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Hunt Allcott
Sendhil Mullainathan
Dmitry Taubinsky

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ABSTRACT

We analyze how the traditional logic of Pigouvian externality taxes changes if consumers undervalue energy costs when buying energy-using durables such as cars and air conditioners. First, with undervaluation, there is an Internality Dividend from Externality Taxes: aside from reducing externalities, they also reduce allocative inefficiencies caused by consumers' underinvestment in energy efficient durables. Second, although Pigouvian taxes are clearly the preferred policy mechanism when externalities are the only market failure, undervaluation provides an Internality Rationale for Energy Efficiency Policy, including fuel economy standards and subsidies for energy efficient goods. However, this Internality Rationale has surprising features: it does not apply to all classes of behavioral biases, and the socially-optimal response to undervaluation may include energy taxes higher or lower than the externality damages, despite the resulting distortion to utilization. We calibrate our results in a simulation model of the US automobile market, finding that Pigouvian taxes actually increase consumer welfare and that the optimal subsidy for high-fuel economy vehicles could be quite large.

Hunt Allcott
Department of Economics
New York University
19 W. 4th Street, 6th Floor
New York, NY 10012
and NBER
hunt.allcott@nyu.edu

Sendhil Mullainathan
Department of Economics
Littauer M-18
Harvard University
Cambridge, MA 02138
and Consumer Financial Protection Bureau
and also NBER
mullain@fas.harvard.edu

Dmitry Taubinsky
Harvard University
taubinsk@fas.harvard.edu

1 Introduction

Since a seminal paper by Hausman (1979), it has frequently been asserted that consumers "undervalue" energy costs relative to purchase prices when they choose between different goods, perhaps because they are inattentive to or imperfectly informed about these costs. Although the empirical evidence varies across settings, this assertion would be consistent with findings that we are inattentive to other ancillary product costs such as sales taxes (Chetty, Looney, and Kroft 2009), shipping and handling charges (Brown, Hossein, and Morgan 2010), and the out-of-pocket costs of insurance plans (Abaluck and Gruber 2011). Consumer undervaluation of energy costs has become an important policy issue: along with energy use externalities such as local air pollution and climate change, it is sometimes used as a justification for major regulations such as Corporate Average Fuel Economy (CAFE) standards and billions of dollars in subsidies for energy efficient durable goods. Despite the policy implications, however, there is little formal guidance on the implications of undervaluation for the design of energy policy.

In this paper, we use a theoretical model and calibrated simulations to characterize optimal policies to address two inefficiencies: undervaluation and externalities. We begin with a theoretical analysis of consumers choosing between two energy-using durable goods. One good, which could be thought of as the "gas sipper," has lower energy costs compared to the other, the "gas guzzler." Consumers have some distribution of utilization demand: for example, some live close to the office, while others have long commutes. When choosing between the two goods, some consumers misoptimize: while they should be indifferent between \$1 in purchase price and \$1 in energy costs because both equally affect consumption of the numeraire good, they undervalue energy efficiency relative to their private optima. In the language of Herrnstein *et al.* (1993), undervaluation causes consumers to impose "internalities" on themselves. We model a policymaker with two instruments: "energy taxes," by which we mean carbon taxes, cap-and-trade programs, gas taxes, and other policies that change the retail energy price, and "product subsidies," by which we mean subsidies for hybrid vehicles, home weatherization, and energy efficient appliances, fuel economy standards, feebates, and other policies that affect the relative purchase price of gas sippers vs. gas guzzlers.

We show that adding undervaluation reverses two basic results from a canonical Pigouvian framework where energy use externalities are the only market failure. The first canonical result is that while Pigouvian taxes increase social welfare, they reduce "consumer welfare," by which we mean social welfare with zero weight placed on the externality. In the current context of climate change policy, this traditional result is extremely relevant: some policymakers place little weight on the externality reduction from a carbon tax and argue against such a policy because it damages the economy in the short term. However, we show that when consumers undervalue energy efficiency, this result is reversed: a carbon tax can actually increase consumer welfare, independent of the externality reduction. Intuitively, this is because undervaluation is a pre-existing distortion that increases demand for gas guzzlers above consumers' private optima, and increasing energy taxes reduces this distortion. Conceptually, this result is related to the Double Dividend hypothesis explored by Bovenberg and Goulder (1996), Parry (1995), and others in the basic sense that it identifies an additional benefit from environmental taxation other than externality reduction. As such, we call this effect the *Internality Dividend from Externality Taxes.* This result is quite important, as it means that clear evidence of undervaluation can fundamentally reshape the climate policy debate.

The second canonical result from the Pigouvian framework is that when energy use externalities are the only market failure, product subsidies are an inefficient second best substitute for Pigouvian energy taxes (Jacobsen 2010, Sallee 2011a). One key reason for this canonical result is that unlike energy taxes, product subsidies do not impose the correct social cost of energy use on consumers' utilization decisions: while product subsidies can induce consumers to buy the first best quantity of gas sippers, they will still drive too much. However, we show that undervaluation of energy costs can justify product subsidies, and the more severe the undervaluation, the larger the subsidy should be. Intuitively, this is a qualified version of the "two market failures requires two instruments" logic: the energy tax primarily targets the externality, and the product subsidy primarily targets the internality. We call this the *Internality Rationale for Energy Efficiency Policy.* This result is fundamentally important, because it means that evidence of undervaluation can eliminate the traditional arguments against many energy efficiency policies.

There are two reasons why we say that this is a *qualified* version of "two market failures requires two instruments." First, while the result applies to a broad class of behavioral biases that could result in undervaluation, it does not apply to all potential biases. As a counterexample, we discuss one empirically-plausible model of consumer choice under which no biased consumers would be marginal to a product subsidy, implying that the subsidy can only distort already-optimal choices by unbiased consumers. This highlights the policy importance of empirical research that can specifically identify whether consumers' actual biases, if any, fit the requirements for the Internality Rationale. Second, we show that an energy tax higher or lower than the externality can optimally be used together with the product subsidy to address undervaluation, despite the fact that this distorts the optimal utilization of the goods. The reason is that the consumers marginal to the energy tax may be more or less biased than those marginal to the product subsidy, and the relative targeting of the two instruments can be used to preferentially affect the decisions of the more highly-biased consumers.

To complement the theoretical analysis, we set up a discrete choice model of US automobile demand and calibrate it using utility function parameters from the literature. In our base case, we assume that internalities are such that the average consumer values three-quarters of gasoline costs when making purchase decisions, while the externality is a $20 per metric ton social cost of carbon dioxide emissions, per Greenstone, Kopits, and Wolverton (2011). We then calibrate the Internality Dividend from Externality Taxes, showing that this level of undervaluation would dramatically change the policy argument around carbon pricing. With no undervaluation, a $20 carbon price abates carbon at an average cost of $6.80 per ton, reducing consumer welfare in the automobile market by $86 million per year. With undervaluation, however, that same $20 carbon price abates carbon at an average cost of *negative* $5.40 per ton and *increases* consumer welfare by $65 million annually. Thus, in this case, internalities don't just partially offset consumer welfare losses from a Pigouvian tax at the level of the externality: they reverse the sign of the effect.

We also document the Internality Rationale for Energy Efficiency Policy by calibrating the socially-optimal combination of product subsidies and energy taxes. With no undervaluation, the optimal policy is simply an energy tax at the level of marginal damages, with zero product subsidy. With undervaluation, however, the optimal product subsidy is significant: it increases the relative price of a 20 mile-per-gallon (MPG) vehicle such as the Subaru Outback by about $640 relative to a 25 MPG vehicle such as the Toyota Corolla. Thus, these results support non-trivial policy actions.

The simulations also highlight areas where additional research would or would not be valuable. First and foremost, the magnitude of undervaluation matters a lot. We demonstrate this by analyzing two alternative scenarios in which the policymaker implements what would be the "optimal" policy under our base case parameter assumptions, but the true extent of undervaluation is the lower bound and the upper bound, respectively, of empirical estimates from Busse, Knittel, and Zettelmeyer (2012). In the lower bound case, in which consumers significantly undervalue gasoline costs, the annual welfare loss from the "optimal" policy relative to the true optimal policy is $296 million. In the upper bound case, in which consumers significantly overvalue, the "optimal" policy is $2.8 billion per year worse than no intervention at all. We also show that as the variance in undervaluation across consumers grows, the socially-optimal energy tax and product subsidy change markedly as they differentially target different types of consumers. However, empirically estimating this variance is not actually very important for policy, as it is almost as effective to implement a heuristic policy of an energy tax at marginal damages and a product subsidy at the level of the marginal internality.

After briefly highlighting related literature, the paper proceeds as follows. In Section 2, we provide more background on undervaluation of energy costs and relevant energy efficiency policies. Section 3 presents our theoretical model and formal results on optimal tax policy. Section 4 details the auto market simulation and results. Section 5 concludes.

1.1 Related Literature

Our paper is related to a theoretical and empirical literature that analyzes public policies when agents misoptimize, including in the contexts of health care (Baicker, Mullainathan, and Schwartzstein (2012), Handel (2011)), cellular phone contracts (Grubb and Osborne 2012), drug addiction (Gul and Pesendorfer 2007), taxation (Chetty, Looney, and Kroft 2009), and many others.[1] Perhaps the most similar paper in this broader literature is by O'Donoghue and Rabin (2006), who study optimal internality taxes for a hypothetical good ("potato chips") that is overconsumed by misoptimizing consumers. When we interpret energy inefficient goods as potato chips, some of our basic theoretical results parallel their original arguments. In particular, because product subsidies are effectively internality taxes on gas guzzlers, the Internality Rationale for Energy Efficiency Policy

[1] Mullainathan, Schwartzstein, and Congdon (2012) review this literature and discuss additional important papers too numerous to cite here. In a discussion in the Journal of Economic Literature, Kroft (2011) argues that there is much progress yet to be made: "The public finance literature is only recently beginning to consider behavioral welfare economics, and there exist few theoretical explorations of optimal policy with behavioral agents."

parallels their result that it is optimal to impose internality taxes if consumers over-consume a good relative to their private optima. The primary way that our paper differs is in our application to energy using durables. This leads us to a theoretical framework with additional features: two inefficiencies (externalities and internalities), two margins (purchase and utilization), and two policy instruments (energy taxes and product subsidies). Without this additional framework, there would be no scope for a result like the Internality Dividend from Externality Taxes. Furthermore, our study of the relative effectiveness and targeting of the two policy instruments obviously requires a model with both instruments, as well as two margins on which they can act. While O'Donoghue and Rabin (2006) demonstrate the insight that internalities justify internality taxes, in the context of energy demand their model cannot tell the policymaker what type of tax to use, and what margin to tax.

Within the environmental economics literature, there are also several important papers that explore ideas related to the Internality Rationale for Energy Efficiency Policy. Fischer, Harrington, and Parry use a simulation model to ask whether an increase in fuel economy standards is merited, using a set of different assumptions around the extent of undervaluation and the magnitude of externalities from driving. Heutel (2011) studies whether incentive-based or command-and-control policies are preferred when consumers are time-inconsistent and then compares welfare effects using a set of alternative behavioral welfare criteria. Parry, Evans, and Oates (2010) and Krupnick *et al.* (2010) also use calibrated simulations to evaluate energy efficiency policies in the automotive and electric power sectors. The primary way that our paper differs is in the generality of our analysis. Our model applies naturally to decisions between many different energy-using durables, including autos, appliances, and weatherization investments. Furthermore, our model of undervaluation is very general, which means that we know that it applies to several different specific forms of bias, including partial attention, present bias, and systematically biased beliefs about energy costs. In several cases where our results are general to some cases but not others, this guides policy-relevant empirical research questions.

2 Background

In this section, we provide background on two basic features of our model. First, what do we mean by "undervaluation" of energy costs? Second, what do we mean by "product subsidies"?

2.1 Undervaluation of Energy Costs

In this paper, we use the generic word "undervaluation" to capture a set of factors that might reduce demand for energy efficient durable goods below consumers' private optima. Several factors are commonly proposed.[2] The first is systematically biased beliefs. For example, the official cost-benefit analysis of the current U.S. fuel economy standard argues that consumers have incorrect "perceptions" of fuel cost savings (NHTSA 2010, page 2). Allcott (2012), Attari *et al.* (2010), and Larrick and Soll (2008) document particular systematic biases in the way that we perceive energy costs of different durable goods, including automobiles.

A second potential factor is inattention. The idea that consumers are inattentive to a product's energy costs would be consistent with empirical evidence from other domains that we are inattentive to other ancillary product costs. Consumers on eBay, for example, are less elastic to shipping and handling charges than to the listed purchase price (Brown, Hossain, and Morgan 2010). Mutual fund investors appear to be less attentive to ongoing management fees than to upfront payments (Barber, Odean, and Zheng 2005). Chetty, Looney, and Kroft (2009) show that shoppers are less elastic to sales taxes than to prices. Abaluck and Gruber (2011) show the seniors choosing between Medicare Part D plans place more weight on plan premiums than on expected out-of-pocket costs. Some suggestive evidence on inattention in automobile purchases comes from the Vehicle Ownership and Alternatives Survey (Allcott 2011), in which 40 percent of Americans report that they "did not think about fuel costs at all" when buying their most recent vehicle. There are many theoretical models of inattention relevant to finance, macroeconomics, and consumer choice, including Gabaix (2012), Gabaix and Laibson (2006), Mackowiak and Wiederholt (2009), Reis (2006a, 2006b), Sallee (2011b), and Sims (2003).

A third potential factor is naive present bias. Loewenstein and Prelec (1992) and many others

[2] See DellaVigna (2009) for a review of the psychology and economics literature, which includes evidence on these biases in other contexts. Gillingham and Palmer (2012) review behavioral biases related to choices between energy-using durables.

document that people are can be time-inconsistent, for example by systematically undervaluing all future consumption relative to consumption in the present. There are also a number of theoretical models of present bias, including Laibson (1997), O'Donoghue and Rabin (1999), and Strotz (1955). Present bias is a special case of our model if purchase prices reduce consumption in the present and energy costs reduce consumption in the future. We consider only cases where consumers are unaware of their biases, leaving sophisticated consumers for future work.

A number of empirical papers dating to the 1970s have tested for undervaluation. Hausman (1979) estimated that the "implied discount rate" that rationalizes consumers' tradeoffs between purchase prices and future energy costs for air conditioners was 15 to 25 percent, above the rates at which most consumers borrowed and invested money. His results were corroborated by Gately (1980), who showed that buyers of energy inefficient refrigerators needed to have discount rates of 45% to 300%, and by Dubin and McFadden (1984), who found that choices and utilization of home heating equipment implied a 20 percent discount rate. Hausman (1979) argued that consumers were making mistakes by not buying more energy efficient appliances, but that this was unsurprising because "at least since Pigou, many economists have commented on a 'defective telescopic faculty.'"

A number of papers have tested for whether automobile consumers appear to undervalue future gasoline costs relative to purchase prices, including Allcott and Wozny (2011), Austin (2008), Busse, Knittel, and Zettelmeyer (2012), Dreyfus and Viscusi (1995), Goldberg (1998), Kilian and Sims (2006), Sallee, West, and Fan (2009), Sawhill (2008), and Verboven (1999, 2002). Greene (2010) reviews 25 studies, of which 12 suggest that consumers tend to undervalue gas costs, five suggest that we overvalue gas costs, and eight indicate that the average consumer makes the tradeoff correctly.

2.2 Existing Product Subsidies and Related Energy Policies

In the U.S., a wide array of state and federal policies encourage energy efficiency. Our analysis focuses specifically on what we call "product subsidies": taxes or subsidies that reduce the relative prices of energy efficient durable goods. Such policies include tax credits of up to $3400 for hybrid vehicles, which were available for the bulk of the last decade, as well as the "gas guzzler tax," an excise tax ranging from $1000 to $7700 on the sale of low fuel economy passenger cars. Another example is the Weatherization Assistance Program, which heavily subsidizes weatherization for about 100,000 low-income homeowners each year. Furthermore, in many states, there are an array of rebates and subsidized loans for weatherization and energy efficient appliances; these "Demand-Side Management programs" cost about $3.6 billion per year (U.S. EIA 2010).

Importantly, our model of product subsidies also captures the effects of the Corporate Average Fuel Economy (CAFE) standard. This policy requires that the fleets of new cars and trucks sold by each auto manufacturer attain a minimum average fuel economy rating. This constraint adds a relative shadow cost to the sale of low fuel economy vehicles, inducing automakers to increase their relative prices. Thus, the CAFE standard affects consumers in the same way as a product subsidy, by changing relative product purchase prices. In the long run, of course, both explicit subsidies and the CAFE standard induce changes in the characteristics of vehicles offered, but this is well beyond the scope of our analysis.[3]

Different readers will have different assessments of the empirical evidence on whether consumers undervalue energy efficiency in particular contexts, as well as different philosophies on whether it is even possible for people to systematically make mistakes and whether policymakers should intervene if they do. However, product subsidies and other policies that cost many billions of dollars are partially or even largely justified as responses to some form of undervaluation. This paper is motivated by the idea that aside from empirically testing if and when consumers misoptimize, it is also crucially important to provide formal theoretical analysis that can help improve the design of these policies. This analysis begins in the following section.

3 Theoretical Model of Optimal Policy

In this section, we set up our model, derive four propositions about optimal policy, and then discuss the targeting of product subsidies vs. energy taxes.

[3]Our study is related to other studies of CAFE standards and other potential policies to decrease the relative purchase prices of energy efficient vehicles, including Anderson, Parry, Sallee, and Fischer (2010), Austin and Dinan (2005), Fischer, Harrington, and Parry (2007), Fullerton and West (2010), Gallagher and Muehlegger (2011), Goldberg (1998), Greene, Patterson, Singh, and Li (2005), Jacobsen (2010), Kleit (2004), and Sallee (2011a).

3.1 Setup

3.1.1 Consumer Utility

We model consumers who choose between an energy inefficient durable I, and an energy efficient durable E. Concretely, we have in mind a choice between hybrid versus non-hybrid cars, compact fluorescent lightbulbs versus incandescents, and standard versus energy efficient versions of air conditioners, washing machines, and other appliances. A durable $j \in \{I, E\}$ consumes e_j units of energy per unit of utilization m, with $e_I > e_E$. Consumers have single unit demand.

Consumers are differentiated by a parameter θ, which corresponds to how much they will utilize the durable good. A high-θ consumer is one who has a long commute to the office or lives in a hot climate that requires lots of air conditioner use. We assume that each consumer chooses a utilization level $m > \theta$, from which he derives utility $u(m - \theta)$. To ensure the existence of an interior optimum, we assume $u' > 0$, $u'' < 0$, $\lim_{x \to 0} u'(x) = \infty$ and $\lim_{x \to \infty} u'(x) = 0$. We also assume that $|xu''(x)/u'(x)| > 1$ to ensure that the price elasticity of utilization is less than one in absolute value, consistent with empirical estimates such as Davis (2008), Davis and Kilian (2011), Gillingham (2010), Hughes, Knittel, and Sperling (2007), and Small and Van Dender (2007). This implies that consumers use less energy when they purchase the more energy efficient durable. The parameter θ is distributed according to some atomless distribution F with full support on the positive reals.[4]

For simplicity, we assume that the two durable goods differ only in energy efficiency and not in how they directly impact a consumer's utility. However, the basic logic of our results also goes through when the goods are differentiated on another attribute which consumers value heterogeneously. For example, we could allow some consumers to derive warm glow utility from owning hybrid vehicles, or we could allow some consumers to prefer the light quality from incandescent lightbulbs.

We assume that there is no outside option. This is useful for two reasons. First, it allows us to remain agnostic about how exactly the undervaluation of energy costs impacts the choice of an outside option. Second, this allows us to interpret our model as a model of consumer choice of

[4] Our results require that for any price difference $p_E - p_I$, there are consumers of each decision utility type with high enough θ such that they purchase good E. In other words, we do not consider the trivial cases where the energy efficient good is so expensive that no consumers buy it. While there are other ways of ensuring this, it is most straightforward to do so through this assumption that θ has no upper bound.

efficiency enhancements such as weatherization. Specifically, I can be viewed as the status quo choice to not weatherize one's home, while E can represent the choice to weatherize.

If p_g is the cost of energy, p_j is the price of durable j, T is a transfer from the government and Y_θ is the budget constraint, then a consumer derives utility

$$\{Y_\theta + T - p_j - p_g m e_j\} + u(m - \theta) \tag{1}$$

from purchasing durable j and choosing m units of utilization. The term in brackets is consumption of the numeraire good: the amount of money from income Y and transfers T that the consumer has left over after purchasing the durable good and paying for energy. Each consumer's budget constraint is large enough so that the optimal choice m^* is an interior solution.

3.1.2 Consumer Choice

It is helpful to define the function v as follows:

$$v(\theta, e, p_g) \equiv \max_m \{u(m - \theta) - p_g m e\}. \tag{2}$$

We call $V_{\mathrm{r}}(\theta, e_E, e_I, p_g) \equiv v(\theta, e_E, p_g) - v(\theta, e_I, p_g)$ the "gross utility gain" from the energy efficient good, and we let $\xi = (\theta, e_E, e_I, p_g)$ denote all the parameters that determine this gross utility gain. In words, the gross utility gain reflects both the energy cost savings and the utility from increased utilization for the energy efficient good relative to the energy inefficient good. A fully optimizing consumer chooses durable E if and only if the gross utility gain exceeds the incremental price $p_E - p_I$:

$$V_{\mathrm{r}}(\xi) > p_E - p_I. \tag{3}$$

As verified in Appendix I, V_{r} is strictly increasing in θ and p_g, and it is unbounded from above as a function of θ.

Misoptimizing consumers do not correctly value how differences in energy efficiency will impact their future utility. Instead, they choose according to decision utility function $\tilde{V}$. These consumers choose E if and only if

$$\tilde{V}(\xi) > p_E - p_I. \tag{4}$$

We assume that $\tilde{V}(\xi) \leq V_{\mathrm{r}}(\xi)$ for all ξ, meaning that consumers either correctly value or undervalue the gross utility gain from energy efficiency. We further assume that $\tilde{V}$ is differentiable, strictly increasing in θ and p_g, and unbounded from above as a function of θ.

An important feature of this framework is that it is very general. As we show formally in Appendix II, it is flexible enough to incorporate a number of sources of undervaluation, including any combination of the following biases:

1. *Exogenous partial inattention:* As in the simple model in DellaVigna (2009), the gross utility gain might be an 'opaque' component of the decision that is processed only partially. Thus $\tilde{V}(\xi) = \gamma V_{\mathrm{r}}(\xi)$, where γ is the degree of attention to the opaque component, and $\gamma = 1$ gives consumers' privately-optimal choice.

2. *Biased beliefs:* Consumers might underestimate the energy intensity difference and think that the energy consumptions of I and E are $\hat{e}_I < e_I$ and $\hat{e}_E > e_E$, respectively. Consumers might also underestimate their utilization; for example, a consumer with utilization need θ will make his purchase decision under the assumption that his utilization need is $\hat{\theta} = \ell(\theta) < \theta$, for some some strictly increasing function function $\ell : R_+ \to R_+$.

3. *Endogenous partial inattention:* In "rational inattention" models, attention might be endogenous to the stakes of the decision. In particular, the higher the potential gross utility gain from purchasing E over I, the more consumers will pay attention to energy cost savings. DellaVigna's (2009) model can be modified to reflect this by allowing γ to be an increasing function of $V_{\mathrm{r}}(\xi)$: $\tilde{V}(\xi) = \gamma(V_{\mathrm{r}}(\xi)) \cdot V_{\mathrm{r}}(\xi)$, where $\gamma'(V_{\mathrm{r}}) \geq 0$.

4. *Present Bias:* Assuming that purchase prices reduce consumption in the present and energy costs reduce consumption in the future, present-biased consumers will weight energy efficiency gains by a factor $\beta < 1$. In our model, this would be reflected by setting $\tilde{V}(\xi) = \beta V_{\mathrm{r}}(\xi)$.

We allow for $k = 1, \ldots, K$ decision utility types, with a type k consumer having decision utility function $\tilde{V}_k$. This discrete distribution of decision utility types is assumed independent of the distribution F of utilization needs. $\tilde{V}_k < V_{\mathrm{r}}$ means that consumers of decision type k misoptimize, while $\tilde{V}_k = V_{\mathrm{r}}$ means that consumers of decision type k perfectly optimize. We will let α_k denote the fraction of consumers with decision utility function $\tilde{V}_k$.

For any two functions $\tilde{V}_1$ and $\tilde{V}_2$, we say that $\tilde{V}_1 < \tilde{V}_2$ if $\tilde{V}_1(\xi) < \tilde{V}_2(\xi)$ for all ξ, and we will say that $\tilde{V}_1 \leq \tilde{V}_2$ if $\tilde{V}_1(\xi) \leq \tilde{V}_2(\xi)$ for all ξ. Notice that $\tilde{V}_1 < \tilde{V}_2$ implies that consumers with decision utility function $\tilde{V}_1$ are more biased than consumers with decision utility function $\tilde{V}_2$. For example, suppose that $\tilde{V}_k(\xi) = \gamma_k V_\Gamma(\xi)$, as in the exogenous partial attention model. Then $\tilde{V}_1 < \tilde{V}_2$ if and only if $\gamma_1 < \gamma_2$.

3.1.3 Producers and the Government

Products $j \in \{E, I\}$ are produced in a competitive economy at a constant marginal cost c_j, with $c_I < c_E$. Similarly, energy is produced in a competitive market at constant marginal cost c_g. The government chooses a subsidy τ_E for good E and an energy tax τ_g.[5] Prices are then given by $p_I = c_I$, $p_E = c_E - \tau_E$, $p_g = c_g + \tau_g$. Throughout the paper, p refers to the price vector (p_I, p_E, p_g) and $\sigma(\theta, k, p)$ denotes the consumer's choice of durable I or E (at prices p). We use τ to refer to the tax policy vector (τ_E, τ_g), and we use $T(\tau)$ to refer to the total tax revenue, which could be negative.

The government maintains a balanced budget. Because $T(\tau)$ is a lump-sum tax or transfer, taxing or subsidizing durables purchases or energy use has no distortionary effects on other dimensions of consumption. We are therefore abstracting to a simplified scenario in which the cost of public funds is 1.

For a consumer of type (θ, k), where k is the subscript of the decision utility function $\tilde{V}_k$, define

$$w(j, \theta, k) \equiv v(\theta, e_j, p_g) - p_j \tag{5}$$

to be the experienced utility from purchasing durable j. Remember that consumers do not always maximize $w(j, \theta, k)$. Define ϕ as the marginal damage per unit of energy used and $Q_g(p)$ as the amount of energy used at prices p. The government wishes to set τ so as to maximize consumer

[5] Because there is no outside option, we do not lose any generality by not considering only the subsidy for E. In our model, subsidies τ'_I and τ'_E for products I and E, respectively, are choice and welfare equivalent to subsidies $\tau_I = 0$, $\tau_E = \tau'_E - \tau'_I$.

utility net of the damage caused by energy use:

$$W(\tau) \equiv \sum_{k=1}^{K} \int [w(\sigma(\theta, k, p), \theta, k) + Y_\theta + T(\tau)] dF(\theta) - \phi Q_g(p). \tag{6}$$

We will call W *social welfare* and call $W^{SB} \equiv \max_\tau W(\tau)$ the *second best*. We will use W^{FB} to refer to the *first best*: the maximum social welfare that is obtainable under any possible combination of choices of durables and utilizations by consumers. Hypothetically, a government that could set individual-specific taxes could achieve the first best. Given the usual constraints on individual-specific tax rates, we only consider tax policies that are uniform across consumers and thus in general generate weakly lower social welfare than the first best.

At times, we will also be interested in *consumer welfare*, by which we mean an objective function that includes only consumer utility and does not include the externality damage. Consumer welfare is denoted W_0 and is defined in exactly the same way as W, except without the final term $\phi Q(p)$.

3.1.4 Graphical Illustration of Equilibrium

Figure 1 illustrates the equilibrium. The black line illustrates the incremental cost of good E; it is horizontal to reflect perfectly elastic supply. Consider first a standard case when all consumers optimize. The demand curve through points c and a reflects the distribution of gross utility gain $V_{\mathrm{r}}(\theta, e_E, e_I p_g)$. The equilibrium is at point a with quantity demanded q^*, and this equilibrium maximizes consumer welfare. As in the standard public finance model, because the marginal consumer optimizes, the fact that she is indifferent between the two goods means that there is no loss to experienced utility when a policy induces her to change the good she purchases.

Consider now a simple case in which all consumers undervalue the gross utility gain, weighting it by exogenous partial attention parameter $\gamma < 1$. This causes the demand curve for good E to rotate downward. The equilibrium is now at point b, and the consumer welfare loss from undervaluation is the triangle abc. Now, because the marginal consumer does not optimize, the fact that she is on the margin does not mean that her experienced utility would be the same with either good. In this example, the marginal consumer would increase experienced utility by the distance between points c and b if she purchased good E instead of good I. The fact that the marginal misoptimizing consumer has a first-order increase in experienced utility when induced to choose differently plays a central role in our upcoming propositions. This is also a central feature of other behavioral welfare analyses in public economics (Mullainathan, Schwartzstein, and Congdon 2012).

3.2 The Internality Dividend from Externality Taxes

Consider first the case when there are externalities, but consumers optimize perfectly and there are no other market failures. A canonical result in this case is that social welfare is maximized when the energy tax is set at the level of marginal damages (Pigou 1932). It is also well-understood that when consumers optimize, such a Pigouvian tax can only reduce consumer welfare W_0. We note this existing logic as Claim 1:

Claim 1 *Suppose that consumers optimize perfectly; that is, $K = 1$ and $\tilde{V}_1 = V_r$. Then consumer welfare W_0 is maximized by $\tau_g^* = 0$ and $\tau_E^* = 0$. Similarly, social welfare W is maximized by $\tau_g^* = \phi$ and $\tau_E^* = 0$.*

When some consumers undervalue energy efficiency, however, this basic result changes. Proposition 1 states that even if the policymaker's objective function places zero weight on externalities, a positive energy tax increases consumer welfare. Furthermore, if there is no product subsidy, the energy tax that maximizes consumer welfare must be greater than zero.

Proposition 1 (Internality dividend from externality taxes) *Suppose that at least some consumers misoptimize: $\tilde{V}_k < V_r$ for some $k \leq K$. Then:*

1. $\frac{\partial}{\partial \tau_g} W_0 > 0$.

2. *If τ_g^* is an optimal tax policy that maximizes W_0 given that $\tau_E = 0$, then $\tau_g^* > 0$.*

The two parts of this proposition are different in that the first part is a local statement about marginal changes, while the second part characterizes the global optimum. The basic intuition for both parts is that undervaluation is a pre-existing distortion that reduces demand for good E below consumers' private optima. A positive energy tax induces some consumers that had misoptimized by choosing good I to instead choose good E, increasing consumer welfare. Although consumers pay more in taxes, this money is recycled to them through transfer T. Appendix I contains the proof of this and all other propositions in the paper.

Figure 1 illustrates how an energy tax increases consumer welfare. Imagine that the dashed red line is the market demand curve, as determined by consumers with a distribution of θ and homogeneous attention weight $0 < \gamma < 1$. An energy tax rotates up the demand curve, shifting the equilibrium from point b to point d. The set of consumers between q_L and q'_L now purchase good E, as they do in the first best, and consumer welfare is higher. The energy tax that maximizes consumer welfare trades off these gains from improved product allocation with the allocative losses from reduced utilization due to higher energy prices.

3.2.1 Discussion

Proposition 1 illustrates how undervaluation reverses the traditional result that energy taxes reduce consumer welfare. Why is this important? One reason is that some policymakers argue against carbon taxes or other energy taxes because they are "bad for the economy," which in our model formally means that they are bad for consumer welfare W_0. Our result shows that even a policymaker who places zero importance on externality reductions would still support an energy tax when there are internalities. This result relates to the Double Dividend hypothesis in the basic sense that it identifies a potential benefit of environmental taxation other than externality reduction. As such, we call this the *Internality Dividend from Externality Taxes*.

Importantly, this proposition holds even if $\tilde{V}_k = V_{\mathrm{r}}$ for some consumers, or even nearly all consumers. If any small group of consumers undervalue energy efficiency, then at least some marginal intervention is still beneficial, even at the cost of distorting other already-optimal choices. This results from the logic in the earlier discussion of Figure 1: if a perfectly optimizing consumer is indifferent between E and I at the policy $(\tau_E, \tau_g) = (0, 0)$, total experienced utility is unaffected by which good the consumer purchases. Thus, the efficiency loss from changing the choices of optimizing consumers who are close to indifferent between E and I is first-order zero. On the other hand, the gain to inducing consumers with $\tilde{V}_k < V_{\mathrm{r}}$ to purchase E is first-order positive. This intuition, which is similar to the basic logic underlying the Envelope Theorem, is also emphasized by O'Donoghue and Rabin (2006) in their analysis of sin taxes for the special case of present-biased consumers.

For this result to hold, the internality must distort the extensive margin decision in the same direction as the externality. If it were instead the case that consumers overvalued energy efficiency, then an energy tax at the level of marginal damages would reduce consumer welfare more than in the fully optimizing case. In fact, with sufficient overvaluation, imposing an energy tax could reduce social welfare. If this were the case, overvaluation would provide an example of Lipsey and Lancaster's (1956) theory of the second best, in which an intervention that would increase welfare in the absence of other distortions could actually decrease welfare.

3.3 The Internality Rationale for Energy Efficiency Policy

Claim 1 reminds us that when externalities are the only market failure, not only does the optimal energy tax give the first best, but the optimal product subsidy is zero. Indeed, the evidence suggests that product subsidies are a highly inefficient substitute for the energy tax when externalities are the only source of inefficiency. For example, Jacobsen (2010) shows that CAFE standards cost 2.5 times more per ton of carbon abated than gas taxes. One of the main reasons for this and related results is that if the energy price is not at the first best level, a product subsidy will cause consumers to buy more energy efficient goods but then use them too much.

In this section, however, we show that this basic result changes when some consumers undervalue energy efficiency. Proposition 2 proves the basic result that undervaluation justifies some additional intervention, either an energy tax above marginal damages or a product subsidy. Proposition 3 shows that the product subsidy is "aligned to the internality," by which we mean that as undervaluation becomes more severe, the socially-optimal product subsidy grows, while the socially-optimal energy tax does not. Proposition 4 shows that when consumers all misoptimize in the same way, the first best policy combination involves an energy tax equal to marginal damages and a product subsidy equal to the marginal internality. These three propositions build the case for product subsidies when some consumers undervalue energy efficiency.

We call these three propositions the *Internality Rationale for Energy Efficiency Policy.* It is fundamentally important because it counters one traditional objection to energy efficiency policies, which is that they are inefficient substitutes for Pigouvian taxes when externalities are the only market failure. However, it is equally interesting to understand situations when the Internality Rationale does not apply. Thus, after presenting these results, we discuss cases that do not satisfy the assumptions of the model, meaning that the social optimum might involve no additional policy to address internalities. We will also discuss the targeting properties of energy taxes and product subsidies, which explain why energy taxes above or below marginal damages might be used in concert with product subsidies to address internalities.

Proposition 2 states two basic results about optimal policies when at least some consumers undervalue energy efficiency:

Proposition 2 (Optimal subsidies and taxes) *Suppose that $\tilde{V}_k < V_r$ for some $k \leq K$. Then:*

1. $\frac{\partial}{\partial \tau_E} W > 0$ *and* $\frac{\partial}{\partial \tau_g} W > 0$ *at* $(\tau_E, \tau_g) = (0, \phi)$.

2. *If* (τ_E^*, τ_g^*) *is an optimal tax policy that maximizes* W*, then either* $\tau_E^* > 0$ *or* $\tau_g^* > \phi$.

The first part of Proposition 2 begins with the socially-optimal policy for the case with externalities but no internalities: no product subsidy, and a Pigouvian energy tax equal to marginal damages. When at least some consumers undervalue energy efficiency, either increasing the product subsidy above zero or increasing the energy tax above marginal damages increases social welfare. The second part of the proposition states that the optimal policy must include either a positive subsidy or an energy tax above marginal damages. As with Proposition 1, the first part of this proposition is a local statement about marginal changes, while the second part characterizes the global optimum. Again because the marginal misoptimizing consumers experience first-order welfare gains when induced to purchase good E, this proposition holds even if only a few consumers undervalue energy efficiency.

Proposition 2 is in some senses very weak: it simply states that undervaluation merits some additional policy in addition to the optimal policy in the case with externalities only. It does not state that product subsidies are necessarily the socially-optimal response to undervaluation. A counterexample helps to clarify. Consider a setting with zero utilization elasticity and one decision utility type that is partially attentive to energy costs, with $\tilde{V}(\xi) = \gamma V_{\mathrm{r}}(\xi)$. In this case, an energy tax of $\tau_g^* = \phi + (1-\gamma)(\phi + p_g)$ with zero product subsidy can achieve the first best, as it can causes all consumers to incorporate into their extensive margin choices the externality plus the share of social costs that were not fully valued.

Proposition 3 takes the argument for product subsidies a step further by showing that the magnitude of the product subsidy is aligned with the magnitude of the undervaluation, while this is not true for the energy tax. Furthermore, Proposition 3 shows that the argument for product subsidies is not just a marginal argument: as the extent of undervaluation grows large, the socially-optimal product subsidy could be a large share of the cost difference between the two goods.

Before formally stating Proposition 3, we must first characterize a notion of "more undervaluation" for a population of consumers. Begin with an economy $\mathcal{E}$ in which consumers have decision utility functions $\tilde{V}_k$, for $k = 1, \ldots K$. Consider now an increasing and unbounded function L such that $L(\nu) < \nu$ for all ν, and construct a "more biased economy" $\mathcal{E}(L)$ in which consumers have transformed decision utility functions $\tilde{V}_k^L$ defined as $\tilde{V}_k^L(\xi) = L(\tilde{V}_k(\xi))$ for all ξ.

Proposition 3 (Product subsidies as undervaluation increases) *Suppose that* (τ_E^*, τ_g^*) *is an optimal tax policy in economy* $\mathcal{E}$. *Then an optimal policy* $(\tau_E^{**}(L), \tau_g^{**}(L))$ *in economy* $\mathcal{E}(L)$ *is characterized as follows:*

1. $\tau_g^{**}(L) = \tau_g^*$
2. $\tau_E^{**}(L) = (c_E - c_I) - L(c_E - c_I - \tau_E^*)$

Relative to Proposition 2, Proposition 3 strengthens the connection between the internality and the product subsidy. It shows that the optimal energy tax $\tau_g^{**}(L)$ is constant in L, while a larger internality implies a larger optimal product subsidy: $\tau_E^{**}(L) > \tau_E^{**}(L^\dagger)$ if $L < L^\dagger$.

To illustrate this proposition, suppose that $\tilde{V}_k = \gamma_k V_{\mathrm{r}}$, as in the basic partial attention model DellaVigna (2009). Consider now what happens as attention decreases, with the attention weight γ_k for all decision utility types being transformed to $\hat{\gamma}_k = \lambda\gamma_k$. For L defined as $L(\nu) = \lambda\nu$, the new decision utility functions are then given by $\tilde{V}_k^L = \lambda\gamma_k V_{\mathrm{r}}$. By Proposition 3, the optimal subsidy is the following function of L:

$$\tau_E^{**}(L) = (c_E - c_I) - \lambda(c_E - c_I - \tau_E^*) = (1 - \lambda)(c_E - c_I) + \lambda\tau_E^*.$$

In other words, τ_E^{**} is a weighted average of the cost difference $c_E - c_I$ and initial subsidy $\tau_E^* < c_E - c_I$, and it is larger if consumers are more biased. Furthermore, the socially-optimal $\tau_E^{**}(L)$ can be large: it becomes a large positive share of the cost difference $c_E - c_I$ when λ is small, and when $\lambda \approx 0$, $\tau_E^{**}(L) \approx c_E - c_I$. This mathematical result would be exactly the same in a model of present biased consumers, where $\gamma < 1$ reflects the weight on future consumption.

3.3.1 Special Case: Homogeneous Undervaluation

In Proposition 3, we solved for the optimal policy as a function of the optimal policy in some initial less biased economy $\mathcal{E}$, but it is not possible in the general case to solve analytically for that initial optimal policy. In the special case of homogeneous decision utility, however, the proposition can be taken further:

Proposition 4 (Product subsidies with homogeneous undervaluation) *Consider an economy in which $K = 1$ and all consumers have decision utility function $\tilde{V}$. Let θ^* be the largest value of θ at which purchasing I is still optimal: $V_r(\theta^*, e_E, e_I, c_g + \phi) = c_E - c_I$. Then the optimal tax policy is characterized as follows:*

1. $\tau_g^*(\tilde{V}) = \phi$
2. $\tau_E^*(\tilde{V}) = (c_E - c_I) - \tilde{V}\left(\theta^*, e_E, e_I, c_g + \phi\right)$

Furthermore, this optimal tax policy achieves the first best social welfare. By contrast, if $K > 1$ and $\tilde{V}_j < \tilde{V}_k$ for some j, k, then the optimal tax policy cannot achieve the first best social welfare.

Proposition 4 is similar to Proposition 3 in that it shows that the product subsidy, but not the energy tax, is aligned with the magnitude of the bias. More precisely, the optimal energy tax τ_g^* is always set at marginal damages, while the optimal subsidy is strictly increasing in the bias: $\tau_E^*(\tilde{V}) > \tau_E^*(\tilde{V}^\dagger)$ if $\tilde{V} < \tilde{V}^\dagger$. Like Proposition 3, Proposition 4 also shows that when undervaluation is severe, the socially-optimal subsidy could be large relative to the cost difference between the two goods. However, Proposition 4 differs from Proposition 3 in that it provides an exact optimal policy. The solution is quite intuitive: the energy tax equals the externality, while the product subsidy equals the internality of the marginal consumer.

To appreciate the intuition behind the formula in Proposition 4, notice that since $V_{\mathrm{r}}(\theta^*, e_E, e_I, c_g) = c_E - c_I$ by definition, we can rewrite $\tau_E^*(\tilde{V}) = V_{\mathrm{r}}(\theta^*, e_E, e_I, c_g) - \tilde{V}(\theta^*, e_E, e_I, c_g)$. This means that $\tau_E^*(\tilde{V})$ is simply the amount by which the utilization type θ^* that is on the margin in the first best undervalues the gross utility gain from purchasing E. In other words, $\tau_E^*(\tilde{V})$ equals the marginal internality.

As an example of the formula in Proposition 4, consider again the same partial attention model from above, with $\tilde{V} = \gamma V_{\mathrm{r}}$. In this model, $\tau_g^* = \phi$ and $\tau_E^*(\tilde{V}) = (1-\gamma)(c_E - c_I)$. This $\tau_E^*(\tilde{V})$ also equals $(1-\gamma)V_{\mathrm{r}}(\theta^*, e_E, e_I, c_g)$, the amount by which the marginal consumer in the first best undervalues the gross utility gain.

Figure 1 can again be used to illustrate Proposition 4. Imagine again that the dashed red line is the market demand curve, as determined by consumers with homogeneous partial attention weight $0 < \gamma < 1$. The product subsidy τ_E shifts down the relative price line, and the after-subsidy equilibrium is at point f, with quantity demanded q^*. The amount of the subsidy is the distance between points a and f, which is the same amount by which the marginal consumer at point a undervalues the gross utility gain.

Proposition 4 also states that the first best can be attained if and only if consumers all optimize or misoptimize in the same way. This can also be seen for the example decision utility function in Figure 1: the allocation of good E after the subsidy is the same as in the equilibrium with no undervaluation, which was at point a. This illustrates how the first best can be achieved if there is only one decision utility type.

If there are multiple different decision utility types, however, there is one unique optimal policy for each type, in which the subsidy equals that type's marginal internality. Any policy that is uniform across different types cannot simultaneously be optimal for all types, and the first best is not achieved. This is why the first best can be achieved only if there is one decision utility type. Similarly, if goods E and I are differentiated along some other dimension for which consumers have heterogeneous preferences, this will also generate heterogeneity in the marginal internality, and Proposition 4 will not hold. This will be the case in the auto market simulations.

3.3.2 Discussion

Models to which our results do not apply. Because our model of undervaluation is very general, we can be assured that the basic results in Propositions 1-4 apply to a wide variety of biases. However, these results depend on the fact that misoptimizing consumers will respond to price changes. A policy cannot increase welfare by correcting internalities if it does not affect the misoptimizing consumers. Because $\tilde{V}(\xi)$ is always positive, continuous, and unbounded in θ, our model guarantees that if there are misoptimizing consumers, at least some will be marginal to both the energy tax and the product subsidy.

However, there are some behavioral models that do not satisfy these conditions. One such model is the "exogenous probabilistic inattention model," in which consumers either correctly value energy efficiency or do not attend to energy efficiency at all, with some exogenous probability. In this model, none of the inattentive consumers buy good E unless it is subsidized to have the same price as good I. This means that no inattentive consumers are marginal to any subsidy τ_E that is less than $c_E - c_I$, so subsidies less than that amount can only distort decisions by rational consumers. Depending on the proportion of each type of consumer in the population and other primitives, the socially-optimal policy may be $\tau_E^* = 0, \tau_g^* = \phi$, the same as when there are no internalities.

This model could correspond to some real-world situations. For example, consider a pair of water heaters: one is a standard model and one is an Energy Star version with higher upfront cost and lower energy use. Some consumers are in the market because their existing water heater has just broken, and in this situation, their attention might be fully focused on getting the cheapest new water heater as soon as possible, not on weighing the future energy costs. Other consumers might be undertaking a long-term renovation and would have time to fully consider the costs and benefits of each option. If the probabilistic inattention model applies in this setting, it predicts that subsidies for Energy Star water heaters would only distort purchases by consumers that already optimize, unless the subsidy was so large as to make the Energy Star model as cheap as the standard model.

Similarly, a frequently-proposed source of inefficiency is that some consumers are unaware of good E. For example, a firm may not be aware of some new energy efficient technology, or home-owners may not know that weatherization programs exist. In these cases, subsidizing good E does not increase sales unless the subsidy somehow induces additional consumers to become aware of the good. These examples highlight the importance of an improved empirical understanding of the mechanics of undervaluation. While our analysis shows that many kinds of undervaluation biases do justify subsidies, there are biases to which our model does not apply.

Overvaluation. If consumers overvalue energy efficiency, our broad framework is still useful, but some of our results would be modified in intuitive ways. If all consumers either correctly value or overvalue the gross utility gain, then Proposition 2 would state that the optimal policy must include an energy tax below marginal damages or a tax on the energy efficient good. In Appendix III, we show how the results change when some consumers undervalue and some overvalue. In that case, there is still an Internality Dividend from Externality Taxes as long as the average consumer who is marginal to the energy tax undervalues energy efficiency. Similarly, positive subsidies, or energy taxes above marginal damages, will still be optimal as long as the average marginal consumer undervalues energy efficiency. In an economy with both undervaluation and overvaluation, the targeting of energy efficiency policies becomes central: a policy that increases adoption of energy efficient goods among consumers who already overvalued energy efficiency reduces welfare. Allcott, Mullainathan, and Taubinsky (2012) focus on this issue and discuss practical situations where this may be the case.

Minimum energy efficiency standards. Since the mid-1980s, there have also been a set of minimum energy efficiency standards for refrigerators, air conditioners, hot water heaters, and some other household appliances. Does the Internality Rationale for Energy Efficiency Policy also extend to these minimum standards? In our model, a minimum standard that banned the sale of the energy inefficient good would be equivalent to a product subsidy that was so large as to drive sales of that good to zero. Since a product subsidy can thereby achieve the same result as a minimum standard, the product subsidy is weakly preferred. Put differently, if the optimal subsidy does not fully eliminate sales of the energy inefficient good, then the optimal subsidy is preferred to a minimum standard. Thus, in order for minimum standards to be optimal, one would have to incorporate additional features into the model, such as political constraints or administrative costs to implementing the optimal product subsidy.

3.4 Heterogeneity and Targeting

The three propositions comprising the Internality Rationale for Energy Efficiency Policy show that product subsidies are an important policy response to undervaluation. However, Propositions 2 and 3 show that it is not generally true that energy taxes should be kept equal to the externality: in the social optimum, energy taxes and product subsidies appear to be used in concert to address internalities. This suggests two questions. First, why is the energy tax not the only instrument for addressing undervaluation? After all, if consumers impose internalities on themselves by undervaluing future energy costs, the internality tax logic from O'Donoghue and Rabin (2006) suggests that the optimal response is simply to increase energy taxes. The second question takes the alternative extreme view: why is the product subsidy not the only instrument used to address internalities? In this section, we use a simple two-type model to show that which instrument is preferred depends on two factors: how well each instrument targets the more biased consumers and how much $\tau_g \neq \phi$ distorts utilization decisions.

To illustrate this precisely, suppose that there are two decision utility types $k = \{L, H\}$. Type L weakly undervalues more than type H, meaning that $\tilde{V}_L \leq \tilde{V}_H$. Each type has corresponding demand $D^k(\tau_E, \tau_g)$ for the energy efficient good. Let b^k denote the social benefit, which may be negative, derived from the marginal type k consumer purchasing E. A change in τ_g also directly affects utilization choices. Let $X'(\tau_g)$ correspond to the marginal social benefit, which may be negative, from this change in utilization induced by an increase in τ_g, holding constant the extensive margin decisions.

Notice two important issues in this setup. First, the derivatives of demand with respect to the product subsidy and the energy tax, which we respectively denote as $D^k_{\tau_E}$ and $D^k_{\tau_g}$, will typically be different for each decision utility type. Depending on the nature of the economy, it may be that a marginal policy change preferentially induces the more biased or less biased consumers to purchase good E. Second, $b^L \geq b^H$: it will always be better for social welfare to change the decision of the marginal consumer of the more biased type.

Denote W_{τ_E} and W_{τ_g} as the derivatives of social welfare with respect to τ_E and τ_g, respectively. Using this notation, we can write the impact on social welfare from a marginal change in each of the two instruments:

$$W\tau_E\partial\tau_E = b^L D^L_{\tau_E}\partial\tau_E + b^H D^H_{\tau_E}\partial\tau_E$$
$$W_{\tau_g}\partial\tau_g = b^L D^L_{\tau_g}\partial\tau_g + b^H D^H_{\tau_g}\partial\tau_g + X'(\tau_g)\partial\tau_g.$$

In words, the product subsidy's effect on social welfare is the sum of the benefits for each type, weighted by the number of consumers of each type on the margin. The energy tax's effect on social welfare is the analogous expression, plus the effect on social welfare from the change in utilization.

To compare the two instruments, we ask how efficient each one is per unit change in total demand for good E. Thus we consider marginal changes $\partial\tau_E$ and $\partial\tau_g$ such that $(D^L_{\tau_E}+D^H_{\tau_E})\partial\tau_E = (D^L_{\tau_g}+D^H_{\tau_g})\partial\tau_g \equiv \partial D$. We re-write the social welfare impacts in terms of ∂D:

$$W_{\tau_E}\partial\tau_E = \left[b^L\frac{D^L_{\tau_E}}{D^L_{\tau_E}+D^H_{\tau_E}} + b^H\frac{D^H_{\tau_E}}{D^L_{\tau_E}+D^H_{\tau_E}}\right]\partial D \tag{7}$$
$$W_{\tau_g}\partial\tau_g = \left[b^L\frac{D^L_{\tau_g}}{D^L_{\tau_g}+D^H_{\tau_g}} + b^H\frac{D^H_{\tau_g}}{D^L_{\tau_g}+D^H_{\tau_g}} + \frac{X'(\tau_g)}{D^L_{\tau_g}+D^H_{\tau_g}}\right]\partial D \tag{8}$$

In comparing the two instruments, consider first the special case with homogeneous decision utility, as we considered in Proposition 4. In this case, $b^L = b^H \equiv b$, $D^L_1 = D^H_1$, and $D^L_2 = D^H_2$. Then equations (7) and (8) become

$$W_{\tau_E}\partial\tau_E = b\partial D$$
$$W_{\tau_g}\partial\tau_g = \left[b + \frac{X'(\tau_g)}{D^L_{\tau_g}+D^H_{\tau_g}}\right]\partial D.$$

$X'(\tau_g)$ will be negative for $\tau_g > \phi$: when the energy tax is larger than marginal damages, consumers drive less than the socially-optimal amount, and this causes welfare losses. Given this, $W_{\tau_E}\partial\tau_g > W_{\tau_g}\partial\tau_E$, and thus setting an energy tax $\tau_g > \phi$ cannot be optimal. Put differently, both the energy tax and the product subsidy can induce consumers to purchase good E, but the energy tax also distorts utilization choices, while the product subsidy does not. This is the intuition behind Proposition 4, which states that the optimal policy in the homogeneous case is $\tau_g^* = \phi$ and τ_E^* at the level of the marginal internality.

Return now to the case where the two types differ. Now, an instrument will be preferred to the extent that it targets the type L consumers, who generate larger social welfare gains per additional energy efficient good purchased. Mathematically, equations (7) and (8) can be re-arranged to show that raising the energy tax when it is already above ϕ must be less effective than raising the subsidy whenever

$$b^L \frac{D^L_{\tau_E}}{D^L_{\tau_E} + D^H_{\tau_E}} + b^H \frac{D^H_{\tau_E}}{D^L_{\tau_E} + D^H_{\tau_E}} \geq b^L \frac{D^L_{\tau_g}}{D^L_{\tau_g} + D^H_{\tau_g}} + b^H \frac{D^H_{\tau_g}}{D^L_{\tau_g} + D^H_{\tau_g}}.$$

Because $b_L \geq b_H$, this is equivalent to

$$\frac{D^L_{\tau_E}}{D^H_{\tau_E}} \geq \frac{D^L_{\tau_g}}{D^H_{\tau_g}}. \tag{9}$$

Equation 9 captures the idea that whenever the subsidy has a higher relative impact on the more biased consumers than the energy tax, the subsidy will be more effective in increasing social welfare. Conversely, if the energy tax is sufficiently well-targeted to overcome its negative effects on the intensive margin, it is optimal to increase the energy tax above ϕ.

We can now return to the two questions that motivated the discussion. The reason why energy taxes are not necessarily the optimal solution to undervaluation of energy costs is that there are now two margins. Aside from improving decisions on the extensive margin, the energy tax also distorts decisions on a second margin where it is not asserted that consumers misoptimize. Thus, it is important not just to have an internality tax, but to have an internality tax on the proper margin. However, the reason why product subsidies are not necessarily the only instrument for addressing internalities is that, depending on the primitives of the problem, the energy tax may preferentially target more biased consumers. Thus, the basic intuition behind the Internality Rationale is a qualified version of "two market failures require two instruments": the energy tax primarily (but not entirely) targets the externality, and the product subsidy primarily (but not entirely) targets the internality.

When will Equation 9 not hold, making the energy tax well-targeted? The key difference between the energy tax and the product subsidy is that the product subsidy affects relative prices equally for all consumers, while the energy tax proportionally increases the perceived energy cost difference between the two goods. Thus, the energy tax will be well-targeted when the more biased types on the margin have larger perceived energy cost differences. This requires the more biased type to have higher utilization and to not be too severely biased, or else the perceived energy cost differences will be small. The simulations highlight this issue.

4 Simulation Model of Optimal Policy in the Vehicle Market

We have shown that in theory, undervaluation means that an energy tax may improve consumer welfare and that some subsidy for energy efficient durable goods is likely to be optimal. In practice, how large is this Internality Dividend from Externality Taxes, and what is the socially-optimal combination of energy taxes and product subsidies? In this section, we calibrate the magnitudes of our theoretical results to the US automobile market using a discrete choice simulation model. We first set up the simulations and then present results.

4.1 Setup

To apply the theoretical model to the automobile sector, we make two changes. First, instead of two goods, our choice set is the entire set of new car and truck models. Second, the goods are no longer identical up to their prices and energy intensities. Instead, consumers have heterogeneous preferences for different models. This heterogeneity enters through a model-level average utility shifter ψ_j and a consumer-by-model unobserved utility shock ϵ_{ij}, which is distributed according to the familiar nested logit model. Experienced utility of consumer i for model j is now:

$$w_i(j,\theta,k) = v(\theta, e_j, p_g) - p_j + \psi_j + \epsilon_{ij} \tag{10}$$

We also make two functional form assumptions. First, we assume that $u(m-\theta)$ takes the Constant Relative Risk Aversion form. Appendix IV gives more detail on this and other aspects of the simulations. Second, we must put some structure on the internality. In the absence of any empirical guidance, we keep things simple. Specifically, we assume the exogenous partial attention model, with $\tilde{V}_k = \gamma_k V_{\mathrm{r}}$. In the base case, we let $K=1$ and work with a homogeneous decision utility function, and in alternative simulations, we let $K=2$.

Otherwise, the model is the same. Misoptimizing consumers still underweight the difference in $v(\theta, e, p_g)$ between vehicles, but they correctly value p, ψ, and ϵ. There no outside option, so total new vehicle sales are constant across different simulations. We still assume a competitive economy, with prices equal to marginal cost. We continue to assume a fixed choice set, meaning that we abstract away from technological change. While markups and investments may respond differently to different tax policies, they are not part of our theoretical arguments about consumer choice and optimal taxation, and endogenous changes to product offerings are particularly difficult to model credibly.

As in the theoretical model, the policymaker has two instruments, an energy tax and a product subsidy. In this context, the "energy tax" can be thought of as a gasoline tax. Given that the choice set includes many models with many different energy intensities, the "product subsidy" now takes the form of an energy intensity tax τ_p that scales linearly in each model's energy intensity, increasing purchase price by amount $\tau_p e_j$. Because there is no substitution to an outside option and budget balance is maintained via lump sum transfers, this energy intensity tax can equally be interpreted as an "MPG subsidy" for energy efficient vehicles, a "feebate" that combines a fee on low-MPG vehicles with a rebate for high-MPG vehicles, or an average fuel economy standard that imposes a relative shadow cost on the sale of low-MPG vehicles. This latter interpretation is important, because it confirms that our model captures the short-run effects of a CAFE standard, which is a policy of particular applied interest.

4.1.1 Data

Table 1 presents an overview of the choice set and simulation assumptions. Our choice set is the 301 new cars and trucks from model year 2007 defined at the level of a manufacturer's model name, such as the "Honda Civic" or "Ford F-150."[6] The price p_j of each model j is from the JD Power and Associates "Power Information Network," a network of more than 9,500 dealers which collects detailed data on about one third of U.S. retail auto transactions. Each model's price is the mean of the final price across all transactions, including any customer cash rebate and adjusting for the true value of any trade-in vehicle. Market shares are from the National Vehicle Population Profile, a

[6] More precisely, this is the set of model year 2007 new cars and trucks that have fuel economy ratings from the U.S. Environmental Protection Agency. We exclude vans as well as ultra-luxury and ultra-high performance exotic vehicles: the Acura NSX, Audi R8 and TT, Chrysler Prowler and TC, Cadilliac Allante and XLR Roadster, Chevrolet Corvette, Dodge Viper and Stealth, Ford GT, Plymouth Prowler, and all vehicles made by Alfa Romeo, Bentley, Ferrari, Jaguar, Lamborghini, Maserati, Maybach, Porsche, Rolls-Royce, and TVR.

comprehensive national database of vehicle registrations obtained from R.L. Polk. Energy intensity e_j is the inverse of the U.S. Environmental Protection Agency (EPA) miles per gallon (MPG) fuel economy ratings. Different submodels within a model - for example, the manual vs. automatic transmission versions or the sedan vs. the coupe - may have different energy intensities, so we use each model's sales-weighted average energy intensity.

The most uncertain parameters in the simulations are the magnitudes of the internalities and externalities. In our base case simulations, we assume that $\gamma = 0.8$. This is slightly more conservative than the Allcott and Wozny (2011) basic specification estimate of $\widehat{\gamma} = 0.72$ and the $\widehat{\gamma} = 0.78$ implied by the corresponding estimates from Busse, Knittel, and Zettelmeyer (2012).[7] We devote a full table to sensitivity analysis around this parameter. We assume that the marginal damage from uninternalized externalities ϕ from gasoline use is \$0.18 per gallon. This reflects a marginal damage from carbon dioxide emissions of \$20 per metric ton, as estimated by the U.S. Government Interagency Working Group on Social Cost of Carbon (Greenstone, Kopits, and Wolverton 2011).

Appendix IV contains full details on how the model is calibrated. In brief, the parameters are set such that the mean own-price elasticity of demand across all models is -5, in order to be consistent with the mean own-price elasticity estimated by Berry, Levinsohn, and Pakes (1995). We set the average utility parameters ψ_j such that the baseline simulated market shares equal the observed 2007 market shares. The nests for the nested logit substitution patterns are nine vehicle classes defined by the U.S. EPA: pickups, sport utility vehicles, minivans, two-seaters, and five classes of cars (mini-compact, sub-compact, compact, mid-size, and large).

We calibrate the parameters of the utilization demand function such that the price elasticity at the mean VMT is -0.15, which is in the range of recent empirical estimates.[8] The mean utilization demand parameter θ is set such that mean vehicle-miles traveled (VMT) matches the observed mean from the National Household Travel Survey. Utility from driving and expenditures on gasoline over vehicle lifetimes are discounted to the time of purchase using empirical data on vehicle scrappage

[7] The average of Busse, Knittel, and Zettelmeyer's (2012) implied discount rates for used vehicle markets using the corresponding assumptions for vehicle miles traveled and scrappage probabilities is 13 percent. Using empirical data on the average opportunity cost of capital for used vehicle buyers, this translates to $\widehat{\gamma} = 0.78$. Our sensitivity analyses will also be important, because both Allcott and Wozny (2011) and Busse, Knittel, and Zettelmeyer (2012) show that using different samples and parameter assumptions can substantially affect the estimates.

[8] Hughes, Knittel, and Sperling (2007) find that between 2001 and 2006, this elasticity was between -0.034 and -0.077. Small and Van Dender (2007) estimate that between 1997 and 2001, this elasticity was -0.022. Using data from California between 2001 and 2008, Gillingham (2010) estimates a short-run elasticity of -0.15 to -0.2.

probabilities and a six percent discount rate, as calculated by Allcott and Wozny (2012). We use a pre-tax gasoline price c_g of \$3 per gallon.

4.2 The Internality Dividend from Externality Taxes

Table 2 presents simulation results for seven different cases. Case 1 is the base equilibrium with no product subsidy or additional energy tax. Cases 2 and 3 assume that there are uninternalized externalities at $\phi = \$0.18$ per gallon, but that there are no internalities, i.e. that $\gamma = 1$ for all consumers. Cases 4-7 assume that $\phi = \$0.18$ per gallon and $\gamma = 0.8$. Case 7 is the first best.

Case 2 simulates an energy tax at $\tau_g = \phi$. This case illustrates the traditional Pigouvian result that when externalities are the only market failure, the energy tax at the level of marginal damages reduces consumer welfare. Of course, social welfare increases from baseline, by an estimated \$5.50 over the life of each new vehicle sold. However, this change in social welfare is the sum of the change in consumer welfare and the externality reduction. The externality reduction is worth \$10.90 per vehicle,[9] while consumer welfare decreases by \$5.40 per new vehicle. Aggregated over the 16 million vehicles sold in a typical year, the annual consumer welfare losses from Pigouvian energy taxes are \$86 million.

Case 4 also simulates an energy tax at $\tau_g = \phi$, but now with $\gamma = 0.8$. In this case, the energy tax helps to reduce the pre-existing allocative distortion from undervaluation, increasing consumer welfare by \$4.10 per vehicle sold. Thus, the energy tax abates carbon while *increasing* consumer welfare by \$5.40 per metric ton of carbon dioxide abated. Aggregated over all new vehicles sold, a Pigouvian tax increases consumer welfare by \$65 million per year the policy is in place. This demonstrates how undervaluation reverses the traditional result that externality taxes are bad for consumer welfare.

Figure 2 plots the gains in consumer and social welfare at different levels of the energy tax, assuming $\gamma = 0.8$ and zero product subsidy. The energy tax that maximizes consumer welfare is \$0.167 per gallon, which coincidentally is very close to the assumed level of marginal damages. Any

[9] Intuitively, basic the reason why this is small relative to total lifetime gasoline costs is that the assumed carbon externality is only six percent of gasoline costs. By comparing the "Resulting Allocations" in Cases 1 and 2 of Table 2, we see that an increase in retail gasoline prices of \$0.18 per gallon does not cause a large change in either the average fuel economy of vehicles sold or the amount that they are driven. Of course, if the extensive or intensive margin elasticities were larger, the distortions would be larger.

energy tax below about \$0.34 per gallon increases consumer welfare. The social welfare-maximizing energy tax is of course larger than the consumer welfare-maximizing energy tax, as the former is set to correct distortions from externalities as well as internalities. This social-welfare maximizing level is about \$0.37 per gallon. Not coincidentally, this is slightly above the point at which a marginal increase begins to decrease consumer welfare. To see the intuition for this, think of the first order condition: the energy tax that maximizes social welfare is such that a marginal change has zero effect on the sum of externality damages and consumer welfare.

4.3 The Internality Rationale for Energy Efficiency Policy

Returning to a world with no internalities, case 3 applies the product subsidy that abates the same amount of carbon dioxide emissions as the first best policy in case 2. Comparing these two cases gives the traditional result that when externalities are the only market failure, the product subsidy is a highly inefficient substitute for the Pigouvian energy tax. Because marginal and average abatement costs increase in the amount of carbon dioxide abated, our comparison between the two policies must hold total abatement constant. The product subsidy that generates the same carbon dioxide abatement as the first best in case 2 is \$69,571 per gallon per mile (GPM). To put this in perspective, a 20 MPG vehicle, such as a Subaru Outback Wagon, uses 0.05 GPM, while a 25 MPG vehicle, such as a Toyota Corolla, uses 0.04 GPM. This τ_p therefore implies a relative price increase of \$696 for the 20 MPG vehicle. At this level of the product subsidy, the consumer welfare loss is \$25.10 per vehicle. This is so large that despite the gains from externality reduction, the change in social welfare is actually negative. While a smaller product subsidy could abate less carbon with smaller consumer welfare losses and generate positive social welfare gains, a smaller energy tax could still generate that smaller amount of abatement much more efficiently.

Case 5 shows how adding internalities to the model reverses this traditional result that product subsidies are highly inefficient. In case 5, we search for the combination of energy tax and product subsidy that maximizes social welfare. The optimal product subsidy is \$64,175 per GPM. Using our example pair of vehicles from above, this implies a relative price increase of \$642 for the 20 MPG Subaru Outback compared to the 25 MPG Toyota Corolla.

Propositions 3 and 4 showed that in a more stylized world without heterogeneous product preferences ϵ_{ij}, when consumers become more biased, the energy tax stays constant and the product subsidy increases linearly in $L(\cdot)$. Figure 3 illustrates that this is also approximately the case under the richer set of preferences in the simulations. The figure shows that as γ changes from 0.4 to 1.0, the socially-optimal product subsidy decreases almost exactly linearly from \$196,000 per GPM to 0. As γ increases from left to right on the graph, the socially-optimal energy tax τ_g starts slightly above marginal damages, increases just slightly, and then decreases to slightly below marginal damages. To see the intuition for this, notice that the heterogeneous preferences ϵ_{ij} generate some variation in the utilization parameters θ of consumers on the margins between vehicles. Because higher-utilization consumers have higher energy costs and thus larger internalities in this model, it is optimal to target them with larger relative price changes. As long as consumers are sufficiently attentive to energy costs, the energy tax can do this. As γ drops below 0.5, however, extensive margin choices become sufficiently insensitive to the energy tax that the targeting benefits are reduced.

The point on Figure 3 where $\gamma = 0.8$ corresponds to case 5 in Table 2. At this point, the socially-optimal energy tax is \$0.20 per gallon, just slightly above the \$0.18 per gallon externality ϕ. Whether the socially-optimal energy tax is above or below marginal damages depends on the joint distribution of primitives such as $\tilde{V}_k$, θ, and ϵ. This is worrisome for two reasons. First, it would be difficult to credibly estimate this joint distribution, given that the differing results reviewed by Greene (2010) suggest that estimating some average internality has been contentious enough. Second, allowing gasoline prices to differ from social marginal cost could generate other unintended distortions. It is for this reason that we also present case 6, a "heuristic" policy that sets the socially-optimal τ_p under the restriction that $\tau_g = \phi$. Importantly, the tax and subsidy levels, as well as the welfare effects, are nearly identical between the second best in case 5 and the heuristic policy in case 6.

4.4 Heterogeneity and Targeting

Because there is little empirical evidence on heterogeneity in consumers' decision utility functions, our base case assumes a homogeneous γ. To see the effects of heterogeneity in γ, we now consider two-type model similar to the one in Section 3.4, with consumers equally distributed between two decision utility types indexed $k = \{L, H\}$, with $\gamma^L \leq \gamma^H$. Figure 4 plots the optimal policies as the difference between γ^H and γ^L grows, holding the average γ constant at 0.8. As we saw in Table 2, the socially-optimal energy tax is just above marginal damages when $\gamma^H = \gamma^L$. However, it decreases monotonically as $\gamma^H - \gamma^L$ increases and eventually becomes negative, implying that it is socially optimal to *subsidize* energy. By contrast, the socially-optimal product subsidy starts at \$64,175 per GPM and increases monotonically.

Why is this the case? When $\gamma^L = \gamma^H = \gamma = 0.8$ on the far left of the figure, internalities differ only due to the variation in ϵ_{ij}, and the variance of the marginal internality is small. Thus, the optimal policy includes an energy tax close to marginal damages and a product subsidy at the marginal internality. However, as we move from left to right on the graph and γ^L decreases, type L's extensive margin choices become less responsive to the energy tax. (In our notation from Section 3.4, $D^L_{\tau_g}$ decreases.) Meanwhile, as γ^H increases, type H responds more to the energy tax. Thus, as the average γ is held constant but the variance in γ increases, the energy tax increasingly affects type H consumers. Because type H is less biased, social welfare increases less when these consumers are induced to buy gas sippers. (In our notation from Section 3.4, b^H becomes increasingly small, and b^L increasingly large, as the heterogeneity increases.) The socially-optimal energy tax rate therefore decreases.

When $\gamma^H - \gamma^L = 0.4$, this means that $\gamma^H = 1$ and $\gamma^L = 0.6$. To the right of this point, type H consumers overvalue energy costs, meaning that they purchase too many gas sippers ($b^H < 0$), while type L consumers begin to severely undervalue. It eventually becomes optimal to *subsidize* gasoline, because this causes the type H consumers to reduce their overconsumption of gas sippers without significantly affecting extensive margin choices by type L consumers because they become highly unresponsive to the energy tax. Meanwhile, this decreasing energy tax is offset by an increasing product subsidy, which induces type L consumers to reduce their overconsumption of gas guzzlers.

As we discussed in Section 3.4, the desirability of allowing τ_g to differ from ϕ in order to target the extensive margin choices of different consumer types is moderated by the resulting distortion on the intensive margin. Figure 4 illustrates this by also plotting optimal policies in alternative simulations where we triple the utilization elasticity, to -0.45 instead of -0.15. In these cases, the socially-optimal energy tax stays significantly closer to ϕ, and the socially-product subsidy stays much closer to its optimal level under zero heterogeneity.

Figure 4 suggests that the heterogeneity in undervaluation might be very important for policy design. Fortunately, while heterogeneity significantly affects the second best tax rates, this does not significantly impact welfare. Figure 5 plots the welfare gains from the first best and second best policies compared to the baseline of no policy. It also plots the welfare gains from the heuristic policy in which we set the product tax to maximize social welfare conditional on $\tau_g = \phi$. The figure demonstrates two things. First, as the heterogeneity in γ grows, the second best policy performs increasingly badly relative to the first best. This is because the second best policy is some "compromise" between the heterogeneous first best tax policies for the different consumer types, and as the types become more heterogeneous, the compromise is less effective for each given type. Second, the figure illustrates that the heuristic policy does almost as well as the second best policy, at least until the variance in γ becomes extreme. For example, the heuristic policy captures more than 90 percent of the welfare gains of the second best as long as $\gamma^H - \gamma^L < 0.7$, and 75 percent of the welfare gains as long as $\gamma^H - \gamma^L < 0.9$.

4.5 Sensitivity Analyses

Table 3 shows how the second best optimal policies under different parameter assumptions. Column 1 re-iterates column 5 of Table 2. Column 2 is identical to column 1, except that we use the two-type model with $\gamma^H = 1$ and $\gamma^L = 0.6$. As suggested in Figure 4, the optimal energy tax is slightly below marginal damages, and the optimal product subsidy increases to compensate. Columns 3-6 show sensitivities to the key utility function parameters: the marginal utility of money η, the nested logit substitution parameter σ, and the utilization elasticity. In each case, the magnitudes of the optimal policies change slightly, because the targeting properties of the two instruments change. However, the reason why these optimal policies do not change very much is that the key determinants of the optimal policy are the magnitudes of the internality and externality, which are constant across these columns. By contrast, the effects on average fuel economy, vehicle-miles traveled, carbon emissions, and welfare are highly sensitive to the parameter assumptions. This is analogous to the simple case of Pigouvian taxation with externalities only: the optimal tax is determined only by the magnitude of the externality, but other elasticity parameters will determine the effects.

The extent of undervaluation in automobile markets, if any, is highly uncertain. To illustrate the importance of the empirical uncertainty in γ, we also simulate the socially-optimal second best policies using the lower and upper bounds on the empirical estimates from Busse, Knittel, and Zettelmeyer (2012), which are $\gamma = 0.62$ and $\gamma = 2.44$.[10] Column 1 of Table 4 again reiterates column 5 of Table 2, the second best policy under our base case parameter assumptions. In column 2, when we assume that $\gamma = 0.62$ instead of 0.8, the optimal product subsidy is much larger. In column 3, when we assume that consumers significantly overvalue gasoline costs, it is optimal to correct this by imposing a very large relative tax on gas sippers, while still imposing a positive gasoline tax to correct the externality. These results parallel Figure 3 and Propositions 3 and 4, showing that the socially-optimal product tax is closely aligned with the magnitude of the internality, while the optimal energy tax is closer to constant.

Columns 4, 5, and 6 show the welfare effects of mistakenly assuming that $\gamma = 0.8$ when γ in fact equals 0.62, 2.44, and 1, respectively. Column 4 shows that mistakenly assuming that $\gamma = 0.8$ when it is actually 0.62 reduces welfare gains from \$99.50 to \$81 per vehicle. Column 5 shows that the costs of assuming $\gamma = 0.8$ when it is in fact 2.44 are very large: social welfare is \$173.20 per vehicle lower than if the policymaker had done nothing at all. Similarly, column 6 shows that the costs of imposing a corrective policy when no consumers misoptimize reduces welfare by \$17.10 per vehicle. This adds up to \$274 million per year that the policy is in place. This highlights the importance of empirical research to understand the magnitude of internalities, if any.[11]

Another way to highlight the importance of studying undervaluation is to return to Table 2 and compare the welfare losses from externalities versus internalities. The welfare losses from externalities alone are the social welfare gains from the first best policy in case 2: \$5.50 per vehicle. The welfare losses from internalities and externalities combined are the social welfare gains from the first best policy in case 7: \$38.60 per vehicle. Intuitively, the additional welfare losses from undervaluation are so large because uninternalized carbon externalities are \$0.18 cents per gallon, or about six percent of gasoline costs, while undervaluation is assumed to be $\gamma = 0.8$, which leaves 20 percent of gasoline costs uninternalized into product choices. Both sources of inefficiency act on

[10] The implied discount rates in Table 7 of Busse, Knittel, and Zettelmeyer (2012) range from negative 6.8 to positive 20.9 percent. Using empirical data on the average opportunity cost of capital for new and used vehicle buyers, these correspond to $\gamma = 2.44$ and $\gamma = 0.62$, respectively. Because of compounding, low and negative implied discount rates imply significant overvaluation.

[11] The Corporate Average Fuel Economy standard is perhaps the most salient example of a "product subsidy" in our model. The regulatory impact analysis of a recent increase in the CAFE standard similarly shows that the policy causes large welfare losses unless consumers misoptimize by undervaluing energy efficiency (NHTSA 2010).

the extensive margin the same way, by inducing consumers to buy more gas guzzlers than in the social optimum, but under these parameter assumptions, undervaluation generates larger allocative distortions and therefore much larger welfare losses. Economists have extensively studied optimal policy under externalities. Based on these potential welfare consequences, internalities seem to merit similarly extensive study, both theoretical and empirical.

5 Conclusion

Many analysts and policymakers have argued that consumers misoptimize in ways that cause us to underinvest in energy efficient durable goods. In this paper, we study optimal energy policy design when some consumers undervalue the benefits of energy efficiency. We show that undervaluation reverses two traditional results from a world where externalities are the only market failure. First, there is an Internality Dividend from Externality Taxes: a Pigouvian tax designed to reduce externalities also increases consumer welfare when there are internalities. This means that clear evidence of undervaluation would fundamentally reframe the discussion around climate policy, as it implies that carbon taxes are immediately "good for the economy." Second, there is an Internality Rationale for Energy Efficiency Policy: whereas energy efficiency subsidies and fuel economy standards are inferior to policies such as carbon taxes when externalities are the only market failure, these policies can increase welfare when there are also internalities.

The analysis highlights several areas where future research can guide policy. First, in order to properly calibrate a corrective policy, it is crucial to know the magnitude of the marginal internality. However, our simulations suggest that more nuanced features of the distribution may be less important in this context. Second, it is important not just to estimate the magnitude of the internality, but to tease out the specific form of the behavioral bias, if any. The conditions for our results to hold exclude some potentially-plausible models under which no misoptimizing types would be marginal to increased energy taxes or product subsidies. Taken together, these results suggest that energy policy with externalities and internalities is more nuanced than previously believed.

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Tables

Table 1: Vehicle Market Simulation Overview

	Mean	*Std. Dev.*	*Min*	*Max*
Choice Set				
Number of Models	301			
Price p_j (\$)	36,267	24,795	12,038	174,541
Gallons per Mile e_j	0.053	0.011	0.022	0.084
2007 Quantity Sold	46,459	72,078	93	616,275
Energy				
Pre-Tax Gasoline Price p_g (\$ per gallon)	3			
Marginal Damage ϕ (\$ per gallon)	0.18			
Consumers				
Valuation Parameter γ	0.8			
Nested Logit Substitution Parameter σ	0.6			
Mean Own-Price Elasticity	-5			
Utilization Elasticity	0.15			
Annual Discount Rate	6%			

Notes: All dollars are real 2005 dollars.

Table 2: Vehicle Market Simulation Results

Source of Inefficiency							
Externalities Only		Yes	Yes				
Externalities and Undervaluation				Yes	Yes	Yes	Yes
Case	1	2	3	4	5	6	7
	No Policy	First Best: $\tau_g = \phi$, $\tau_p = 0$	$\tau_g = 0$, τ_p to Abate Same CO2 as Case 2	$\tau_g = \phi$ $\tau_p = 0$	τ_g and τ_p to Max Social Welfare	Heuristic: $\tau_g = \phi$, τ_p to Max Social Welfare	First Best
Policies							
Gas Tax τ_g ($/gallon)	0.00	0.18	0	0.18	0.20	0.18	0.18
Product Subsidy τ_p ($/GPM)	0	0	69,571	0	64,175	65,573	
Resulting Allocations							
Average MPG	19.9	19.9	20.2	19.9	20.2	20.2	20.2
Average Lifetime VMT	153,660	152,400	154,020	152,390	152,580	152,720	152,730
Average PDV of Gas Cost	15,427	16,160	15,236	16,187	16,082	15,997	15,978
Average CO2 Tons Emitted	67.2	66.4	66.4	66.5	65.7	65.7	65.6
Welfare vs. No Policy							
ΔConsumer Welfare/Vehicle		-5.4	-25.1	4.1	14.8	15.6	16.4
ΔCO2 Damages/Vehicle		-10.9	-10.9	-10.3	-22.0	-21.1	-22.2
ΔSocial Welfare/Vehicle		5.5	-13.7	14.4	36.8	36.7	38.6
ΔConsumer Welfare/ton CO2		-6.8	-30.2	5.4	9.3	10.2	10.2

Notes: All dollars are real 2005 dollars. Carbon emissions and damages are denominated in metric tons of carbon dioxide. Welfare effects are per new vehicle sold, discounted at 6 percent per year over the vehicle's life.

Table 3: Second Best Policies under Alternative Assumptions

Change from Base Case	1	2	3	4	5	6
	None (Base Case, Column 5 from Table 2)	$\gamma_L = 0.6$, $\gamma_H = 1$	High η: Average Own-Price Elasticity is -10	Logit Sub Patterns ($\sigma = 0$)	Nested Logit $\sigma = 0.9$	High Utilization Elasticity $\eta_{VMT} = -0.45$
Product Subsidies						
Gas Tax τ_g ($/gallon)	0.20	0.15	0.22	0.19	0.24	0.19
Product Subsidy τ_p ($/GPM)	64,175	67,548	63,125	64,251	63,288	65,613
Resulting Allocations						
Average MPG	20.2	20.2	20.5	20.0	20.8	20.2
Average Lifetime VMT	152,580	152,970	152,840	152,360	153,090	153,250
Average PDV of Gas Cost	16,082	15,854	15,866	16,230	15,698	15,854
Average CO2 Tons Emitted	65.7	65.8	64.4	66.4	63.4	65.0
Welfare vs. No Policy						
ΔConsumer Welfare/Vehicle	14.8	14.7	33.3	7.8	47.2	8.6
ΔCO2 Damages/Vehicle	-22.0	-19.5	-19.5	-16.8	-47.2	-32.8
ΔSocial Welfare/Vehicle	36.8	34.1	69.2	24.7	94.4	41.4
ΔConsumer Welfare/ton CO2	9.3	10.4	12.8	6.4	13.8	3.6

Notes: This simulates the socially-optimal energy tax and product subsidy under different parameter assumptions. All dollars are real 2005 dollars. Carbon emissions and damages are denominated in metric tons of carbon dioxide. Welfare effects are per new vehicle sold, discounted at 6 percent per year over the vehicle's life.

Table 4: Simulations with More or Less Undervaluation

Change from Base Case	1	2	3	4	5	6
	None (Base Case, Column 5 from Table 2)	$\gamma = 0.62$ Optimal Policy	$\gamma = 2.44$ Optimal Policy	$\gamma = 0.62$ Incorrect Optimal Policy from Base	$\gamma = 2.44$ Incorrect Optimal Policy from Base	$\gamma = 1$ Incorrect Optimal Policy from Base
Optimal Product Subsidies						
Gas Tax τ_g ($/gallon)	0.20	0.21	0.10	0.20	0.20	0.20
Product Subsidy τ_p ($/GPM)	64,175	123,210	-152,090	64,175	64,175	64,175
Resulting Allocations						
Average MPG	20.2	20.4	19.3	20.2	20.2	20.2
Average Lifetime VMT	152,580	152,800	152,160	152,560	152,560	152,600
Average PDV of Gas Cost	16,082	15,976	16,244	16,108	16,030	16,054
Average CO2 Tons Emitted	65.7	65.0	68.5	65.8	65.5	65.5
Welfare vs. No Policy						
ΔConsumer Welfare/Vehicle	14.8	67.8	118.3	59.6	-197.3	-39.7
ΔCO2 Damages/Vehicle	-22.0	-31.7	-31.7	-21.4	-24.1	-22.6
ΔSocial Welfare/Vehicle	36.8	99.5	100.7	81.0	-173.2	-17.1
ΔConsumer Welfare/ton CO2	9.3	29.4	-92.5	38.3	-112.6	-24.2

Notes: This simulates the socially-optimal energy tax and product subsidy under different assumptions for γ. All dollars are real 2005 dollars. Carbon emissions and damages are denominated in metric tons of carbon dioxide. Welfare effects are per new vehicle sold, discounted at 6 percent per year over the vehicle's life.

Figures

Figure 1: Equilibrium with Energy Taxes or Product Subsidies

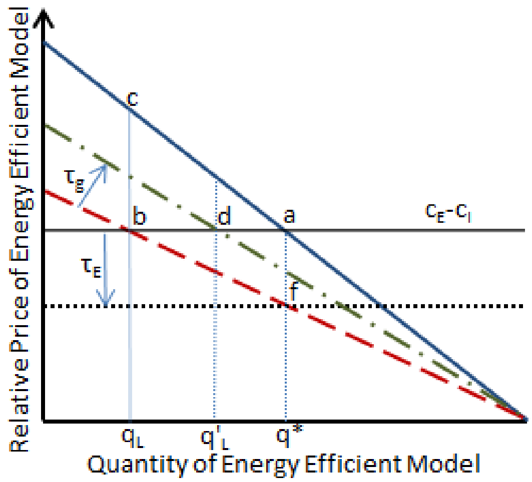

Figure 1:

Notes: The solid blue line on this figure is the demand curve for the energy efficient good if all consumers are rational. The dashed red line is the demand curve with undervaluation. Triangle abc is the consumer welfare loss from undervaluation. The dot-dashed green line reflects the demand curve with undervaluation after the energy tax τ_g is applied. The dotted black line reflects the new supply curve after the product subsidy τ_E is applied.

Figure 2: The Internality Dividend from Externality Taxes

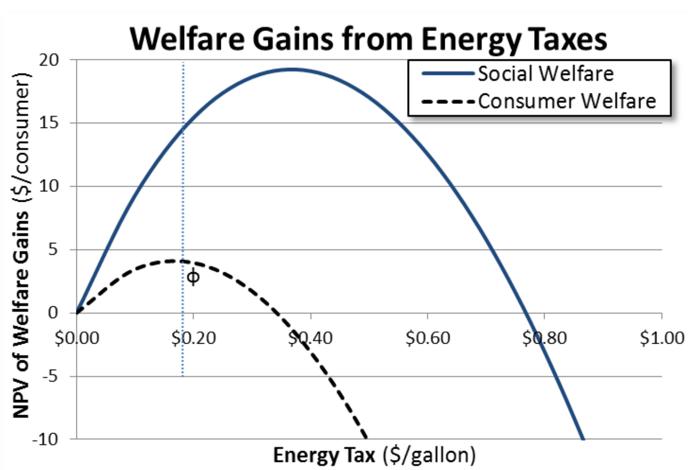

Figure 2:

Notes: This figure shows the simulated vehicle market welfare gains from different levels of energy taxes, with the product subsidy set to zero.

Figure 3: Optimal Energy Taxes and Product Subsidies by Valuation Level

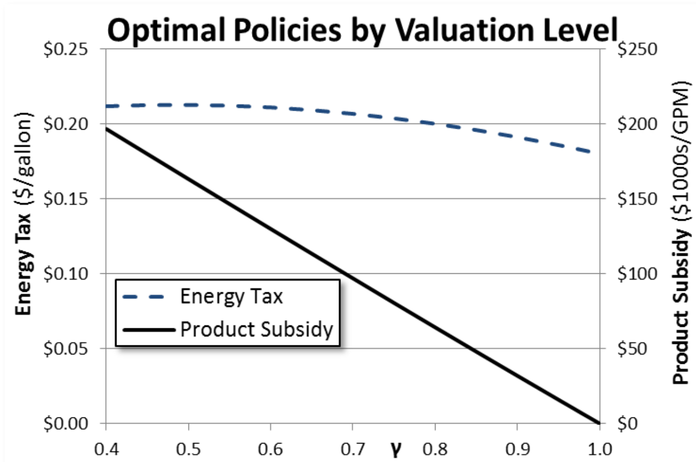

Figure 3:

Notes: This figure shows socially-optimal policies as a function of γ.

Figure 4: Optimal Energy Taxes and Product Subsidies under Increasing Heterogeneity

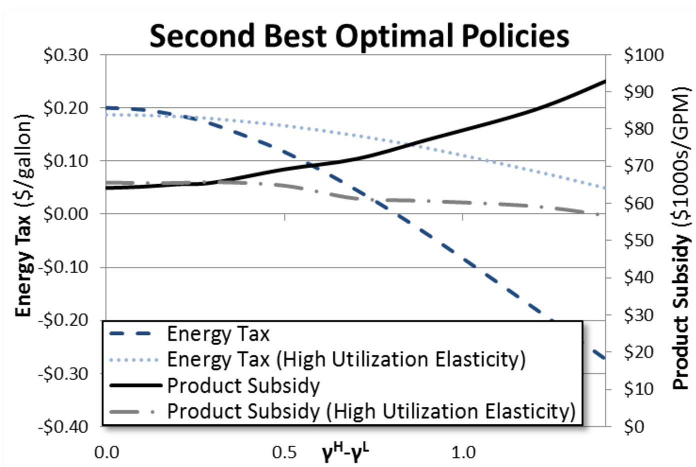

Figure 4:

Notes: This figure shows optimal policies as a function of $\gamma^H - \gamma^L$ in the base case, which has utilization elasticity = -0.15, and an alternative case, which has utilization elasticity = -0.45.

Figure 5: Welfare Gains from Optimal vs. Heuristic Policies

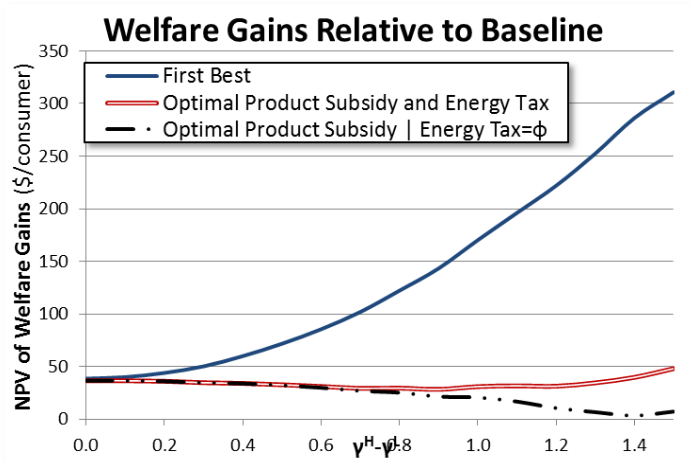

Figure 5:

Notes: This figure shows that social welfare gains relative to no policy as a function of $\gamma^H - \gamma^L$.

Appendix I: Proofs

We begin with a series of auxiliary lemmas that will be used throughout subsequent proofs.

Lemma 1 *Set* $m^*(\theta, e, p_g) \equiv argmax\{u(m-\theta) - p_g me\}$. *Then* $\frac{\partial}{\partial\theta} m^*(\theta, e, p_g) = 1$.

Proof. Follows from differentiation of the first order condition for m^* and algebra. ■

Lemma 2 $v(\theta_2, e, p_g) = (\theta_2 - \theta_1)p_g + v(\theta_1, e, p_g)$ *for* $\theta_2 > \theta_1$. *Thus* $v(\theta_2, e, p_g)$ *is linearly increasing in* θ.

Proof. By the previous lemma, $m^*(\theta_2, e, p_g) - \theta_2 = m^*(\theta_1, e, p_g) - \theta_1$ for all θ_1, θ_2. But now $v(m^*(\theta_2, e, p_g) - \theta_2) = u(m^*(\theta_2, e, p_g) - \theta_2) - p_g m^*(\theta_2, e, p_g) = u(m^*(\theta_1, e, p_g) - \theta_1) - p_g(\theta_2 - \theta_1) - p_g m^*(\theta_1, e, p_g)$. ■

Lemma 3 $em^*(\theta, p_g, e)$ *is increasing in* e

Proof. We have

$$\frac{\partial}{\partial e} em^*(\theta, p_g, e) = m^*(\theta, p_g, e) + e\frac{\partial}{\partial e} m^*(\theta, p_g, e). \tag{11}$$

Differentiating the first order condition $u'(m^* - \theta) - p_g e = 0$ with respect to e yields $u''(m^* - \theta)\frac{\partial m^*}{\partial e} = p_g$. Thus

$$\frac{\partial}{\partial e} em^* = m^* - \frac{ep_g}{u''(m^* - \theta)} = m^* - \frac{u'(m^* - \theta)}{u''(m^* - \theta)}.$$

But $m - \theta > 0 > \frac{u'(m-\theta)}{u''(m-\theta)}$, and thus the expression (11) is positive. ■

Lemma 4 $V_r(\theta, e_E, e_I, p_g) = v(\theta, e_E, p_g) - v(\theta, e_I, p_g)$ *is strictly increasing in* θ *and* p_g. *It is also strictly decreasing in* e_E *and strictly increasing in* e_I.

Proof. From the envelope theorem and lemma 1, we have that

$$\frac{\partial}{\partial\theta} v(\theta, e, p_g) = -p_g e.$$

Thus

$$\frac{\partial}{\partial\theta}[v(\theta, e_E, p_g) - v(\theta, e_I, p_g)] = p_g(e_I - e_E) > 0. \tag{12}$$

We also have

$$\frac{\partial}{\partial p_g} v(\theta, e, p_g) = -m^* e$$

and thus

$$\frac{\partial}{\partial p_g}[v(\theta, e_E, p_g) - v(\theta, e_I, p_g)] = m^*(\theta, e_I, p_g)e_I - m^*(\theta, e_E, p_g)e_E \tag{13}$$

That $V_r(\theta, e_E, e_I, p_g)$ is increasing in e_I and decreasing in e_E is obvious: the more energy a product consumes, the worse off the consumer will be with that product. ■

Lemma 5 *Let $\theta^\dagger$ be the value that satisfies $V_r(\theta^\dagger, e_E, e_I, p_g) = \Delta p$, where $\Delta p = p_E - p_I$. Then*

1. $\frac{\partial}{\partial \Delta p}\theta^\dagger > 0$
2. $\frac{\partial}{\partial p_g}\theta^\dagger < 0$

Proof. Since $\frac{\partial}{\partial \Delta p}(V_\mathrm{r} - \Delta p) = -1$ and $\frac{\partial}{\partial \Delta\theta}(V_\mathrm{r} - \Delta p) > 0$, we have

$$\frac{\partial}{\partial \Delta p}\theta^\dagger = -\frac{\frac{\partial}{\partial \Delta p}(V_\mathrm{r} - \Delta p)}{\frac{\partial}{\partial \Delta\theta}(V_\mathrm{r} - \Delta p)} > 0.$$

Similarly, since $\frac{\partial}{\partial p_g}(V_\mathrm{r} - \Delta p) < 0$, we have

$$\frac{\partial}{\partial p_g}\theta^\dagger = -\frac{\frac{\partial}{\partial p_g}(V_\mathrm{r} - \Delta p)}{\frac{\partial}{\partial \Delta\theta}(V_\mathrm{r} - \Delta p)} < 0.$$

■

Lemma 6 *The function $M(\theta, e, p_g) \equiv v(\theta, e, p_g) + (p_g - c_g - \phi)em^*(\theta, e, p_g)$ is differentiable in p_g and attains its maximum at $p_g = c_g + \phi$.*

Proof. Since

$$\frac{\partial}{\partial p_g}v(\theta, e, p_g) = m^* e$$

some algebra shows that

$$\frac{\partial}{\partial p_g}M(\theta, e, p_g) = (p_g - c_g - \phi)e\frac{\partial}{\partial p_g}m^*(\theta, e, p_g).$$

Since

$$\frac{\partial}{\partial p_g}m^*(\theta, e, p_g) < 0$$

we know that $\frac{\partial}{\partial p_g}M(\theta, e, p_g)$ is positive for $p_g < c_g + \phi$ and negative for $p_g > c_g + \phi$. ■

Proofs of claims and propositions in paper

Proof of Claim 1. Obviously the proposed policy achieves the first best.

We now check that no other policy achieves the first best. First, notice that by Lemma 6, $\tau_g = \phi$ in any policy that achieves the first best; otherwise the intensive margin choice will be inefficient. Now with τ_g fixed at ϕ, $\tau_E \neq 0$ can only create an inefficiency in the extensive-margin choice of durables. ■

Proof of Proposition 1. More generally, we show that $\tau_g^* > \phi$ if the government maximizes W. This will prove the desired result by setting $\phi = 0$.

Let W_k be the social welfare corresponding to type $\tilde{V}_k$ consumers. Total welfare is given by $\sum_k W_k$. Let $\theta_k^\dagger$ correspond to the utilization need of the marginal type $\tilde{V}_k$ consumers and set $\Delta c \equiv c_E - c_I$. We calculate $\frac{\partial}{\partial \tau_g} W_k$ at $p_g = c_g + \tau_g$ and $\tau_E = 0$:

$$\begin{aligned}\frac{\partial W_k}{\partial \tau_g} &= [M(\theta_k^\dagger, e_E, p_g) - M(\theta_k^\dagger, e_I, p_g) - \Delta c]\frac{\partial \theta_k^\dagger}{\partial \tau_g} f(\theta_k^\dagger) \qquad (14)\\ &+ \left[\int_{\theta \le \theta_k^\dagger} \frac{\partial}{\partial p_g} M(\theta, e_I, p_g) dF(\theta) + \int_{\theta \ge \theta_k^\dagger} \frac{\partial}{\partial p_g} M(\theta, e_E, p_g) dF(\theta)\right] \qquad (15)\end{aligned}$$

where f is the probability density function of F. Line 1 corresponds to the extensive margin effect, call it ∂W_k^{ext}, while line 2 corresponds to the intensive margin effect, call it ∂W_k^{int}.

Let θ^* be the type such that in the first best allocation, any consumer with utilization $\theta > \theta^*$ must purchase E and any consumer with utilization $\theta < \theta^*$ must purchase I. Now at $\tau_g = \phi$ at τ_E, $\theta_k^\dagger \ge \theta^*$ since $\tilde{V}_k(\theta, e_E, e_I, p_g) \le V_{\rm r}(\theta, e_E, e_I, p_g)$ for all θ. And by Lemma 5, this means that $\theta_k^\dagger < \theta^*$ when $\tau_E \le 0$ and $\tau_g \le \phi$; and $\theta^\dagger > \theta^*$ if $\tau_g < \phi$ and $\tau_E \le 0$. Moreover $\theta^\dagger > \theta^*$ if additionally either $\tau_g < \phi$ or $\tau_E < 0$ or $\tilde{V}_k < V_{\rm r}$. Thus

$$\begin{aligned}\partial W_k^{ext} &= M(\theta_k^\dagger, e_E, p_g) - M(\theta_k^\dagger, e_I, p_g) - \Delta c\\ &= v(\theta_k^\dagger, e_E, p_g) - v(\theta_k^\dagger, e_I, p_g) + (c_g + \phi - p_g)(e_I m^*(\theta, e_I, p_g) - e_E m^*(\theta, e_E, p_g)) - \Delta c \le 0\end{aligned}$$

when $p_g \le c_g + \phi$ and $\theta^\dagger \ge \theta^*$. Additionally, $\partial W_k^{ext} > 0$ if either $p_g < c_g + \phi$ or $\tau_E < 0$ or $\theta^\dagger > \theta^*$.

Consider now the total change in welfare (with respect to a change in τ_g): $\frac{\partial W}{\partial \tau_g} = \sum_k \alpha_k \frac{\partial W_k}{\partial \tau_g} W_k$. When $\tau_g \le \phi$ and $\tau_E \le 0$, the above analysis implies that $\frac{\partial W_k}{\partial \tau_g} \ge 0$ for all k and is strictly positive for at least one k (since $\tilde{V}_k < V_{\rm r}$ for some k by assumption). Thus $\frac{\partial W}{\partial \tau_g} > 0$ when $\tau_g \le \phi$ and $\tau_E \le 0$. Thus $\tau_g \le \phi$ and $\tau_E \le 0$ cannot constitute an optimal tax policy. ■

Proof of Proposition 2. We have already shown that $\frac{\partial}{\partial \tau_g} W > 0$ at $(\tau_E, \tau_g) = (0, \phi)$. The proof that $\frac{\partial}{\partial \tau_p} W > 0$ at $(\tau_E, \tau_g) = (0, \phi)$ follows similarly. And as was already shown in proof of Proposition 1, $\tau_E \le 0$ and $\tau_g < \phi$ cannot constitute an optimal tax policy. ■

Proof of Proposition 3. Here will we prove a more general version of the proposition. We prove the statement of the proposition for any strictly increasing and unbounded function L.

Suppose that (τ_E^*, τ_g^*) is an optimal policy in economy $\mathcal{E}$. Let $\theta_k^\dagger$ be such that $\tilde{V}_k(\theta_k^\dagger, e_E, e_I, c_g + \tau_g^*) = c_E - c_I - \tau_E^*$. Then the total welfare is given by

$$\begin{aligned}W &= \sum_k \alpha_k \left[\int_{\theta \le \theta_k^\dagger} v(\theta, e_I, c_g + \tau_g^*) dF + \int_{\theta > \theta_k^\dagger} v(\theta, e_E, c_g + \tau_g^*) dF\right] \qquad (16)\\ &- \sum_k \alpha_k \left[\int_{\theta \le \theta_k^\dagger} (\phi - \tau_g) e_I m^*(\theta, e_I, c_g + \tau_g^*) dF + \int_{\theta > \theta_k^\dagger} (\phi - \tau_g) e_E m^*(\theta, e_E, c_g + \tau_g^*) dF\right] \qquad (17)\end{aligned}$$

Notice that the welfare depends directly only on the $\theta_k^\dagger$ and the energy tax τ_g, but it does not depend directly on τ_E^*.

We now show how to obtain the same level of social welfare in economy $\mathcal{E}(L)$. The key is simply that if $\tilde{V}_k(\theta_k^\dagger, e_E, e_I, c_g+\tau_g^*) = c_E - c_I - \tau_E^*$ then $\tilde{V}_k^L(\theta_k^\dagger, e_E, e_I, c_g+\tau_g^*) = L(c_E - c_I - \tau_E^*)$. This means that $\tilde{V}_k^L(\theta_k^\dagger, e_E, e_I, c_g+\tau_g^*) = c_E - c_I - \tau_E^{**}$ if $\tau_g^{**}(L) = \tau_g^*$ and $\tau_E^{**}(L) = c_E - c_I - L(c_E - c_I - \tau_E^*)$. Thus at $(\tau_g^{**}(L), \tau_E^{**}(L))$, the welfare will remain identical to what's in lines (16) and (17).

Thus any level of social welfare that is obtainable in economy $\mathcal{E}$ is also obtainable in $\mathcal{E}(L)$. Notice that this holds for *any* strictly increasing L. Thus since L^{-1} is also strictly increasing, an identical argument implies that any level of social welfare that is obtainable in economy $\mathcal{E}(L)$ is also obtainable in economy $\mathcal{E}$. This means that the second-best levels of social welfare in $\mathcal{E}$ and $\mathcal{E}(L)$ are identical. Thus $(\tau_g^{**}(L), \tau_E^{**}(L))$ must be an optimal policy since it obtains that second-best level of social welfare. ■

Proof of Proposition 4. As before, let θ^* be the value of θ such that $V_{\mathrm{r}}(\theta^*, e_E, e_I, c_g+\phi) = c_E - c_I$. Let $\theta^\dagger$ be such that $V_{\mathrm{r}}(\theta^*, e_E, e_I, c_g+\tau_g^*) = c_E - c_I - \tau_E^*$ at the optimal tax policy (τ_E^*, τ_g^*). The computation in lines (16) and (17) shows that if $\tau_g^* = \phi$ and if τ_E^* is such that $\theta^\dagger = \theta^*$ then

$$W = \int_{\theta \le \theta^*} v(\theta, e_I, c_g+\tau_g^*)dF + \int_{\theta > \theta^*} v(\theta, e_E, c_g+\tau_g^*)dF$$

which is exactly the first-best level of welfare. Thus the proposition will be proven if τ_E^* can be set such that $\theta^\dagger = \theta^*$. But notice that $\theta^\dagger$ is given by

$$\tilde{V}(\theta^\dagger, e_E, e_I, c_g+\phi) = c_E - c_I - \tau_E^* \tag{18}$$

when $\tau_g^* = \phi$. Thus when $\tau_E^* = (c_E - c_I) - \tilde{V}(\theta^*, e_E, e_I, c_g+\phi)$, equation (18) reduces to $\tilde{V}(\theta^\dagger, e_E, e_I, c_g+\phi) = \tilde{V}(\theta^*, e_E, e_I, c_g+\phi)$, implying that $\theta^\dagger = \theta^*$.

Notice that this proof does not make use of the fact that $\tilde{V}(\xi) < V_{\mathrm{r}}(\xi)$ for all ξ. All that is needed for this proof to work is that V_{r} is strictly increasing, unbounded, and continuous in θ. ■

Appendix II: Specific Behavioral Biases

Partial (exogenous) attention and present bias

Consider first the simple case in which $\tilde{V} = \gamma V_{\mathrm{r}}$ for some $\gamma > 0$. Since V_{r} is strictly increasing in θ and p_g by Lemma 4, $\tilde{V}$ clearly inherits those properties as well. And since $V_{\mathrm{r}} \to \infty$ as $\theta \to \infty$ by Lemma 2, $\tilde{V}$ also inherits those properties.

Underestimation of energy intensity

Suppose that consumers make their extensive margin choice thinking that E consumes $\hat{e}_E = H_E(e_E, e_I) > e_E$ units of energy and I consumes $\hat{e}_I = H_I(e_E, e_I) < e_I$ units of energy. The functions are H_E and H_I are such that $H_E(e_E, e_I) > e_E$ for all $e_E > e_I > 0$ and such that $H_I(e_E, e_I) < e_I$ for all $e_E > e_I > 0$. For example, consumers might be right about energy efficiency on average, but not adjust sufficiently: $\hat{e}_E = \kappa e_E + (1-\kappa)e_I$ and $\hat{e}_I = \kappa e_I + (1-\kappa)e_E$ for $\kappa \in (0,1)$. Note that $\hat{e}_E + \hat{e}_I = e_E + e_I$, even though $\hat{e}_I < e_I$ and $\hat{e}_E > e_E$.

Now for a consumer with utilization need θ with incorrect beliefs about energy efficiency, $\tilde{V}(\theta, e_E, e_I, p_g) = V_{\mathrm{r}}(\theta, H_E(e_E, e_I), H_I(e_E, e_I), p_g)$, which is clearly a function of the parameters $\xi = (\theta, e_E, e_I, p_g)$. By Lemma 4, $\tilde{V}(\xi) < V_{\mathrm{r}}(\xi)$.

Underestimation of utilization needs

For a consumer with utilization need θ with incorrect beliefs about his need, $\tilde{V}(\theta, e_E, e_I, p_g) = V_{\mathrm{r}}(\ell(\theta, e_E, e_I, p_g)$, which is clearly a function of the parameters $\xi = (\theta, e_E, e_I, p_g)$. By Lemma 4, $\tilde{V}(\xi) < V_{\mathrm{r}}(\xi)$, if $\ell(\theta) < \theta$ for all θ.

Endogenous partial attention

With endogenous partial attention, $\tilde{V} = \gamma(V_{\mathrm{r}})V_{\mathrm{r}}$, where the attention weight $\gamma : \mathbb{R} \to (0,1)$ is a strictly increasing function of V_{r}. Since V_{r} is increasing in θ, $\gamma(V_{\mathrm{r}})V_{\mathrm{r}}$ is increasing in θ as well. Similarly, since V_{r} is increasing in p_g, $\gamma(V_{\mathrm{r}})V_{\mathrm{r}}$ is increasing in p_g as well.

Appendix III: Results with Overvaluation

In this appendix we discuss the more general case of overvaluation.

We begin by noting that Propositions 3 and 4 are general to overvaluation. As the proof of Proposition 3 shows, the statement of Proposition 3 is true for any L that is strictly increasing and continuous in θ. Thus if consumers severely overvalued energy efficiency, then Proposition 3 would imply that a very large tax on E is needed to address this overvaluation.

Proposition 4 also holds when there is overvaluation. Again, the additional assumption that $\tilde{V}(\xi) \le V_{\mathrm{r}}(\xi)$ is not needed for that proposition to be true. If consumers homogeneously overvalued energy efficiency, Proposition 4 would imply that this overvaluation of energy efficiency should be addressed solely through a tax on the energy efficient product, and not through a tax on energy consumption.

Next, we consider conditions under which $\frac{\partial}{\partial \tau_g} W > 0$. Evaluated at the policy $(\tau_E = 0, \tau_g = \phi)$,

$$\frac{\partial}{\partial \tau_g} W = \sum_k \alpha_k \left[v(\theta_k^\dagger, e_E, c_g + \phi) - v(\theta_k^\dagger, e_I, c_g + \phi) - (c_E - c_I) \right] \frac{\partial \theta_k^\dagger}{\partial \tau_g} f(\theta_k^\dagger) \tag{19}$$

where $\theta_k^\dagger$ is the utilization need of the marginal consumer of valuation type $\tilde{V}_k$. As before, let θ^*, defined by $v(\theta^*, e_E, c_g + \phi) - v(\theta^*, e_I, c_g + \phi) = c_E - c_I$, correspond to the utilization need at which it first becomes socially efficient to purchase E. Notice that $\theta_k^\dagger > \theta^*$ if $\tilde{V}_k < V_{\mathrm{r}}$ but $\theta_k^\dagger < \theta^*$ if $\tilde{V}_k > V_{\mathrm{r}}$.

In the proofs of Propositions 1 and 2, we argued that $\frac{\partial}{\partial \tau_g} W > 0$ when $\theta_k^\dagger \geq \theta^*$ for all k and $\theta_k^\dagger > \theta^*$ for at least one k. Having $\theta_k^\dagger > \theta^*$ implies that $v(\theta_k^\dagger, e_E, c_g + \phi) - v(\theta_k^\dagger, e_I, c_g + \phi) - (c_E - c_I) > 0$. With overvaluation, it is no longer true that $v(\theta_k^\dagger, e_E, c_g + \phi) - v(\theta_k^\dagger, e_I, c_g + \phi) - (c_E - c_I) > 0$ for all k. However, it is still true that $\frac{\partial}{\partial \tau_g} W > 0$ as long as $v(\theta_k^\dagger, e_E, c_g + \phi) - v(\theta_k^\dagger, e_I, c_g + \phi) - (c_E - c_I) > 0$ for enough consumers on the margin. In particular what is needed is that $\alpha_k \frac{\partial \theta_k^\dagger}{\partial \tau_g} f(\theta_k^\dagger)$ is relatively high for consumers who undervalue energy efficiency. This can happen for several reasons. First, if α_k is high for undervaluing consumers, meaning that undervaluing consumers are simply a large portion of the population. Second, if $\frac{\partial \theta_k^\dagger}{\partial \tau_g}$ is high for the undervaluing consumers, meaning that they are especially responsive to the tax. Third, if $f(\theta_k^\dagger)$ is high for the undervaluing consumers, meaning that they populate the margin. An analogous analysis holds for $\frac{\partial}{\partial \tau_E} W$.

Appendix IV: Vehicle Market Simulation Details

For the vehicle market simulation, we assume a CRRA functional form for $u(m - \theta)$:

$$u(m_{ij} - \theta_i) = \frac{A}{1 - r} (m_{ij} - \theta_i)^{1-r} \tag{20}$$

Given this functional form, the choice of m_{ij} that maximizes utility in Equation (24) below is:

$$m_{ij}^* = \theta_i + \left(\frac{\eta p_g e_j}{A} \right)^{-1/r} \tag{21}$$

The parameter r is related to the price elasticity of utilization demand $\eta_{VMT} < 0$:

$$r = \frac{1}{-\eta_{VMT}} \frac{m_{ij}^* - \theta_i}{m_{ij}^*} \tag{22}$$

We assume a uniform distribution of θ, with support ranging from zero to twice the mean. We set A such that $\overline{\theta} = \frac{\overline{m}}{2}$, which ensures that elasticity does not vary too much over the support of θ.

The mean value of θ is set to match nationally-representative data on VMT from the 2001 National Household Travel Survey (NHTS), the most recent national survey with available odometer readings. As part of the survey, odometer readings for about 25,000 vehicles were recorded twice, with several months between the readings, and these data were used to estimate annualized VMT. The variable θ captures potential VMT if the vehicle lasts all the way through an assumed 25-year maximum lifetime. To calibrate θ, we use the NHTS data to calculate the nationally-representative average annual VMT $\overline{m}_a^*$ for vehicles of each age a from 1 to 25. For example, these average annual VMTs decline from 14,500 when new to 9,600 at age 12 and 4,300 at age 25. The U.S. average VMT over a 25-year potential lifetime is the sum of annualized VMT at each age, or $\sum_{a=1}^{25} \overline{m}_a^* \approx 236,000$.

We must translate this undiscounted sum over a potential lifetime to a discounted sum over an expected lifetime. To do this, we apply a scaling factor Λ. We assume a six percent discount rate, which reflects the average discount rate for vehicle buyers calculated by Allcott and Wozny (2011), giving a discount factor $\delta = \frac{1}{1.06}$. We use data on nationwide registrations of new and used vehicles from 1999 to 2008 to calculate the average survival probability of vehicles at each age a. These are multiplied to construct cumulative survival probabilities, denoted ϕ_a. For example, a new vehicle has a 60 percent chance of surviving to age 12 and a ten percent chance of surviving to age 25. The scaling factor Λ is:

$$\Lambda = \frac{\sum_{a=1}^{25} \delta^a \overline{m}_a^* \phi_a}{\sum_{a=1}^{25} \overline{m}_a^*} \approx 0.436 \tag{23}$$

After these modifications, we now have the modification of the utility function in Equation (1). The utility that consumer i experiences from purchasing product j, choosing optimal utilization m_{ij}^*, and receiving a transfer T is:

$$\left\{Y_i + T - p_j - \Lambda p_g m_{ij}^* e_j\right\} + \frac{\Lambda}{\eta} u(m_{ij}^* - \theta_i) + \frac{\psi_j}{\eta} + \frac{\epsilon_{ij}}{\eta} \tag{24}$$

In this equation, the variable η is a scaling factor for the marginal utility of money, which is set such that the average own-price elasticity of demand is -5. We calibrate the ψ_j using the Berry, Levinsohn, and Pakes (1995) contraction mapping. Analogously to Equation (1), the term in brackets is consumption of the numeraire good, while the three terms on the right represent the utility that the consumer derives from owning and using the vehicle.

To calculate welfare effects, we follow the Allcott (2012) approach to calculating consumer surplus in logit models when consumers misoptimize. In brief, the approach exploits the fact that experienced utility can written as the difference between a decision utility function, which represents a function that the consumer acts as if he is optimizing, and the internality, which captures the magnitude by which the consumer misoptimizes. Decision consumer surplus is the integral over consumers of decision utility, which can be calculated using the nested logit version of standard discrete choice consumer surplus formulas from Small and Rosen (1981). The total internality is simply the sum over consumers of the internality. The change in W_0 is the change in decision consumer surplus minus the change in the total internality.