributed over $[0,\lambda^{\max}]$ with distribution $g(\lambda)$. The consumer's private net benefits from the use of product j in period 2 are:

$$B_j = \theta b(h) - px_j h\,, \tag{3}$$

where p is the price of energy. We assume that $b(\ )$ is increasing and strictly concave in h. We further assume benefits are independent of the product type, thus allowing energy efficiency rather than the tradeoff between efficiency and product quality to be the product attribute influencing consumer choice. Conditional on the purchase of a type j product, a consumer of type θ chooses h to maximize (3). Optimization yields $h^*(\theta, x_j, p)$, with $\frac{dh^*}{d\theta} > 0,\ \frac{dh^*}{dx_j} < 0,$ and $\frac{dh^*}{dp} < 0.$ For the rest of the analysis, we will use the short-hand notation $h^*(\theta, x_j, p) \equiv h_j(\theta, p)$ and $b(h^*(\theta, x_j, p)) \equiv b_j(\theta, p)$.

An agent finds an immediate reward tempting. In this case, the immediate "reward" is represented by the lower purchase price of the less efficient model, $P_L < P_H$. We focus only on the choices of consumers who plan to buy a new product. Hence, we assume that the parameter values in our model are such that consumers always purchase one of the two products. Each consumer thus faces a choice set S containing the pair of options $\{H, L\}$ and makes a period-1 choice from this set. We adapt (2) to this 2-period framework by defining:

$$\phi_j \equiv u_j + v_j + \delta B_j\,. \tag{4}$$

Thus, ϕ_j represents the consumer's preferences over choices *within* a given choice set S. A consumer will purchase product $j \in S$ that maximizes (4). Note that u_j is simply the period-1 payoff, which is the negative of the purchase price. We follow Gul and Pesendorfer (2004) and Miao (2008) and specify the temptation utility as $v_j = \lambda u_j$. Given this, (4) becomes:

$$\phi_j = -(1+\lambda)P_j + \delta\big(\theta b_j(\theta, p) - p x_j h_j(\theta, p)\big). \tag{5}$$

Notice that, for $\lambda = 0$, i.e. for an individual with no self-control problem, this model reduces to a standard utility model.

The next step is to characterize the agent's preferences *across* sets, which are represented by the function $W(S)$. Adapting (2) to our framework and maintaining our previous functional form assumptions, we obtain $W(S)$ for a consumer faced with set $S = \{H, L\}$:

$$\begin{aligned} W(S) &= \max_{j\in S}\{-P_j - \lambda P_j + \delta(\theta b_j(\theta, p) - p x_j h_j(\theta, p))\} - \lambda \max_{j\in S}(-P_j) = \\ &= \max_{j\in S}\{-(1+\lambda)P_j + \delta(\theta b_j(\theta, p) - p x_j h_j(\theta, p))\} + \lambda P_L \end{aligned} \tag{6}$$

Once again, for $\lambda = 0$, (6) yields the standard utility model. The maximized utility of an agent faced with a choice set $S = \{H, L\}$ is:[16]

$$W(S) = \begin{cases} w_L \equiv -P_L + \delta(\theta b_L(\theta, p) - p x_L h_L(\theta, p)) & \text{if } \phi_L > \phi_H \\ w_H \equiv -P_H + \delta(\theta b_H(\theta, p) - p x_H h_H(\theta, p)) - \lambda(P_H - P_L) & \text{if } \phi_L \le \phi_H \,. \end{cases} \tag{7}$$

The first line in (7) corresponds to the outcome when the agent "gives into temptation," purchases the inefficient product, and incurs no self-control cost. The second line corresponds to the outcome when the individual "resists temptation" and buys the high-efficiency product, but incurs a self-control cost equal to $\lambda(P_H - P_L)$.

4. Consumer Choices in the Absence of Policy Intervention

In the initial analysis, we assume that all agents share the same λ and draw inferences conditional on a given λ. In Section 7, we discuss the implications of allowing λ to vary across consumers.

To characterize the agent's purchase decisions, we define a cutoff value $\hat{\theta}(\lambda, p)$[17] implicitly through $\phi_H = \phi_L$, i.e.

$$-P_H + \delta\left(\hat{\theta} b_H\left(\hat{\theta}, p\right) - p x_H h_H\left(\hat{\theta}, p\right)\right) - \lambda\left(P_H - P_L\right) + P_L - \delta\left(\hat{\theta} b_L\left(\hat{\theta}, p\right) - p x_L h_L\left(\hat{\theta}, p\right)\right) \equiv 0. \quad (8)$$

The function $\hat{\theta}(\lambda, p)$ plays an important role in the analysis below. Define $\theta_0 = \hat{\theta}(\lambda, p)$ as the cutoff value in the absence of policy intervention. The following proposition characterizes the purchase decision in the absence of any policy. (The proofs of this and all remaining propositions are provided in the Appendix.)

Proposition 1: *For a given λ, when presented with the choice set $\{H, L\}$, a consumer with type θ will purchase H if and only if $\theta \geq \theta_0$.*

The consumer's use decision depends on θ. Higher θ (i.e. larger benefits of use) results in greater use of the product and, consequently, higher total energy costs. *Ceteris paribus*, higher energy costs make it more likely that the total (purchase and use) discounted costs of product *H* will be lower than the discounted costs of *L* for a given consumer, and, hence, it is more likely that this consumer chooses *H*. In Fig. 1, individuals with $\theta \in [\underline{\theta}, \theta_0)$ purchase *L* and those with $\theta \in [\theta_0, \overline{\theta}]$ choose *H*.

Using the Implicit Function Theorem, we obtain:

$$\frac{d\hat{\theta}}{d\lambda} = \frac{P_H - P_L}{\delta\left(b_H - b_L\right)} > 0; \qquad \frac{d\hat{\theta}}{dp} = -\frac{x_L h_L - x_H h_H}{b_H - b_L}. \quad (9)$$

The sign of $d\hat{\theta}/d\lambda$ follows from the model, and simply implies that more consumers are likely to purchase the low efficiency model when temptation is greater. However, the sign of $d\hat{\theta}/dp$ depends on the magnitude of the "rebound effect", i.e., the impact of an improvement in energy efficiency on use. Most estimates of the magnitude of the rebound effect suggest that it is less than 100% for automobiles and household appliances.[18] This implies $d\hat{\theta}/dp < 0$,[19] which we assume throughout the remainder of the paper. Assuming that consumers always purchase one of the two products, $d\hat{\theta}/dp < 0$ and Proposition 1 imply that as p increases, the number of consumers choosing H increases, while the number of individuals who buy L decreases.[20] Thus, as expected, *ceteris paribus* increases in the price of energy induce more consumers to buy the more energy efficient product.

Energy consumption generates environmental damages.[21] We assume that these damages are linear in energy use and denote marginal damages by d. Then, assuming no other distortions in the energy markets, $(p+d)x_j$ represents the full marginal social cost of product use. Given this, we can define social welfare. In general, social welfare will depend on both the choice set available to consumers and the choices they make, which in turn depend on whether (or at what level) energy is taxed, i.e. $SW = SW(S,t,\lambda)$ where t is the energy tax. Thus, for a given λ, social welfare in the absence of any policy, i.e. when $S = \{H, L\}$ and $t = 0$, is given by:

$$\begin{aligned} SW_0 \equiv SW(S,0,\lambda) = \int_{\underline{\theta}}^{\theta_0} [-P_L + \delta(\theta b_L(\theta,p) - px_L h_L(\theta,p) - dx_L h_L(\theta,p))] f(\theta) d\theta + \\ + \int_{\theta_0}^{\bar{\theta}} [-P_H + \delta(\theta b_H(\theta,p) - px_H h_H(\theta,p) - dx_H h_H(\theta,p)) - \lambda(P_H - P_L)] f(\theta) d\theta . \end{aligned} \tag{10}$$

Note that, as in Gul and Pesendorfer (2001, 2004), we treat self-control costs as “real” costs that are included in social welfare.

5. First-Best Choices

The first-best scenario is equivalent to assuming that a planner dictates the most efficient choice for each agent, implying that agents do not experience temptation. First-best choice for a given agent is defined as $j \in \{H, L\}$ that maximizes this agent's commitment utility when environmental damages are internalized. Adapting (8) and Proposition 1 to this framework, we note that the first-best cutoff value θ^* is equal to $\hat{\theta}(0, p+d)$, which is the cutoff value that would exist in the absence of self-control costs (i.e., if $\lambda = 0$) when consumers face the full marginal social cost of use, $p+d$. As shown in Fig. 1, L is the first-best choice for consumers with $\theta \in [\underline{\theta}, \theta^*)$, and H is the first-best choice for the remaining consumers. Note that, because of consumer heterogeneity, it is still efficient (i.e., first-best) for *some* consumers, namely, those with low θ and hence low use, to buy the low-efficiency product. Nonetheless, under the first-best outcome fewer consumers would use the low-efficiency product than in the no-policy case. The resulting social welfare under the first-best outcome is:

$$SW^* \equiv SW(S, d, 0) = \int_{\underline{\theta}}^{\theta^*} [-P_L + \delta(\theta b_L(\theta, p+d) - (p+d) x_L h_L(\theta, p+d))] f(\theta) d\theta + \\ + \int_{\theta^*}^{\bar{\theta}} [-P_H + \delta(\theta b_H(\theta, p+d) - (p+d) x_H h_H(\theta, p+d))] f(\theta) d\theta. \quad (11)$$

In the absence of policy intervention, both an externality (pollution) and an internality (temptation) are present. While pollution, as a classic negative externality, results in private decisions inadvertently imposing costs on others, an "internality" occurs because the choices of individuals impose costs upon *themselves*. In particular, temptation prevents the individual from taking into account the full effect of her current choice on her future payoff. Due to the presence of pollution and temptation, the market outcome deviates from the first-best outcome in three ways:

(i) Inefficient purchase: This inefficiency is a consequence of both the externality and the internality affecting consumer purchases. As seen in Fig. 1, consumers under-invest in the

energy-efficient product under the market outcome, i.e. $\theta^* = \hat{\theta}(0, p+d) < \hat{\theta}(\lambda, p) = \theta_0$. This underinvestment stems from the positive value of both *d* and *λ*.

(ii) Inefficient use: The presence of a pollution externality also results in suboptimal use decisions, since individuals do not account for pollution damages in their use decisions.

(iii) Self-control costs: With $\lambda > 0$, individuals who resist temptation and purchase the high-efficiency product incur a self-control cost. This cost creates a welfare loss relative to the first-best outcome.

In the next section, we investigate whether it is possible to address those inefficiencies and costs through energy policies. While the first-best outcome might not be feasible under certain conditions, we ask whether social welfare could be improved relative to (10) and how social welfare compares under alternative policies.

6. Comparison of Alternative Policy Instruments

We examine the welfare effects of imposing three alternative policies: an energy tax, an efficiency standard, and a combination of tax and standard. Depending on the values of *d* and *λ* in the model, an externality, an internality, or both could be present in the market, which triggers different optimal policy responses.

Under a tax, the cutoff value for θ that determines the purchase decision will be different from θ_0. In particular, individuals now face extra costs of use generated by the energy tax *t*. We can extend (8) by adding a tax to the energy price, which yields a cutoff value $\theta_T = \hat{\theta}(\lambda, p+t)$. Following Proposition 1, individuals with type $\theta \geq \theta_T$ purchase *H*, while the remaining consumers choose *L*. Note that the assumption about the sign of $d\hat{\theta}/dp < 0$ in (9) implies

$\theta_T < \theta_0$, as shown in Fig. 1. For a given λ, the resulting social welfare under the tax policy is given by:

$$SW_T \equiv SW(S,t,\lambda) = \int_{\underline{\theta}}^{\theta_T} \left[-P_L + \delta\left(\theta b_L(\theta, p+t) - (p+d)x_L h_L(\theta, p+t)\right)\right] f(\theta)\, d\theta + \\ + \int_{\theta_T}^{\bar{\theta}} \left[-P_H + \delta\left(\theta b_H(\theta, p+t) - (p+d)x_H h_H(\theta, p+t)\right) - \lambda(P_H - P_L)\right] f(\theta)\, d\theta. \tag{12}$$

Although in practice energy efficiency standards are usually defined in terms of minimum efficiency levels, their key characteristic is that they restrict product choice for consumers. We capture this feature by modeling the efficiency standard as a ban on the inefficient product. Let $S = \{H, L\}$ denote the consumption set in the presence of both products and $S' = \{H\}$ be the set under an efficiency standard that eliminates the inefficient product from the market, thereby "forcing" the consumers to buy *H*. Note that no self-control costs are incurred when a standard is in place. This yields the following social welfare:

$$SW_S \equiv SW(S', 0, \lambda) = \int_{\underline{\theta}}^{\bar{\theta}} \left[-P_H + \delta\left(\theta b_H(\theta, p) - (p+d)x_H h_H(\theta, p)\right)\right] f(\theta)\, d\theta\,. \tag{13}$$

Finally, if the tax and the standard are combined, all consumers are still "forced" to buy the high efficiency product, but in addition they pay the tax on energy use. Social welfare is then:

$$SW_{T+S} \equiv SW(S', t, \lambda) = \int_{\underline{\theta}}^{\bar{\theta}} \left[-P_H + \delta\left(\theta b_H(\theta, p+t) - (p+d)x_H h_H(\theta, p+t)\right)\right] f(\theta)\, d\theta. \tag{14}$$

6.1 Externality Only ($d > 0, \lambda = 0$)

To highlight the role of the different distortions, we first consider policy impacts with only the externality or temptation (but not both) present. We then consider the case of interest, i.e. the case where both are present.

With no temptation, our model reduces to a standard model with rational consumers and a pollution externality. Thus, the implications of that standard model are preserved in our framework, as stated in the following results.

Proposition 2: *If* $d > 0$ *and* $\lambda = 0$, *then an energy tax of* $t^* = d$ *is first-best.*

Proposition 3: *If* $d > 0$ *and* $\lambda = 0$, *then* (i) *starting from an unregulated equilibrium, an efficiency standard can be welfare-improving, i.e.* $SW_S > SW_0$, *for sufficiently high values of d, but* (ii) *an efficiency standard alone is never first-best, i.e.* $SW_S < SW^*$, *for all d.*

The result in statement (i) of Proposition 3 is due to the impact of the standard on purchase decisions. For individuals with $\theta \in [\theta^*, \overline{\theta}]$ purchasing *H* is the efficient choice, but for those with $\theta \in [\underline{\theta}, \theta^*)$ this choice is inefficient given their low use. Since $\theta^* = \hat{\theta}(0, p+d)$ is decreasing in *d*, larger damages reduce the distortion in purchases under the standard and make the standard more desirable, *ceteris paribus*. However, even if *d* is high enough so that it is optimal for all consumers to purchase *H*, a standard alone is never first-best due to the inefficient use.

Corollary 1: *In the absence of temptation, a Pigovian tax is unambiguously preferred to a standard.*

Thus, with a market featuring a use-related externality only, our model gives the standard result that a Pigovian tax is first-best and leads to greater *SW* than an energy efficiency standard.[22]

6.2 Internality Only ($d = 0, \lambda > 0$)

With no externality present in the market, the inefficiency in use disappears, while temptation results in inefficient purchases and welfare losses due to the self-control costs incurred by some consumers. We show that in this case a tax policy is suboptimal, while a standard may be welfare-improving.

Proposition 4: *If* $d = 0$ and $\lambda > 0$*, a tax of* $t > 0$ *is always welfare-reducing relative to no policy.*

In the absence of policy intervention, welfare (which includes self-control costs) is higher for consumers with $\theta \in [\underline{\theta}, \theta_0)$ when they choose *L* rather than *H*. Once a tax is imposed, consumers with $\theta \in [\theta_T, \theta_0)$ switch to *H*. Because the tax does not eliminate or reduce self-control costs, welfare for these consumers is now lower. In addition, imposing a tax distorts the use decision for all consumers (h_j is now suboptimally low). As a result, social welfare under any $t > 0$ is lower than SW_0.

An efficiency standard bans *L* from the market, thus serving as a commitment device and eliminating temptation. As a result, the welfare loss due to self-control costs is avoided. However, as already seen in Section 6.1, a standard corrects the purchase decision for some individuals, while distorting it for others. The tradeoff between gains from commitment and partially correcting the purchase decision vs. losses due to consumer heterogeneity determines whether a standard is welfare-improving.

Proposition 5: *If* $d = 0$ and $\lambda > 0$, *then* (i) *starting from an unregulated equilibrium, an energy efficiency standard can be welfare-improving, i.e.* $SW_S > SW_0$*, for sufficiently high* λ*, and* (ii) *a standard alone is never first-best, i.e.* $SW_S < SW^*$ *for all* λ*.*

As λ increases, $\theta_0 = \hat{\theta}(\lambda, p)$ increases but $\theta^* = \hat{\theta}(0, p + d)$ remains unchanged. In Fig. 1, the range of consumer types $[\theta^*, \theta_0)$ for which the purchase decision is corrected relative to no policy increases, while the range $[\underline{\theta}, \theta^*)$ for which the purchases are distorted remains unchanged. As a result, the difference $SW_S - SW_0$ stemming from the purchase impact of the standard increases with λ. Furthermore, higher λ also results in greater welfare gains from avoided self-control costs when a standard is imposed. Thus, *ceteris paribus*, an increase in λ makes it more likely that a standard would be welfare-improving relative to an unregulated market. However, due to the distortion in purchases, imposing an efficiency standard does not result in a first-best outcome.

The following policy ranking holds in this scenario.

Corollary 2: *In the absence of a pollution externality, an efficiency standard is preferred to any tax* $t > 0$ *for sufficiently high* λ.

6.3 Externality and Internality ($d > 0, \lambda > 0$)

When both pollution and temptation are present, a Pigovian tax alone is welfare-improving, but does not generate a first-best outcome.

Proposition 6: *If* $d > 0$ and $\lambda > 0$, *then* (i) *starting from an unregulated equilibrium, a marginal increase in the energy tax improves social welfare; and* (ii) *when used as the sole policy instrument, a tax of* $t^* = d$ *maximizes social welfare; but* (iii) *a Pigovian energy tax alone does not give a first-best outcome in the presence of temptation, i.e.* $SW_T < SW^*$ *when* $\lambda > 0$.

In an unregulated market, an energy tax addresses only the pollution externality by bringing the consumer's energy price closer to the social cost of $p + d$. This leads to a reduction in the gap between θ_0 and θ^*, thus correcting some of the inefficiency in the purchase decision.

Conditional on the purchase decision, it also partially restores the efficiency in use by reducing the disparity between private use $h_j(\theta, p+t)$ and socially optimal use $h_j(\theta, p+d)$. However, a tax does not address the temptation internality, which is the other cause for the inefficiency in purchase decisions. In theory, correcting some market imperfections while not addressing others does not necessarily lead to an increase in social welfare. However, since both pollution and temptation work in the same direction, i.e. they both reduce the purchases of H below the socially optimal level, a small increase in those purchases is welfare-improving. This outcome, coupled with the reduction in use inefficiency, implies that a marginal tax increase, starting from an unregulated equilibrium, leads to an unambiguous increase in social welfare. Since the tax does not eliminate or reduce temptation, any increase beyond $t = d$ would result in a reduction of social welfare, as shown in Proposition 4. Thus, $t^* = d$ is welfare-maximizing and $SW_T > SW_0$. However, since a Pigovian tax $t = d$ does not address the temptation internality, the purchase decision remains inefficient, i.e., a gap still exists between θ^* and θ_T, as shown in Fig. 1, implying that too many consumers buy the low-efficiency product. Furthermore, temptation costs are still present. Hence, a first-best outcome cannot be achieved through a Pigovian tax.

If an efficiency standard is imposed instead of a tax, it can potentially improve welfare relative to no regulation, but also does not achieve a first-best outcome. This result is summarized in the following proposition.

Proposition 7: (i) *Starting from an unregulated equilibrium, an efficiency standard is welfare-improving, i.e.* $SW_S > SW_0$, *for sufficiently high values of* λ *and/or d.* (ii) *An efficiency standard alone is never first-best, i.e.* $SW_S < SW^*$.

As seen in Sections 6.1 and 6.2, the magnitude of temptation and pollution damages determines whether the welfare gains from commitment and efficient purchases for some consumers outweigh the losses resulting from inefficient use and consumer heterogeneity when a standard is imposed. Propositions 3 and 5 establish that if at least one of these two parameters is large enough, the efficiency standard is welfare-improving relative to an unregulated market. However, as discussed in Proposition 3, the use inefficiency under the standard remains even if purchases are efficient and thus a first-best outcome cannot be achieved.

Next, we proceed to establish a welfare ranking between a Pigovian tax and a standard. Having determined that the optimal tax should be set at the level of marginal damages, the difference between *SW* under the standard alone and *SW* under the welfare-maximizing tax alone can be written as:

$$\begin{aligned}
&\int_{\underline{\theta}}^{\theta^*}\left[-P_H+\delta(\theta b_H(\theta,p+d)-(p+d)x_H h_H(\theta,p+d))+P_L-\delta(\theta b_L(\theta,p+d)-(p+d)x_L h_L(\theta,p+d))\right]fd\theta+\\
&+\int_{\theta^*}^{\theta_T}\left[-P_H+\delta(\theta b_H(\theta,p+d)-(p+d)x_H h_H(\theta,p+d))+P_L-\delta(\theta b_L(\theta,p+d)-(p+d)x_L h_L(\theta,p+d))\right]fd\theta+\\
&+\int_{\underline{\theta}}^{\bar{\theta}}\left[\delta(\theta b_H(\theta,p)-(p+d)x_H h_H(\theta,p))-\delta(\theta b_H(\theta,p+d)-(p+d)x_H h_H(\theta,p+d))\right]fd\theta+\\
&+\lambda(P_H-P_L)\int_{\theta_T}^{\bar{\theta}}fd\theta.
\end{aligned}\qquad(15)$$

The first two terms capture the difference in social welfare resulting from the impacts of the two instruments on purchase decisions. When a tax is imposed, agents in the range $[\underline{\theta},\theta^*)$ choose *L*, which is a first-best decision. In contrast, a standard forces these consumers to choose *H*. Therefore, the first term in (15) is negative. On the other hand, consumers $[\theta^*,\theta_T)$ make a suboptimal purchase decision under the tax (because of temptation they choose *L*, while the first-best choice for them is *H*), whereas under the standard they make the first-best choice *H*. Thus, the second term in (15) is positive. The third term reflects the welfare difference arising from the impacts of both policies on use. Conditional on the purchase decision, a tax ensures that use is first-best. Under a standard, individuals fail to internalize the environmental damages and are thus making suboptimal use decisions. For this reason, the third term has a negative sign. Finally, the last term captures the difference in social welfare that stems from the effect of a standard vs. a tax on the self-control costs. As already discussed, a Pigovian tax does not eliminate these costs, whereas an efficiency standard does. Hence, the last term is positive.

It can be shown that for a given *d*, the expression $SW_S - SW_T$ is increasing in λ. This is due to the fact that an efficiency standard, unlike a Pigovian tax, eliminates self-control costs. Hence, the relative welfare gain of imposing a standard vs. a tax increases as these costs increase, *ceteris paribus*. We define the function $\tilde{\lambda}(d)$ implicitly through $SW_S = SW\left(S', 0, \tilde{\lambda}\right) \equiv SW\left(S, d, \tilde{\lambda}\right) = SW_T$. An efficiency standard yields higher social welfare than a tax for all (d, λ) combinations that lie above the $\tilde{\lambda}(d)$ locus, while a Pigovian tax is preferred to a standard for all combinations below the locus. However, the function $\tilde{\lambda}(d)$ is not monotonic (see further discussion below), which leads to the following proposition.

Proposition 8: *For a given λ, the welfare ranking between a Pigovian tax and an efficiency standard is as follows:*

(i) *for sufficiently low λ, the Pigovian tax yields higher SW than the standard;*

(ii) *for intermediate values of λ, the ranking depends on the magnitude of environmental damages per unit of energy use: for sufficiently low and sufficiently high values of d, the Pigovian tax is preferred, while for intermediate values of d, the standard yields higher SW;*

(iii) *for sufficiently high λ, the ranking again depends on d: the standard yields higher SW for sufficiently low values of d, and the Pigovian tax is preferred if d is sufficiently high.*

As already discussed, for low values of λ and especially at $\lambda = 0$, a Pigovian tax is always preferred to a standard. This finding is summarized in statement (i) of the proposition. To see the intuition behind statements (ii) and (iii), we separate the effects on the welfare ranking of the two instruments resulting from the purchase and use decisions. First, suppose both policies have identical impacts on the use decision. This is equivalent to assuming that use is perfectly inelastic with respect to energy price. In this case, the impacts upon the purchase decisions and self-control costs determine which instrument yields greater *SW*. Since the standard eliminates self-control costs while the tax does not, for a given d a standard is preferred as long as λ is sufficiently high. Similarly, for a given λ the standard is preferred for sufficiently high d. This is because higher d reduces the purchase distortion under a standard, as discussed in Section 6.1. In contrast, under a Pigovian tax, the inefficiency in purchase arises from temptation, i.e. it depends on λ and is unaffected by an increase in d. As a result, a standard is the preferred instrument for sufficiently high λ and/or d and, in the absence of a use effect, $\tilde{\lambda}(d)$ is downward sloping.

Now suppose both policies have identical impacts on purchase decisions, i.e. $\theta_T = \underline{\theta}$. This is equivalent to eliminating the first two terms in equation (15). In this scenario, it is the impact on use and self-control costs that determines the optimal instrument, and $\tilde{\lambda}(d)$ is upward sloping. Since a Pigovian tax fully corrects the use inefficiency, while a standard does not, for a given λ and a sufficiently high d, the tax is the preferred instrument. At $d = 0$ the use inefficiency disappears, resulting in greater welfare under the standard for any $\lambda > 0$. Similarly, for a given $d > 0$, a sufficiently high λ results in the standard being the preferred instrument, as the gains due to eliminated self-control costs are sufficiently large.

When both purchase and use effects are present in the welfare analysis, the net effect is a non-monotonic (U-shaped) $\tilde{\lambda}(d)$ curve, shown in Fig. 2. If λ is low, e.g. λ^L, a Pigovian tax is the optimal policy option. The non-monotonic relationship between d and $\tilde{\lambda}$ suggests that at intermediate values of λ (e.g. at λ^M) taxes would not necessarily yield higher welfare than standards. It also implies that at high values of λ, an efficiency standard would be the preferred instrument as long as per unit damages are not too large (e.g. $d \le d_0$ at λ^H).

Proposition 8 implies that when taxes and standards are considered as substitute policy tools, the welfare ranking is ambiguous when both pollution and temptation are present. Furthermore, when both pollution and temptation are present, it may be possible to improve social welfare by combining the two policy tools rather than using them as substitutes. The welfare impacts of the combined policy are summarized in the following proposition.

Proposition 9: (i) *When an efficiency standard is coupled with an energy tax, a tax of* $t^* = d$ *maximizes social welfare.*

(ii) *Starting from an unregulated equilibrium, a combined policy is welfare-improving for sufficiently high values of* λ *and/or d.*

(iii) *If per-unit pollution damages are high enough to make the purchase of H efficient for all consumers with a given* λ*, a combined policy achieves the first-best outcome.*

In the presence of a standard, the self-control costs are eliminated, but the use decision is inefficient and the purchase decision is partially distorted. The purchase "decision" trivially constitutes a choice of *H* and is unaffected by the imposition of a tax along with the standard. By setting this tax at $t = d$, product use is at its socially optimal level $h_H(\theta, p+d)$ and welfare is maximized. However, because the standard forces all consumers to buy *H* (including the low use consumers for whom purchasing *L* is efficient), a combined policy is not always welfare-improving. The purchase distortion is reduced as *d* becomes larger, as discussed in Section 6.1, implying that with sufficiently high *d* the combined policy will be welfare-improving. However, even when damages are low, a combined policy may still be welfare-improving provided that λ

is sufficiently high, so that the gain from eliminated self-control costs outweighs the loss due to inefficient purchases. Of course, if *d* is sufficiently high that the first-best outcome is for all consumers to choose *H* (i.e., $d \geq \overline{d}$, where $\hat{\theta}(0, p + \overline{d}) = \underline{\theta}$), then eliminating *L* from the market fully corrects the purchase decision. Furthermore, the Pigovian tax ensures that the use decision is optimal, and the standard eliminates self-control costs. Thus, a first-best outcome can be achieved by a combined policy, provided that damages are sufficiently high.

Since in the U.S. and many other countries efficiency standards are already in place, a relevant question is whether there exists an argument in favor of imposing a Pigovian tax in addition to the existing standards.

Proposition 10: *Starting from a market regulated by an efficiency standard alone, adding a Pigovian tax improves social welfare, i.e.* $SW_{T+S} > SW_S$.

This result follows from statement (i) of Proposition 9.

Similarly, we examine the potential for adding a standard when a tax is already in place.

Proposition 11: *A combination of an efficiency standard and a Pigovian tax yields higher SW than a Pigovian tax alone, i.e.* $SW_{T+S} > SW_T$, *for sufficiently high values of* λ *and/or d.*

To see this, define $\overline{\lambda}(d)$ implicitly through $SW_{T+S} - SW_T \equiv 0$. Unlike $\tilde{\lambda}(d)$ in the previous section, the $\overline{\lambda}(d)$ curve is weakly monotonic. This is because a combined policy corrects the use decision and, hence, the shape of $\overline{\lambda}(d)$ is determined by the "Purchase Effect" only. As shown in Fig. 3, for all combinations of *d* and λ lying to the left of the $\overline{\lambda}(d)$ curve, a Pigovian tax results in higher *SW*. This is due to the distortion in purchases under a combined policy for low values of *d*. In addition, for $d < \overline{d}$, as long as λ is sufficiently low, the purchase inefficiency along with the self-control costs under a Pigovian tax are small enough to result in higher SW under the tax. In contrast, for sufficiently high d and λ values, the combined policy prevails due to the smaller distortion in purchase and higher gains from the elimination of self-control costs. Finally, for $d \geq \bar{d}$ the combined policy achieves the first-best outcome and is preferred to a Pigovian tax for any positive λ.

Figure 4 summarizes the ranking of the alternative policies relative to each other and with respect to the no-policy scenario and the first-best outcome for the case of an "intermediate" level of pollution damages. Note that a Pigovian tax alone is always preferred to no policy intervention, i.e. $SW_T > SW_0$, as long as damages are positive.[23] It is first-best in the absence of temptation, i.e. $SW_T = SW^*$ at $\lambda = 0$, but not when temptation is present, i.e. $SW_T < SW^*$ for all positive values of λ. Furthermore, as depicted in Figure 4, there is no universal ranking of the tax with respect to the other policy instruments. While a Pigovian tax is superior to a combined policy and a standard at low values of λ, the ranking is reversed when temptation becomes sufficiently strong. When used as a sole policy instrument, an efficiency standard can be preferred to no regulation (e.g. for sufficiently high λ), but it is never first-best. Furthermore, as shown in Fig. 4, combining the standard with a Pigovian tax is always welfare-improving, i.e. $SW_{T+S} > SW_S$.[24]

While our focus is on energy taxes and energy efficiency standards, our framework also allows us to draw inferences about the welfare impacts of other price instruments, such as product rebates. In the context of our model, a full rebate $R = P_H - P_L$ given to consumers who purchase H is equivalent to a ban on L. With a full rebate, consumers effectively pay P_L while enjoying the higher net benefits of use under the H product. Furthermore, equalizing the effective purchase prices eliminates self-control costs. Thus, all agents choose H, and, since the rebate is a transfer payment, social welfare is equal to SW_S.[25]

7. Heterogeneous Self-Control Costs

Our analysis thus far has been based on the assumption that all agents share the same λ. Hence, all conclusions derived in the preceding section are conditional on the value that λ takes. The model can be extended by allowing λ to vary across consumers. If θ and λ are distributed independently, $f(\theta|\lambda) = f(\theta)$ and equations (10)-(14) now represent *SW* for a segment of the consumer population. When weighted by $g(\lambda)$ and integrated over λ, each one of these expressions gives the aggregate social welfare for the entire population.

The welfare-maximizing tax should be set at the level of marginal damages, as Propositions 2, 4, and 6 taken together suggest that $t^* = d$ regardless of the value of λ. Since a Pigovian tax was shown to be first-best only for $\lambda = 0$, it will no longer be first-best for a population of consumers with varying λ. Furthermore, the ranking of a standard alone vs. no policy now depends on $g(\lambda)$ and *d*, but it is still true that a standard alone can be, but is not necessarily, welfare-improving. Finally, the conclusion that a standard is not first-best was shown to hold for all λ and *d* and will still be valid for a range of λ's.

In addition, as before, there is no universal ranking between a Pigovian tax and a standard. Depending on the consumers' λ and the level of environmental damages, it is possible that a Pigovian tax is first- or second-best for some individuals, while a standard is second-best for others. Then, for a given *d*, the ranking of the instruments depends on the distribution of consumers. Similarly, while a combined policy is welfare-improving relative to a standard alone (Proposition 10 holds for all values of λ), it is not always superior to a Pigovian tax. As shown in Fig. 3, for a sufficiently low *d*, welfare for consumers with low λ's might be higher under the tax. Hence, the second-best instrument in this setting depends on the relative proportion of consumers with $\lambda \leq \overline{\lambda}(d)$ vs. consumers with $\lambda > \overline{\lambda}(d)$. Furthermore, if d is sufficiently high so that it is efficient for all consumers to purchase H, then a combined policy is first-best regardless of the distribution of λ.[26]

8. Conclusion

Typical explanations for the "energy-efficiency gap" include both rational and bounded rationality arguments. This paper explores another potential factor that could be contributing to the existence of the gap, namely, the possibility that consumers are "tempted" by the low purchase price of products with low energy efficiency and hence sometimes purchase these products even when it is not in their interest to do so. We model this behavior using a time-consistent model of consumer choice. The time-consistency of consumer preferences allows for clear comparison of social welfare under a set of alternative policies that could be used to address the inefficiency in various markets for energy-using durable goods.

We find that, although welfare-improving, a Pigovian tax is not a first-best instrument in markets where consumers are "tempted" by the low purchase price of the less energy-efficient product. There exists the potential for using energy-efficiency standards in order to address temptation in these markets. We explore the optimal role of standards by examining the possibility of using them either as substitutes or complements for taxes. A standard alone is not necessarily welfare-improving when imposed in an unregulated market and never leads to a first-best outcome. However, there exist conditions under which it could result in greater social welfare than a Pigovian tax alone. We also find that adding a standard on top of an existing tax could in some cases be welfare-improving and even lead to a first-best outcome. Finally, given that the current policy in the U.S. and many other countries relies heavily on efficiency standards, we conclude that, rather than replacing these standards with taxes as the existing literature prescribes, policymakers could potentially achieve greater social welfare by using the two instruments as complements.

While we believe that our analysis provides useful insight into the potential role of energy efficiency standards, we recognize that it does not incorporate all potentially important dimensions of this question. For example, it does not directly address the fact that, in practice, it might be much easier to apply a tax across all uses of energy (residential, commercial, and industrial) than to apply standards on all energy-using durables (see, for example, Parry *et al.* 2010). Therefore, the results from our analysis should be interpreted as applying to products that can be regulated, assuming that substitution from regulated to unregulated products is not substantial. Similarly, our study focuses only on the demand for products, assuming that they differ only in their price and energy efficiency, and we model energy efficiency standards as minimum efficiency standards. Further extensions to our framework could involve modeling use benefits as dependent on the product type (thus exploring the role of quality-efficiency tradeoffs on consumer choice), adding a supply side to the model (along with potential supply-related market failures), and introducing average efficiency standards (rather than a ban on the inefficient product) among the policy options. While inclusion of these additional features would make our analysis richer (and we plan to address these in future research), we believe that they would not change our fundamental message, namely, if consumers are tempted by low purchase prices when buying energy-using durables, then energy efficiency standards may have a role to play as a commitment device, and, if temptation and/or environmental damages are sufficiently high, coupling a Pigovian tax with an energy efficiency standard can yield higher welfare than a Pigovian tax alone.

REFERENCES:

Agras, Jean, and Duane Chapman (1999). "The Kyoto Protocol, CAFE Standards, and Gasoline Taxes." *Contemporary Economic Policy*, 17(3): 296-308.

Allcott, Hunt, and Nathan Wozny (2010). "Gasoline Prices, Fuel Economy, and the Energy Paradox." *Working Paper, Massachusetts Institute of Technology*.

Allcott, Hunt, Sendhil Mullainathan, and Dmitry Taubinsky (2011). "Externalizing the Internality." *Working Paper, Massachusetts Institute of Technology*.

Ameriks, John, Andrew Caplin, John Leahy, and Tom Tyler. 2007. "Measuring Self-Control Problems." *American Economic Review*, 97(3): 966–972.

Ariely, Dan, and Klaus Wertenbroch (2002). "Procrastination, Deadlines, and Performance: Self-Control by Precommitment." *Psychological Science*, 13(3): 219-224.

Ausubel, Lawrence (1999). "Adverse Selection in the Credit Card Market." *Working Paper, University of Maryland*.

Carson, Richard, and Brigitte Tran (2009). "Discounting Behavior and Environmental Decisions." *Journal of Neuroscience, Psychology, and Economics*, 2(2): 112-130.

Davis, Lucas (2008). "Durable Goods and Residential Demand for Energy and Water: Evidence from a Field Trial." *RAND Journal of Economics*, 39(2): 530-546.

Davis, Lucas (2010). "Evaluating the Slow Adoption of Energy Efficient Investments: Are Renters Less Likely to Have Energy Efficient Appliances?" In Fullerton, Don, and Catherine Wolfram (eds.): *The Design and Implementation of U.S. Climate Policy*. University of Chicago Press.

DellaVigna, Stefano (2009). "Psychology and Evidence: Evidence from the Field." *Journal of Economic Literature*, 47(2): 315-372.

Fan, Qin, and Jonathan Rubin (2009). "Two-Stage Hedonic Price Model for Light-Duty Vehicles: Consumers' Valuations of Automotive Fuel Economy in Maine." *89th Annual Meeting of the Transportation Research Board*, Washington, D.C.

Fischer, Carolyn, Winston Harrington, and Ian Parry (2007): "Should Automobile Fuel Economy Standards Be Tightened?" *The Energy Journal*, 28(4): 1-29.

Fishbach, Ayelet, and Benjamin Converse (2010). "Walking the Line between Goals and Temptations: Asymmetric Effects of Counteractive Control." In Hassin, Ran, Kevin Ochsner, and Yaacov Trope (eds.): *Self-Control in Society, Mind, and Brain*. Oxford University Press: 389-407.

Frederick, Shane, George Loewenstein, and Ted O'Donoghue (2002). "Time Discounting and Time Preference: A Critical Review." *Journal of Economic Literature*, 40(2): 351-401.

Gillingham, Kenneth, Richard Newell, and Karen Palmer (2006). "Energy Efficiency Policies: A Retrospective Examination." *Annual Review of Environment and Resources*, 31: 161-192.

Gillingham, Kenneth, Richard Newell, and Karen Palmer (2009). "Energy Efficiency Economics and Policy." *Annual Review of Resource Economics*, 1: 597-619.

Greene, David (2010a). "How Consumers Value Fuel Economy: A Literature Review." *U.S. Environmental Protection Agency Technical Report EPA-420-R-10-008*.

Greene, David (2010b). "Rebound 2007: Analysis of U.S. Light-Duty Vehicle Travel Statistics." *Energy Economics*, forthcoming.

Gruber, Jonathan, and Botond Koszegi (2001). "Is Addiction "Rational"? Theory and Evidence." *Quarterly Journal of Economics*, 116(4): 1261-1303.

Gul, Faruk, and Wolfgang Pesendorfer (2001). "Temptation and Self-Control." *Econometrica*, 69(6): 1403-1435.

Gul, Faruk, and Wolfgang Pesendorfer (2004). "Self-Control, Revealed Preference and Consumption Choice." *Review of Economic Dynamics*, 7(6): 243-264.

Hausman, Jerry (1979). "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables." *The Bell Journal of Economics*, 10(1): 33-54.

Hausman, Jerry, and Paul Joskow (1982). "Evaluating the Costs and Benefits of Appliance Efficiency Standards." *American Economic Review*, 72(2): 220-225.

Herrnstein, Richard, George Loewenstein, Drazen Prelec, and William Vaughan (1993). "Utility Maximization and Melioration: Internalities in Individual Choice." *Journal of Behavioral Decision Making*, 6(3): 149-185.

Heutel, Garth (2011). "Optimal Policy Instruments for Externality-Producing Durable Goods under Time Inconsistency." *NBER Working Paper 17083*.

Huang, Kevin, Zheng Liu, and John Zhu (2007). "Temptation and Self-Control: Some Evidence and Applications." *Working Paper, Vanderbilt University.*

Jacobsen, Mark (2010). "Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity." *Working Paper, University of California San Diego.*

Kan, Kamhon (2007). "Cigarette Smoking and Self-Control." *Journal of Health Economics*, 26(1): 61-81.

Karp, Larry, and Yacov Tsur (2011). "Time Perspective and Climate Change Policy." *Journal of Environmental Economics and Management*, 62(1): 1-14.

Laibson, David (1997). "Golden Eggs and Hyperbolic Discounting." *The Quarterly Journal of Economics*, 112(2): 443-477.

Laibson, David, Andrea Repetto, and Jeremy Tobacman (2007). "Estimating Discount Functions with Consumption Choices over the Lifecycle." *NBER Working Paper 13314*.

Linares, Pedro, and Xavier Labandeira (2010). "Energy Efficiency: Economics and Policy." *Journal of Economic Surveys*, 24(3): 573-592.

Loewenstein, George and Drazen Prelec (1992). "Anomalies in Intertemporal Choice: Evidence and an Interpretation." *The Quarterly Journal of Economics*, 107(2): 573-597.

McManus, Walter (2007). "The Link between Gasoline Prices and Vehicle Sales." *Business Economics*, 42(1): 53-60.

Miao, Jianjun (2008). "Option Exercise with Temptation." *Economic Theory*, 34: 473-501.

O'Donoghue, Ted, and Matthew Rabin (2001). "Choice and Procrastination." *The Quarterly Journal of Economics*, 116(1): 121-160.

Parry, Ian, David Evans, and Wallace Oates (2010). "Are Energy Efficiency Standards Justified?" *Resource for the Future Discussion Paper 10-59*.

Shapiro, Jesse (2005). "Is There a Daily Discount Rate? Evidence from the Food Stamp Nutrition Cycle." *Journal of Public Economics*, 89(2-3): 303-325.

Small, Kenneth, and Kurt Van Dender (2007). "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect." *The Energy Journal*, 28(1): 25-51.

Small, Kenneth (2011). "Energy Policies for Passenger Motor Vehicles." *Working Paper 101108, University of California Irvine*.

Sorrell, Steve, John Dimitropoulos, and Matt Sommerville (2009). "Empirical Estimates of the Direct Rebound Effect: A Review." *Energy Policy*, 37(4): 1356-1371.

Trope, Yaacov, and Ayelet Fishbach (2000). "Counteractive Self-Control in Overcoming Temptation." *Journal of Personality and Social Psychology*, 79(4): 493-506.

Wertenbroch, Klaus (1998). "Consumption Self-Control by Rationing Purchase Quantities of Virtue and Vice." *Marketing Science*, 17(4): 317-337.

Zhang, Ying, Szu-chi Huang, and Susan Broniarczyk (2010). "Counteractive Construal in Consumer Goal Pursuit." *Journal of Consumer Research*, 37(1): 129-142.

No policy: $\theta_0 = \hat{\theta}(\lambda, p)$

First-best: $\theta^* = \hat{\theta}(0, p + d)$

Pigovian tax: $\theta_T = \hat{\theta}(\lambda, p + d)$

Fig. 1: Cutoff Values for the Purchase Decision under Alternative Scenarios

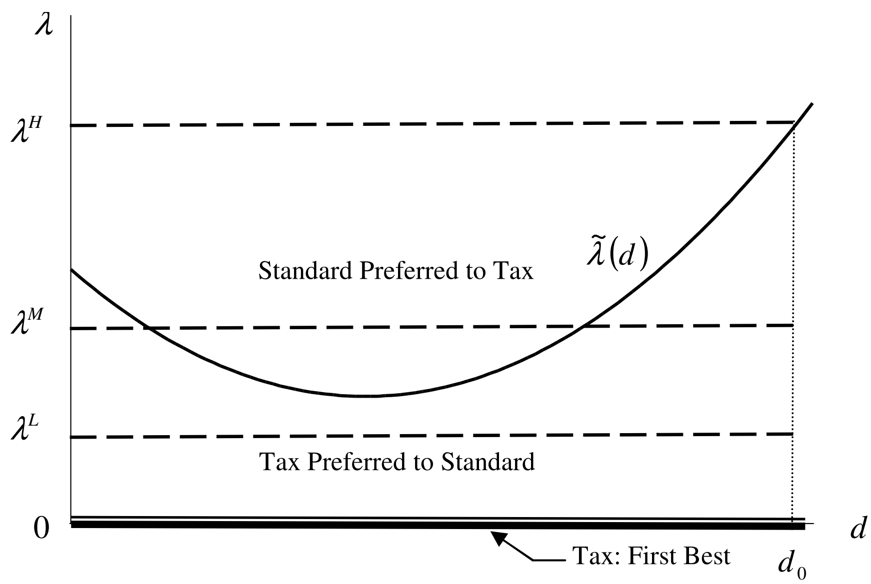

Fig. 2: Welfare Ranking of Standard vs. Pigovian Tax

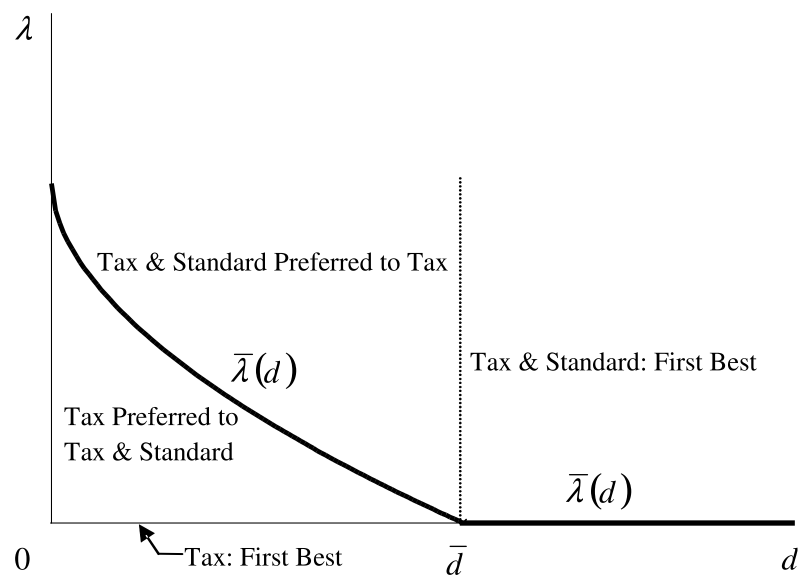

Fig. 3: Welfare Ranking of Combined Policy vs. Pigovian Tax

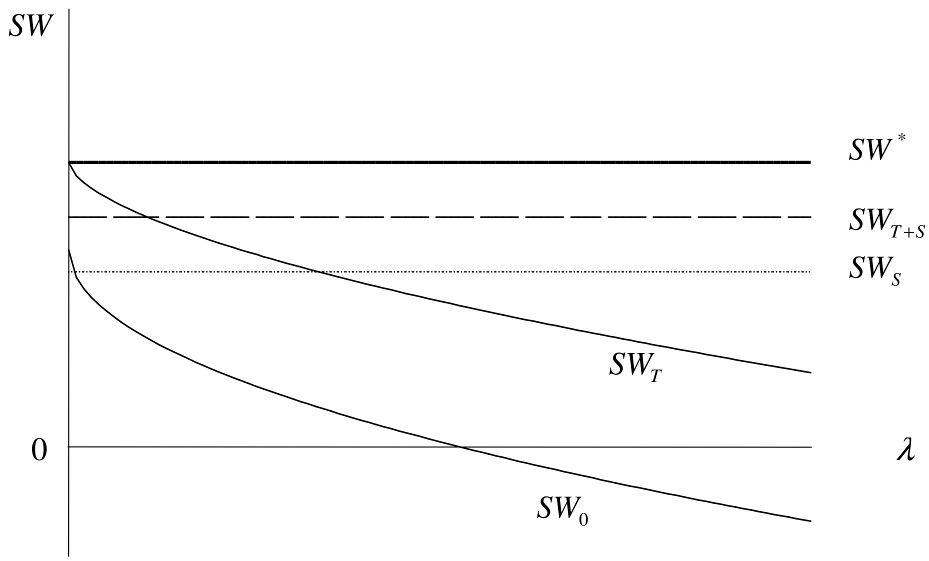

Fig. 4: Policy Ranking for Intermediate Values of *d*

APPENDIX: PROOFS

Proof of Proposition 1: By the Envelope Theorem, $\frac{d\phi_j}{d\theta} = \delta b_j > 0$. Furthermore, $b' > 0$ and $\frac{dh}{dx_j} < 0$ imply that $\frac{d\phi_H}{d\theta}_{|\theta=\theta_0} = \delta b(\theta_0, x_H, p) > \delta b(\theta_0, x_L, p) = \frac{d\phi_L}{d\theta}_{|\theta=\theta_0}$. Given λ and $S = \{H, L\}$, $\phi_H = \phi_L$ at θ_0. Thus, if $\theta \geq \theta_0$, a consumer with θ will purchase *H*.

Q.E.D.

Proof of Proposition 2: At $\lambda = 0$ and $t = d$, $\theta_T = \hat{\theta}(\lambda, p+d) = \hat{\theta}(0, p+d) = \theta^*$ and $SW_{T_{|\lambda=0}} = SW^*$.

Q.E.D.

Proof of Proposition 3: (i) Note that $\lim_{d\to 0} SW_{0_{|\lambda=0}} = SW^* > \lim_{d\to 0} SW_{S_{|\lambda=0}}$, while

$$SW_S - SW_{0|_{\lambda=0}} = \int_{\underline{\theta}}^{\hat{\theta}(0,p)} \{[-P_H + \delta(\theta b_H(\theta,p) - (p+d)x_H h_H(\theta,p))] + [P_L - \delta(\theta b_L(\theta,p) - (p+d)x_L h_L(\theta,p))]\} f d\theta =$$

$$= A + \delta d \int_{\underline{\theta}}^{\hat{\theta}(0,p)} (x_L h_L(\theta,p) - x_H h_H(\theta,p)) f d\theta = A + dB,$$ where A and B are not functions of d and $B > 0$ due to $x_L h_L > x_H h_H$. So, $\lim_{d\to\infty}[SW_S - SW_{0|_{\lambda=0}}] = \infty$. Finally, $SW_S - SW_{0|_{\lambda=0}}$ is monotonic in *d*, since $\delta \int_{\underline{\theta}}^{\hat{\theta}(0,p)} (x_L h_L(\theta,p) - x_H h_H(\theta,p)) f d\theta > 0$. Thus, $SW_S - SW_{0|_{\lambda=0}} > 0$ for large enough *d*.

(ii) For $d \in (0, \bar{d})$, where $\hat{\theta}(0, p+\bar{d}) = \underline{\theta}$, there is inefficiency in both purchase (for some consumers) and use (for all consumers) decisions under the standard. If $d = 0$, the inefficiency in use disappears, but the inefficiency in purchase remains. If $d \geq \bar{d}$, the inefficiency in purchase is eliminated, but the inefficiency in use remains.

Q.E.D.

Proof of Proposition 4:

$$\frac{\partial SW(S,t,\lambda)}{\partial t}_{|d=0} = \{-P_L + \delta(\theta_T b_L(\theta_T, p+t) - p x_L h_L(\theta_T, p+t))\} f(\theta_T) \frac{\partial \hat{\theta}(\lambda, p+t)}{\partial t} +$$

$$+ \{P_H - \delta(\theta_T b_H(\theta_T, p+t) - p x_L h_H(\theta_T, p+t)) + \lambda(P_H - P_L)\} f(\theta_T) \frac{\partial \hat{\theta}(\lambda, p+t)}{\partial t} +$$

$$+ \int_{\underline{\theta}}^{\theta_T} \delta\left(\theta b_L{}'(\theta, p+t) - p x_L\right) \frac{dh_L(\theta, p+t)}{dt} f d\theta + \int_{\theta_T}^{\bar{\theta}} \delta\left(\theta b_H{}'(\theta, p+t) - p x_H\right) \frac{dh_H(\theta, p+t)}{dt} f d\theta =$$

$$= \delta t\left(x_L h_L(\theta_T, p+t) - x_H h_H(\theta_T, p+t)\right) f(\theta_T)\frac{\partial \hat{\theta}(\lambda, p+t)}{\partial t} + \int_{\underline{\theta}}^{\theta_T} \delta\left(\theta b_L'(\theta, p+t) - p x_L\right)\frac{dh_L(\theta, p+t)}{dt} f d\theta +$$

$$+ \int_{\theta_T}^{\bar{\theta}} \delta\left(\theta b_H'(\theta, p+t) - p x_H\right)\frac{dh_H(\theta, p+t)}{dt} f d\theta$$

From the agents' first-order conditions, $\theta b_j'(\theta, p+t) - p x_j > \theta b_j'(\theta, p+t) - (p+t)x_j = 0$.

Furthermore, $x_L h_L > x_H h_H$, $dh/dp < 0$, and $d\hat{\theta}/dp < 0$. So, $\frac{\partial SW(S,t,\lambda)}{\partial t}\Big|_{d=0} < 0$.

Q.E.D.

Proof of Proposition 5: (i) As in proposition 3, $\lim_{\lambda \to 0} SW_{0|d=0} = SW^* > \lim_{\lambda \to 0} SW_{S|d=0}$.

$$SW_S - SW_{0|_{d=0}} = \int_{\underline{\theta}}^{\theta_0} \left\{\left[-P_H + \delta\left(\theta b_H(\theta, p) - p x_H h_H(\theta, p)\right)\right] + \left[P_L - \delta\left(\theta b_L(\theta, p) - p x_L h_L(\theta, p)\right)\right]\right\} f d\theta +$$

$+ \lambda \int_{\theta_0}^{\bar{\theta}} (P_H - P_L) f d\theta$. Therefore:

$$\lim_{\lambda \to \infty}\left[SW_S - SW_{0|_{d=0}}\right] = \int_{\underline{\theta}}^{\bar{\theta}} \left\{\left[-P_H + \delta\left(\theta b_H(\theta, p) - p x_H h_H(\theta, p)\right)\right] + \left[P_L - \delta\left(\theta b_L(\theta, p) - p x_L h_L(\theta, p)\right)\right]\right\} f d\theta +$$

$+ \lim_{\lambda \to \infty} \lambda (P_H - P_L) = \infty$. Also, $SW_S - SW_{0|_{d=0}}$ is monotonic in λ. Thus, $SW_S - SW_{0|_{d=0}} > 0$ for large enough λ.

(ii) It is first-best for consumers with $\theta \in [\underline{\theta}, \hat{\theta}(0, p))$ to choose *L*. It can be shown that $\hat{\theta}(0, p) > \underline{\theta}$, since $\hat{\theta}(0, p+d) > \underline{\theta}$ by assumption and $\hat{\theta}(0, p) > \hat{\theta}(0, p+d)$ by (9).

Q.E.D.

Proof of Proposition 6:

(i) $$\frac{\partial SW(S,t,\lambda)}{\partial t} = \delta(t-d)\left(x_L h_L(\theta_T, p+t) - x_H h_H(\theta_T, p+t)\right) f(\theta_T)\frac{\partial \hat{\theta}(\lambda, p+t)}{\partial t} +$$

$$+ \int_{\underline{\theta}}^{\theta_T} \delta\left(\theta b_L'(\theta, p+t) - (p+d)x_L\right)\frac{dh_L(\theta, p+t)}{dt} f d\theta +$$

$$+ \int_{\theta_T}^{\bar{\theta}} \delta\left(\theta b_H'(\theta, p+t) - (p+d)x_H\right)\frac{dh_H(\theta, p+t)}{dt} f d\theta$$

Thus, $$\frac{\partial SW(S,t,\lambda)}{\partial t}\Big|_{t=0} = -\delta d\left(x_L h_L(\theta_0, p) - x_H h_H(\theta_0, p)\right) f(\theta_0)\frac{\partial \hat{\theta}(\lambda, p+t)}{\partial t}\Big|_{t=0} +$$

$$+ \int_{\underline{\theta}}^{\theta_0} \delta\left(\theta b_L'(\theta, p) - (p+d)x_L\right)\frac{dh_L(\theta, p+t)}{dt}\Big|_{t=0} f d\theta +$$

$$+\int_{\theta_0}^{\bar{\theta}} \delta\left(\theta b_H{}'(\theta, p) - (p+d)x_H\right) \frac{dh_H(\theta, p+t)}{dt}\Big|_{t=0} fd\theta$$

From the agents' first-order conditions, $\theta b_j{}'(\theta, p) - (p+d)x_j < \theta b_j{}'(\theta, p) - px_j = 0$.

Furthermore, $x_L h_L > x_H h_H$, $dh/dp < 0$, and $d\hat{\theta}/dp < 0$. So, $\frac{\partial SW(S,t,\lambda)}{\partial t}\Big|_{t=0} > 0$.

(ii) $$\frac{\partial SW(S,t,\lambda)}{\partial t}\Big|_{t=d} = \int_{\underline{\theta}}^{\hat{\theta}(\lambda, p+d)} \delta\left(\theta b_L{}'(\theta, p+d) - (p+d)x_L\right) \frac{dh_L(\theta, p+t)}{dt}\Big|_{t=d} fd\theta +$$

$$+ \int_{\hat{\theta}(\lambda, p+d)}^{\bar{\theta}} \delta\left(\theta b_H{}'(\theta, p+d) - (p+d)x_H\right) \frac{dh_H(\theta, p+t)}{dt}\Big|_{t=d} fd\theta = 0$$ after invoking the agents' first-order conditions.

(iii) $$SW_T = SW^* - \int_{\theta^*}^{\theta_T} \{[-P_H + \delta(\theta b_H(\theta, p+d) - (p+d)x_H h_H(\theta, p+d))] + [P_L - \delta(\theta b_L(\theta, p+d) - (p+d)x_L h_L(\theta, p+d))]\} fd\theta -$$

$$- \lambda(P_H - P_L)\int_{\theta_T}^{\bar{\theta}} fd\theta < SW^*$$

Q.E.D.

Proof of Proposition 7: Proof follows from Propositions 3 and 5.

Q.E.D.

Proof of Proposition 8: Define $f(\lambda, d) \equiv SW_S - SW_T$. From $f(\tilde{\lambda}, d) = 0$, apply the Implicit Function Theorem to obtain $\frac{d\tilde{\lambda}}{dd}$: (1) $\frac{\partial f}{\partial \tilde{\lambda}} = (P_H - P_L)\int_{\hat{\theta}(\tilde{\lambda}, p+d)}^{\bar{\theta}} fd\theta > 0$,

(2) $$\frac{\partial f}{\partial d} = \int_{\underline{\theta}}^{\hat{\theta}(\tilde{\lambda}, p+d)} \delta(x_L h_L(\theta, p+d) - x_H h_H(\theta, p)) fd\theta + \int_{\hat{\theta}(\tilde{\lambda}, p+d)}^{\bar{\theta}} \delta(x_H h_H(\theta, p+d) - x_H h_H(\theta, p)) fd\theta,$$

by dropping the terms from agents' first-order conditions and using the definition of $\hat{\theta}(\tilde{\lambda}, p+d)$.
Note the following:

$$\lim_{d\to 0} \frac{\partial f}{\partial d} = \int_{\underline{\theta}}^{\hat{\theta}(\tilde{\lambda}, p)} \delta(x_L h_L(\theta, p) - x_H h_H(\theta, p)) fd\theta > 0, \quad \lim_{d\to\infty} \frac{\partial f}{\partial d} = \int_{\underline{\theta}}^{\bar{\theta}} \delta x_H (h_H(\theta, \infty) - h_H(\theta, p)) fd\theta < 0,$$

and
$$\frac{\partial^2 f}{\partial d^2} = \delta\left\{\left(x_L h_L(\hat{\theta}, p+d) - x_H h_H(\hat{\theta}, p+d)\right)\right\} f(\hat{\theta}) \frac{d\hat{\theta}(\tilde{\lambda}, p+d)}{dd} +$$
$$+ \delta x_L \int_{\underline{\theta}}^{\hat{\theta}(\tilde{\lambda}, p+d)} \frac{dh_L(\theta, p+d)}{dd} fd\theta + \delta x_H \int_{\hat{\theta}(\tilde{\lambda}, p+d)}^{\bar{\theta}} \frac{dh_H(\theta, p+d)}{dd} fd\theta < 0, \quad \forall d$$

The last inequality is due to $x_L h_L(\theta, p) - x_H h_H(\theta, p) > 0, \forall \theta, p$; $\frac{d\hat{\theta}}{dp} < 0$; and $\frac{dh_j}{dp} < 0$.

Finally, for $\lambda = 0$, we always have $SW_S - SW_T < 0$, since both positive terms from (15) disappear. It is easy to show that $\frac{d}{d\lambda}(SW_S - SW_T) > 0$. Therefore, $\tilde{\lambda}(d) > 0, \forall d$, while $\frac{d\tilde{\lambda}}{dd} < 0$ for low *d* and $\frac{d\tilde{\lambda}}{dd} > 0$ for high *d*.

Q.E.D.

Proof of Proposition 9:

(i) $\frac{\partial}{\partial t} SW(S', t, \lambda)_{|t=d} = \int_{\underline{\theta}}^{\bar{\theta}} \left[-P_H + \delta\left(\theta b_H{}'(\theta, p+d) - (p+d)x_H \right) \right] \frac{dh_H(\theta, p+t)}{dt}_{|t=d} f d\theta = 0$, after invoking the agents' first-order conditions.

(ii) Note that $SW_{0}\big|_{d=0,\lambda=0} = SW^* > SW_{T+S}\big|_{d=0,\lambda=0}$, whereas $\lim_{\substack{d\to\infty \\ \lambda\to\infty}} SW_{T+S} = 0$ and $\lim_{\substack{d\to\infty \\ \lambda\to\infty}} SW_0 = -\infty$.

Also, $SW_{T+S} - SW_0$ is monotonic in λ and *d*:

$$\frac{d}{d\lambda}\{SW_{T+S} - SW_0\} = \delta d(x_L h_L(\theta_0, p) - x_H h_H(\theta_0, p)) f(\theta_0) \frac{\partial \theta_0}{\partial \lambda} + (P_H - P_L) \int_{\theta_0}^{\bar{\theta}} f d\theta > 0,$$

$$\frac{d}{dd}\{SW_{T+S} - SW_0\} = \delta \int_{\underline{\theta}}^{\theta_0} (x_L h_L(\theta, p) - x_H h_H(\theta, p+d)) f d\theta + \delta x_H \int_{\theta_0}^{\bar{\theta}} (h_H(\theta, p) - h_H(\theta, p+d)) f d\theta > 0$$

by $x_L h_L(\theta, p) > x_H h_H(\theta, p), \forall \theta, p$; and $dh/dp < 0$.

Thus, $SW_{T+S} > SW_0$ for large enough *d* and/or λ

(iii) For $d \geq \bar{d}$, $\theta^* \leq \underline{\theta}$. Thus:

$$SW^* = \int_{\underline{\theta}}^{\bar{\theta}} [-P_H + \delta(\theta b_H(\theta, p+d) - (p+d)x_H h_H(\theta, p+d))] f d\theta = SW_{T+S}.$$

Q.E.D.

Proof of Proposition 10:

$\frac{\partial}{\partial t} SW(S', t, \lambda)_{|t=0} = \int_{\underline{\theta}}^{\bar{\theta}} \left[-P_H + \delta\left(\theta b_H{}'(\theta, p) - (p+d)x_H \right) \right] \frac{dh_H(\theta, p+t)}{dt}_{|t=0} f d\theta > 0$, due to

$\theta b_H{}'(\theta, p) - (p+d)x_H < \theta b_H{}'(\theta, p) - px_H = 0$ from the first-order conditions and $\frac{dh}{dp} < 0$. Then, as shown in Proposition 9, $\frac{\partial}{\partial t} SW(S', t, \lambda)_{|t=d} = 0$

Q.E.D.

Proof of Proposition 11: Define $g(\lambda, d) \equiv SW_{T+S} - SW_T$, i.e. $g(\overline{\lambda}, d) = 0$.

Find $d\overline{\lambda}/dd$: (1) $\frac{\partial g}{\partial \overline{\lambda}} = (P_H - P_L) \int_{\hat{\theta}(\overline{\lambda}, p+d)}^{\overline{\theta}} f d\theta > 0$; (2) $\frac{\partial g}{\partial d} = \delta \int_{\underline{\theta}}^{\hat{\theta}(\overline{\lambda}, p+d)} (x_L h_L(\theta, p+d) - x_H h_H(\theta, p+d)) f d\theta$

Note that $\frac{\partial g}{\partial d} > 0$, as long as $\hat{\theta}(\overline{\lambda}, p+d) > \underline{\theta}$. Thus, $\frac{d\overline{\lambda}}{dd} < 0$ for $\hat{\theta}(\overline{\lambda}, p+d) > \underline{\theta}$ and $\frac{d\overline{\lambda}}{dd} = 0$ otherwise. Recall that $\hat{\theta}(0, p+\overline{d}) = \underline{\theta}$. For $d \geq \overline{d}$, $g(\lambda, d) = 0$, i.e. $\overline{\lambda}(d) = 0$, $\forall\ d \geq \overline{d}$. By $\hat{\theta}(0, p) > \hat{\theta}(0, p+d) \equiv \theta^* > \underline{\theta}$, it follows that $\overline{d} > 0$. If $\overline{\lambda}(\overline{d}) = 0$ at $\overline{d} > 0$ and $\frac{d\overline{\lambda}}{dd} < 0$ for $d < \overline{d}$, it follows that $\overline{\lambda}(0) > 0$. Therefore, for low *d*, i.e. $d < \overline{d}$, there exist values $\lambda \in [0, \overline{\lambda}]$ for which $SW_{T+S} < SW_T$.

Q.E.D.

ENDNOTES

[1] See http://www.nhtsa.gov/fuel-economy for an overview of the CAFE standards.

[2] See http://www.energystar.gov for more information about the program.

[3] See Gillingham *et al*. (2006) and Sorrell *et al*. (2009) for a review of the literature on the rebound effect.

[4] See Frederick *et al.* (2002) and Carson and Tran (2009) for a summary of these studies.

[5] For further evidence of such behavior, see Loewenstein and Prelec (1992), Frederick *et al.* (2002), and DellaVigna (2009).

[6] See Greene (2010a) for a review of studies estimating consumers' valuations of fuel economy. The evidence he finds is mixed: some studies report undervaluing and some overvaluing of fuel costs.

[7] These preferences are sometimes referred to as "quasi-hyperbolic," since their discount function is only an approximation of the generalized hyperbola.

[8] Karp and Tsur (2011) show that in some contexts hyperbolic discounting can lead to time-consistent policy outcomes. They consider a climate change model where the concentration of a stock pollutant increases over time. In this setting, a policy decision involving either perpetual stabilization of the stock or perpetual lack of abatement is time-consistent. However, any other policy in this model (e.g. partial stabilization or varying abatement) is time-inconsistent.

[9] See Fishbach and Converse (2010) for further evidence of commitment behavior.

[10] For example, Shapiro (2005) observes that food stamp recipients tend to over-consume during the early days of the stamp month and discusses the role of policy as a commitment device. In particular, he suggests that an increase in the frequency of transfer payments, while reducing the amount of each payment, could benefit consumers. Kan (2007) finds empirical evidence that smokers intending to quit would support public policies that impose costs on smoking, such as cigarette excise taxes or smoking bans in public places.

[11] A similar conclusion is reached by Agras and Chapman (1999), who show that a combination of CAFE standards and taxes allows for meeting the Kyoto Protocol emissions target at a substantially lower cost relative to a stand-alone standard or tax policy. Fischer *et al*. (2007), Parry *et al*. (2010), and Small (2011) also analyze the welfare impacts of a combined policy, in a scenario where consumers undervalue future energy costs, and find that such a policy can be welfare-improving. Although their conclusions are generally consistent with our study, they hinge on the assumption of consumer misperceptions, while the driving factor in our model is temptation.

[12] See Gul and Pesendorfer (2001) for a list of assumptions on these functions.

[13] Note that this setup is specific to our context (see Section 3). More generally, multi-period self-control preferences can be represented by $W_t(S_t) = \max_{z_t \in S_t}\{u_t(z_t) + v_t(z_t) + \delta W_{t+1}(S_{t+1})\} - \max_{z_t \in S_t} v_t(z_t)$, $t \geq 1$. See Gul and Pesendorfer (2004) for a detailed discussion and applications of this dynamic framework.

[14] This single use period can be interpreted as representing the total net benefits from all future periods of use, discounted back to period 1 after the purchase.

[15] For example, in the market for light bulbs, *H* denotes a compact fluorescent light bulb (CFL), and *L* stands for an incandescent bulb with comparable light output. In other markets for household appliances, *H* could refer to an Energy Star appliance and *L* to a non-Energy Star product with comparable physical and technical characteristics. In car markets, *H* and *L* could be a hybrid and a comparable non-hybrid model.

[16] By convention, we assume that consumers who are indifferent buy *H*.

[17] The remaining parameters in the $\hat{\theta}$ function, namely P_H, P_L, x_H, x_L, and δ, have been suppressed for simplicity.

[18] See Small and Van Dender (2007), Davis (2008), Sorrell *et al.* (2009), and Greene (2010b).

[19] The rebound effect coefficient is $\eta = \frac{\partial h}{\partial P_x}\frac{P_x}{h}$, where $P_x \equiv px$, i.e. cost per hour of use. As efficiency improves from x_L to x_H, P_x falls. A rebound effect less than 100% implies that $|\eta| < 1$, so $P_x h$ will decrease with P_x, i.e. $px_L h_L > px_H h_H$.

[20] This purchase pattern does not necessarily hold if we allow consumers the option not to buy either of the two products. In that case, as p becomes sufficiently large, low-θ agents are better off not buying either of the products. For sufficiently large values of p, none of the consumers will buy either of the two products. Thus, when a "do not buy" option exists, the number of L-consumers falls with p, while there is a non-monotonic (hill-shaped) relationship between the number of H-consumers and energy prices.

[21] In their analysis of the automobile market, Parry *et al.* (2010) consider both CO_2 emissions, which result from gasoline consumption, as well as externalities related to miles driven (e.g. congestion, accidents, and local pollution). We only model externalities related to energy consumption. While excluding the second class of externalities may potentially affect the robustness of our results when applied to the automobile market, it is less of an issue in the context of electricity-using durables.

[22] Among recent literature, see Jacobsen (2010) and Parry *et al.* (2010).

[23] For $d = 0$, the SW_T and SW_0 curves overlap, but the ranking pattern with respect to the other two policies and the first-best outcome remains the same.

[24] If damages are sufficiently high, i.e. $d \geq \bar{d}$, the SW_{T+S} curve overlaps with SW^* and $SW_S > SW_0$ for all λ, while the remaining ranking pattern is preserved.

[25] Note also that unless the rebate is set at $P_H - P_L$, it cannot fully address the effects of temptation. If a partial rebate $R < P_H - P_L$ is given for the purchase of H, the magnitude of R can be adjusted so that the purchase inefficiency is eliminated. However, in this case self-control costs cannot be fully eliminated due to the difference in effective product prices.

[26] It can also be shown that the results from Section 6 do not change qualitatively even if we relax the assumption of independence between θ and λ. The above discussion about the optimal magnitude of the tax and the ranking of the tax and standard relative to no policy or first-best remains valid. Proposition 10 holds for all λ, and hence its outcome does not depend on the distributional assumptions about θ and λ. It remains true that the expressions $SW_S - SW_T$, $SW_{T+S} - SW_T$, and $SW_{T+S} - SW_0$ are not necessarily positive for a given λ. Hence, when these expressions are integrated over the entire population, it is not always the case that a standard alone or a combined policy is welfare-improving over a Pigovian tax, or that a combined policy is welfare-improving over no policy. Therefore, the conclusions obtained in Section 6 remain consistent even when we introduce variation in λ.