

Do Energy Efficiency Standards Increase Social Welfare?

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1. Introduction

In recent years, the political pendulum has swung back towards a far more interventionist role for governments in US energy markets. A major manifestation of this movement has been the proliferation of actual and proposed energy efficiency standards. Most prominent are the recent rulings on new light-duty vehicles that will require manufacturers to increase the fleetwide average fuel economy to approximately 35 mpg by 2016. In addition, there are numerous efficiency standards for household appliances, incandescent light bulbs are being phased out, and new energy efficiency standards are proposed for residential and commercial buildings.

What kinds of market failure could justify energy efficiency standards? An obvious possibility is pollution externalities, especially carbon dioxide (CO₂). The problem with this justification is that generally speaking efficiency standards are an inferior instrument to energy or emissions taxes. Unlike the pricing approach, efficiency standards do not reduce the intensity of use of energy durables; in fact, they tend to increase their use through the “rebound effect” (Khazzoom 1980). Nor do they reduce pollution emissions per unit of energy, or produce least-cost outcomes through equating marginal abatement costs across different sectors.

A second class of potential market failures is associated with the so-called “energy paradox,” the reluctance of energy users to adopt apparently cost-effective, efficient technologies (Jaffe and Stavins 1994). This is reflected in a series of empirical studies finding very high implicit rates of return on energy-saving technologies, ranging from 25 to over 100 percent (Allcott and Wozny 2009, Hausman 1979, Sanstad et al. 2006, Train 1985). Some analysts cite this as evidence that consumers misperceive energy efficiency benefits because of “missing” information so that the true benefits and costs are not recognized. Others however, point out that there might be “hidden costs” not accounted for in these studies such as those related to product attributes (e.g., objectionable aspects of the quality of fluorescent lighting), various search costs, and aversion towards “irreversible investments” with uncertain returns (Hassett and Metcalf 1993).¹ At the same time, certain information programs (like the voluntary EPA Green Lights program and various EnergyStar programs) appear to have increased energy-efficiency investments (e.g., Howarth et al. 2000).

The general issue is important because the source of the failures has direct policy implications. For externalities the preferred approach is pricing measures, while for misperceptions information programs can play an important role. In either case, efficiency standards appear to be a second-best measure, whose justification presumably depends on practical constraints on the economically preferred policy.

The actual and prospective adoption of energy efficiency standards raises a number of interrelated policy issues. First, what are their overall welfare effects, under different scenarios for emissions pricing, and how do these compare with the welfare effects of other policy options? Second, what combinations of market failures, particularly related to CO₂ damages and the extent of misperceptions market failures, justify efficiency standards of given stringencies? And third, even in the absence of misperceptions market failures, to what extent can efficiency standards, in combination with other regulatory approaches, achieve the cost-effectiveness of CO₂ pricing instruments (should the latter prove difficult to implement in practice)?

¹ Another possibility is that, rather than utility maximization, consumer behavior is based on simplified decision processes, like “rules of thumb”, due to cognitive constraints on processing information. There is, however, little empirical work relating these kinds of behavioral failures directly to decision-making on energy efficiency. For a broad discussion of market and other potential failures in energy markets see Gillingham et al. (2009) and Tietenberg (2009).

Our paper provides a conceptual framework for understanding these questions and for gaining some approximate sense of the empirical magnitude of welfare effects at stake, for policies affecting energy efficiency in both the transport and power sectors. To do this we develop a static, general equilibrium model with CO₂ emissions produced from vehicle fuel combustion, power generation, and “other” sectors. The model captures the possibility of sub-optimal investment in energy efficiency for vehicles and electricity durables, broader externalities (which are especially important for automobiles), energy efficiency regulations applying comprehensively to automobiles and partially to electricity durables, and possible taxes on energy and CO₂ as well as possible regulations on the power generation mix. The model is applied based on aggregating (detailed) data on (regulated and unregulated) electricity durables and recent reviews of automobile parameters. While a richer framework might incorporate capital dynamics, greater product disaggregation, and producer heterogeneity, a good deal may still be learned from the parsimonious, transparent model developed here which, we believe, captures the most important determinants of welfare effects.

Although a limited, prior literature provides insight on some components of our welfare analysis, none provides the type of overarching framework needed for the policy questions posed here. For example, previous studies have been sector specific and therefore do not compare the welfare effects of standards versus economy-wide pricing, nor do they compare and contrast standards across different sectors, or explore to what extent regulatory packages can mimic emissions pricing. There has been little attempt to simultaneously integrate externalities and informational market failures. And the conditions required to justify standards of different stringencies, with and without constraints on first-best emissions pricing, have not been explicitly modeled.²

We summarize our findings as follows.

First, energy efficiency standards for the transport sector face a high hurdle to be warranted on welfare grounds. Even under our upper bound case for misperceptions market failures, efficiency standards are not part of the optimal policy to address market failures for automobiles (this applies regardless of damage assumptions for CO₂). Fuel taxes have a much

² An emerging literature has quantified the welfare effects of fuel economy standards, though with conflicting implications for policy (e.g., Austin and Dinan 2002, Kleit 2002, Fischer et al. 2007, Small 2009). Stanstad and Auffhammer (2009) discuss the costs and benefits of efficiency standards in the power sector. We relate our findings to these studies below.

lower net cost because of ancillary externality benefits associated with reduced product use (reduced traffic congestion and so on, assuming these broader externalities remain largely unpriced). In contrast, fuel economy standards (moderately) increase these other externalities. This relative disadvantage for efficiency standards more than outweighs (just) any potential advantage at targeting misperceptions failures more directly than fuel taxes. If fuel taxes are fixed at their current level (40 cents/gallon), efficiency standards can significantly improve welfare but only if CO₂ damages are very high (upwards of \$100 per ton) or consumers fail to internalize a substantial portion (more than half) of savings from higher fuel efficiency.

Second, in contrast in the power sector, where there are no large ancillary externalities related to product use, and pre-existing energy taxes are relatively small, any misperceptions market failure implies a potential role for efficiency standards as part of the optimal policy response. Even with no misperceptions, efficiency standards to cut total economy-wide electricity use by several percent could still be warranted.

<additional results to be completed>

The paper is organized as follows. The next section develops the analytical model and derives key formulas. Section 3 comments on the baseline data. Section 4 presents the main quantitative findings and sensitivity analysis. Section 5 offers concluding remarks and discusses model limitations.

2. Analytical Framework

A. Model Structure

(i) *Household utility.* We adopt a static, long run model of the economy. At the start of the period, households purchase three durable goods for use over the period, indexed by i : automobiles (A), an electricity-intensive durable good (R) representing an aggregation of final and intermediate products that are, or could potentially be, subject to binding energy efficiency regulations (e.g., appliances, lighting), and an electricity-intensive durable good (N) representing an aggregation of all electricity-using goods that might be difficult to regulate.³

³ In the transport sector, standards are defined over an average of all vehicles within a manufacturer's car and light-truck fleets. Therefore, an individual vehicle is still affected by the regulation even if its own fuel economy exceeds

The representative agent's utility function is:

$$(1a) \quad u = u(v_A, v_R, v_N, I, Y, \overline{CO_2}, \bar{Z}_A, \bar{Z}_E)$$

$$(1b) \quad v_i = v_i(S_i, m_i, \mu_i(e_i))$$

In (1b), $v_i(\cdot)$ is sub-utility from use of durable good i , S_i is purchases (at the start of the period), or the stock, of durable good i , and m_i is the intensity with which this good is used—miles driven per auto over the period or hours of operation for electricity-using goods.⁴ e_i is energy consumption per unit of use of durable good i , that is, fuel use per unit distance of driving or electricity use per unit of time—the inverse of e_i is thus energy efficiency. The role of e_i in the utility function is to capture possible hidden costs from reductions in energy intensity. For example, fuel-saving technologies have hidden costs if they imply reduced vehicle power; to take another example, florescent bulbs may have hidden costs if households prefer the brighter, instantaneous lighting from incandescent bulbs. Thus, μ_i represents a broad index of attributes from product i , where $\mu_i(\cdot)$ is weakly concave with $\mu'_i \geq 0$. The e_i may be determined by household choices (implicitly through their choice of models with and without advanced energy-saving technologies); alternatively, e_A and e_R may be set by the government, if energy intensity standards are binding.⁵

In (1a), CO_2 is carbon dioxide emissions; Z_A is an index of externalities related to automobile use including local pollution, congestion, and accidents; Z_E is local pollution from electricity generation. Here we have omitted externalities from oil dependence because they are difficult to define, let alone quantify—including them would be equivalent to attaching a higher value to CO_2 reductions from the transport sector (this issue is discussed further below). Finally, I is an aggregate of industrial consumer products, while Y is an aggregate of non-industrial consumer goods and services that do not use electricity. The former sector captures CO_2 emissions outside of the power and (light-duty) transport sectors, while the latter represents “clean” consumption.

the standard. In contrast in the power sector standards are often set separately for different models within a product class. If, for a particular model, the standard is exceeded, these models are effectively in the non-regulated sector.

⁴ m_i and S_i enter v_i separately, rather than as a product, to avoid the corner solution where only one good of type i is purchased in the entire economy.

⁵ Historically, standards for autos have been defined in terms of fuel economy rather than fuel intensity. However, they are now integrated with CO_2 (and hence energy) standards per mile.

All variables are economy-wide aggregates, expressed in per capita terms (variables are therefore continuous even though the quantity of durables is discrete at the individual level). A bar denotes a variable perceived as exogenous by individuals. $u(\cdot)$, overall utility, is increasing and quasi-concave in its first five arguments and declining in the last three, while $v_i(\cdot)$ is increasing and quasi-concave in its arguments.

(ii) *Perceived energy costs.* The (actual) lifetime energy cost for durable good i , denoted L_i , is

$$(2) \quad L_i = (q_E + t_E)m_i e_i, \quad i = R, N, \quad L_A = (q_G + t_G)m_A e_A$$

where discounting over the lifecycle is implicit. q_E and q_G are the producer prices of electricity and gasoline respectively, while t_E and t_G are specific taxes on these goods (residential electricity use is currently taxed at the state level while gasoline is taxed at both federal and state levels). Lifetime costs equal product use, times energy consumption per unit of use, times the tax-inclusive consumer price.

The lifetime cost, as *perceived* by agents when the good is purchased, is $(1-\rho_i)L_i$, where $0 \leq \rho_i \leq 1$ reflects the extent to which agents misperceive, or otherwise fail to internalize, future energy costs relative to actual costs. Such undervaluation could result from misperceptions over future energy efficiency, limitations on their cognitive ability to absorb and process information on energy efficiency, or systematic errors in forecasting energy prices or use of energy durables. Implicitly, government programs, such as required fuel economy stickers on salesroom cars, or certified labeling of appliance efficiency through EnergyStar, imply a lower value of ρ_i .

(iii) *Externalities.* Externalities are defined by:

$$(3a) \quad CO_2 = z_{CO_2}^G G + z_{CO_2}^E E + z_{CO_2}^I I, \quad Z_A = z_A m_A S_A, \quad Z_E = z_E E$$

$$(3b) \quad G = e_A m_A S_A, \quad E = E_R + E_N, \quad E_i = e_i m_i S_i, \quad i \neq G$$

In (3b), G is gasoline consumption (the fuel consumption rate times miles per vehicle times the vehicle stock), similarly E_i is electricity use from product i , and E is total electricity use. In (3a), $z_{CO_2}^G$, $z_{CO_2}^E$ and $z_{CO_2}^I$ denote the CO₂ intensity of gasoline, electricity, and industrial production respectively. $z_{CO_2}^G$ and $z_{CO_2}^I$ are given while $z_{CO_2}^E$ is chosen by firms, implicitly through their chosen mix of power generation fuels. z_A is an index of congestion, accident, and local pollution

externalities per mile of automobile travel; local emissions vary with mileage rather than fuel use given that all vehicles must satisfy the same emissions per mile standards regardless of their fuel economy, which decouples emissions from fuel economy (Parry and Small 2005). z_E is an index of local emissions that vary in proportion to power generation (this includes NO_X and mercury, but not SO₂ which is fixed by a cap).

(iv) *Production*. All firms are competitive and produce under constant returns; thus, producer prices equal unit production costs. For our purposes, this assumption seems reasonable for automobiles.⁶ For the power sector, we shall relax this assumption in the sensitivity analysis.

Product and energy prices are determined by:

$$(4a) \quad p_i = C_i(e_i), \quad p_I = \bar{p}_I, \quad p_Y = \bar{p}_Y$$

$$(4b) \quad q_G = \bar{q}_G + t_{CO_2} z_{CO_2}^G$$

$$(4c) \quad q_E = C_E(z_{CO_2}^E) + t_{CO_2} z_{CO_2}^E$$

$$(4d) \quad C'_E(z_{CO_2}^E) = t_{CO_2}$$

where t_{CO_2} is a uniform, economy-wide “price” on CO₂ emissions, assumed not to exceed its Pigouvian level. For now this represents an emissions tax, but later we also consider cap-and-trade systems.

In (4a), p_i is the consumer price and $C_i(\cdot)$ the unit production cost, for durable good i , respectively. $C_i(\cdot)$ is increasing with respect to reductions in e_i , reflecting the incorporation of (costly) energy-saving technologies into the product. \bar{p}_I and \bar{p}_Y denote the (fixed) unit production costs of the industrial and clean good, respectively. In (4b), the producer price of gasoline equals the (fixed) unit production cost \bar{q}_G plus the pass through of the CO₂ price. In (4c), $C_E(\cdot)$ is the unit production cost for power generation, which is increasing and convex with respect to reductions in $z_{CO_2}^E$, reflecting costs of substituting coal with cleaner fuels (or possibly, down the road, installation of emissions capture technologies). The producer price of electricity

⁶ Although in practice there are significant differences between the price of new autos and their unit production cost, this appears to make little quantitative difference to the overall efficiency costs of fuel economy regulations and fuel taxes (e.g., Austin and Dinan 2005).

equals this cost plus the pass through of the CO₂ price. In (4d) we assume that power companies abate CO₂ emissions until the incremental cost equals the (avoided) tax payment.

Firms play a passive role, meeting household demand for products, fuel, electricity, and energy efficiency (if it is not fixed by regulation).

(v) *Government.* The government sets maximum energy efficiency standards for automobiles, \bar{e}_A and regulated electricity durables, \bar{e}_R . We also consider a policy combination involving these standards and a emissions standard imposed on the power sector, $z_{CO_2}^E$.

The government budget constraint, equating spending and revenue from gasoline, electricity, and emissions pricing, is:

$$(5) \quad GOV = t_G G + t_E E + t_{CO_2} CO_2$$

where GOV is a lump-sum government transfer to households.

(vi) *Household optimization.* Households optimize in two steps. First, they make upfront choices over product purchases and energy efficiency, based on perceived lifecycle costs, planned use of durables and consumption goods, subject to a perceived, fixed-income budget constraint. Second, during the course of the period, they may re-optimize over product usage if energy costs differ from initial perceptions.⁷ As shown in Appendix A, this optimization implies the private benefit from one additional durable good equals its price plus perceived lifetime energy cost; the private benefit from incremental usage of the durable good equals its (tax-inclusive) energy cost; and energy intensity is reduced until the resulting increase in cost of the durable equals the marginal saving in perceived lifetime energy costs less the value of any reduction in other product attributes. Undervaluation of lifetime energy costs therefore leads to excessive energy intensity and excessive purchases of energy durables. However, this is reversed to the extent that binding energy efficiency standards affect the first and third conditions, through driving up prices of energy durables (net of reductions in lifetime costs) and forcing energy intensity below the point at which private marginal costs and benefits are equated.

⁷ This is reasonable because vehicle or appliance usage is an ongoing decision, unlike the one-off consumer durable purchase decision, which requires forecasting energy use and prices over a long period of time.

All demands are taken to be constant elasticity functions of the relevant own-price—product prices plus perceived lifetime energy costs for durables, and energy prices for product usage and energy intensity (see Appendix A). In addition, we make the approximation that the demand for travel, industrial goods, and regulated and unregulated electricity durables are independent in demand; this rules out, for example, the possibility that reduced emissions from sector-specific policies in the transport sector are partly offset by extra emissions in the industrial and power sectors. We believe this approximation is reasonable.⁸ From the demand functions we can decompose the following relations (Appendix A):

$$(6) \quad \eta_G^{m_G} + \eta_G^{S_G} + \eta_G^{e_G} = \eta_G, \quad \eta_E^{m_i} + \eta_E^{S_i} + \eta_E^{e_i} = \eta_{E_i}, \quad i \neq A$$

$\eta_G^{m_A}$, $\eta_G^{S_A}$ and $\eta_G^{e_A}$ are the elasticity of miles/vehicle, vehicle demand, and gasoline intensity with respect to gasoline prices, while the sum of these elasticities η_G is the overall gasoline price elasticity. $\eta_E^{m_i}$, $\eta_E^{S_i}$ and $\eta_E^{e_i}$ are the elasticity of usage/product of electricity durable i , the demand for that good, and its electricity intensity, with respect to electricity prices, while η_{E_i} is the elasticity of electricity consumption by good i with respect to the electricity price. (All elasticities are negative.)

B. Welfare Formulas

We now discuss formulas—derived in Appendix A—for the marginal welfare effects of policy-induced reductions in gasoline, electricity, and CO₂ emissions. We focus on marginal costs (denoted MC), defined net of efficiency benefits from correcting market failures—thus, policies improve welfare up to the point where MC is zero. Marginal costs are obtained by totally differentiating the household’s indirect utility function with respect to a policy variable, accounting for changes in pollution, other externalities, and (balanced budget) government transfers, and dividing by the induced change in gasoline, electricity, or CO₂. We also briefly discuss how results change when CO₂ is fixed by a cap, when efficiency standards should complement pricing instruments, the relation between information dissemination programs and

⁸ For example in Small (2009) the impacts of transportation policies on the power sector are negligible. Down the road, the power and transportation sectors may become more integrated if policy induces a substantial market penetration of plug-in electric vehicles and there is greater competition between the two sectors for biomass-based fuels. Moreover, for the most part, electricity durables that are unregulated (e.g., TV sets) are not close substitutes for regulated electricity durables (e.g., refrigerators, buildings).

efficiency standards, and a policy that combines efficiency standards with emission rate standards.

(i) *Reducing gasoline use.*

Gasoline tax. The marginal cost of a tax-induced reduction in gasoline, expressed per gallon, can be decomposed as follows:

$$(7a) \quad MC_G^{t_G} = t_G - (EXT_{CO_2} - t_{CO_2})z_{CO_2}^A - \frac{EXT_A}{e_A} \cdot \frac{\eta_G^{m_A} + \eta_G^{S_A}}{\eta_G} - \rho_A \cdot (q_G + t_G) \cdot \frac{\eta_G^{e_A} + \eta_G^{S_A}}{\eta_G}$$

where

$$(7b) \quad t_G = (q_G^0 + t_G^0)(1 - \Delta\hat{G})^{1/\eta_G} - q_G^0, \quad \Delta\hat{G} = \frac{G^0 - G}{G^0}$$

$$(7c) \quad EXT_{CO_2} = -u_{z_{CO_2}} / \lambda, \quad EXT_A = -z_A \cdot u_{z_A} / \lambda$$

$$(7d) \quad \eta_G^{e_A} = 0 \text{ if } \bar{e}_A \text{ is binding}$$

where $\Delta\hat{G}$ denotes the proportionate reduction in gasoline (and similarly for other variables with $\hat{\cdot}$ below) and superscript 0 denotes an initial value prior to policy change. As indicated in (7c), EXT_{CO_2} is the (monetized) disutility, or external cost, per additional unit of CO₂ emissions, while EXT_A is the external cost from congestion, accidents, and local pollution, per extra car mile. We assume EXT_{CO_2} and EXT_A are constant (which is reasonable over the range of fuel reductions considered below).

The first component of the marginal cost in (7a) is the prevailing fuel tax rate or wedge between forgone consumer benefits and savings in supply costs, per gallon reduction in gasoline. In (7b) the tax rate rises with respect to the proportionate reduction in gasoline. Thus, this first component determines the slope of the marginal cost as well as contributing t_G^0 to its intercept, given pre-existing gasoline taxes. All other components in (7a) serve to shift down the marginal cost curve and reduce its intercept.

The second component nets out the marginal external benefit from reducing CO₂ emissions per gallon, less any amount of this externality internalized through a CO₂ tax.

The third component nets out the marginal external benefit from reduced auto mileage. It equals EXT_A , divided by e_A to express in costs per gallon, where e_A falls with higher taxes as

manufacturers incorporate fuel-saving technologies into vehicles. In addition, this component is multiplied by the fraction of the gasoline demand elasticity that is due to reduced overall mileage (through reduced intensity of vehicle use and reduced demand for vehicles) as opposed to improved fuel economy (see also Parry and Small 2005).

The final component nets out the potential welfare gain from offsetting misperceptions market failures. It equals the non-internalized fraction of fuel economy benefits, times the value per gallon of gasoline savings, times the fraction of the gasoline reduction that comes from improved fuel economy, and also reduced vehicle purchases (recall that vehicle demand is excessive when $\rho_A < 1$). Thus, different assumptions about the share of the incremental gasoline reduction that comes from improved fuel economy, as opposed to reduced mileage per vehicle, will alter the relative magnitude of the last two cost components, but in opposite directions.

Finally, from (7d) pre-existing and binding fuel economy standards alter the tax-induced welfare cost indirectly by eliminating the reduction in fuel intensity. This reduces (greatly) the last cost component. However, it also implies that mileage now falls in proportion to gasoline use, which (greatly) *increases* mileage-related externality benefits per gallon reduction in gasoline. As discussed in Small (2009), the assumption that $\eta_G^{eA} = 0$ is somewhat extreme in practice, hence our analysis with and without binding standards provides bounding cases.⁹

Energy efficiency standard. The marginal cost from tightening a (binding) fuel per mile standard is (Appendix A)

$$(8a) \quad MC_G^{eA} = \delta_G - (EXT_{CO_2} - t_{CO_2})z_{CO_2}^A + \frac{EXT_A}{\bar{e}_A} \cdot \frac{r_A}{1-r_A} - \rho_A \cdot (q_G + t_G) \cdot \frac{1 + \eta_{eG}^{S_A}}{1-r_A}$$

$$(8b) \quad \delta_G = (q_G^0 + t_G)(1 - \Delta \hat{G})^{\frac{1}{\eta_G^{eA}(1+\eta_G^{m_A})}} - q_G^0$$

$$(8c) \quad r_A = -\frac{e_A}{m_A S_A} \cdot \frac{d(m_A S_A)}{d\bar{e}_A} \equiv -\eta_G^{m_A} + \eta_{eG}^{S_A}$$

where $\eta_{eG}^{S_A}$ is the elasticity of vehicle demand with respect to changes in fuel intensity. r_A denotes the rebound effect, that is, the fraction of the initial fuel savings from an incremental reduction in fuel intensity ($m_A S_A$) that is offset by the increase in mileage in response to lower fuel costs per

⁹ For example, higher fuel taxes may induce a demand shift from light-trucks to cars which raises fleet wide fuel economy because cars are subject to a stricter standard (differential standards are not captured by our model).

mile ($-e_A \cdot d(m_A S_A) / d\bar{e}_A$). For a given vehicle stock, the rebound effect is equivalent to $-\eta_G^{m_A}$ because a proportionate reduction in fuel consumption, and in fuel prices, have equivalent effects on per mile fuel costs. More generally, if the vehicle stock falls in response to tighter regulation, then $r_A < -\eta_G^{m_A}$.

δ_G is the shadow price on gasoline. As shown in Appendix A, it corresponds to the gap between the increase in vehicle costs, and possible loss of vehicle attributes, net of the actual savings in lifetime fuel costs, expressed per gallon of fuel savings. Its initial value (when $\hat{G} = 0$) is the pre-existing fuel tax (as the tax distorts equally all margins of behavior affecting fuel consumption). However, this shadow cost rises more rapidly with respect to \hat{G} than the gasoline tax does in (7b), because the policy places the entire burden of fuel savings on improved efficiency and does not exploit savings from reduced mileage. In other words $MC_G^{e_A}$ is more steeply sloped than $MC_G^{t_G}$. In fact, due to the rebound effect, an even larger improvement in fuel economy is required to achieve a given \hat{G} (i.e., the rebound effect increases the rate at which δ_G rises).

The second component in (8a), reflecting net CO₂ benefits per gallon, is the same as in (7a). However the third component in (8a) is a positive (rather than negative) cost because mileage-related externalities increase due to the rebound effect—thus, this component shifts up the marginal cost curve. On the other hand, to the extent that lifecycle costs are not internalized, the last component is a *larger* gain than under the tax. This is because *all*, rather than a fraction, of the gasoline reduction comes from improved fuel economy. These gains are magnified (moderately) to the extent that the fuel economy increase must be higher to compensate for the rebound effect and dampened (slightly) to the extent that higher standards reduce vehicle demand.

(ii) *Reducing electricity use.* The marginal cost of reducing electricity through higher electricity taxes, expressed per kWh, is given by:

$$(9a) \quad MC_E^{t_E} = t_E - (EXT_{CO_2} - t_{CO_2}) z_{CO_2}^E - \sum_{i=R,U} EXT_E \cdot \frac{\eta_E^i}{\eta_E} - \sum_{i=R,U} \rho_i \cdot (q_E + t_E) \cdot \frac{\eta_E^{e_i} + \eta_E^{s_i}}{\eta_E}$$

where

$$(9b) \quad t_E = (q_E^0 + t_E^0)(1 - \Delta \hat{E})^{1/\eta_E} - q_E^0$$

$$(9c) \quad EXT_E = -z_E \cdot u_{z_E} / \lambda$$

$$(9d) \quad \frac{de_R}{dt_E} = 0 \text{ if } \bar{e}_R \text{ is binding}$$

EXT_E is the external cost from non-CO₂ pollution, per extra kWh (assumed constant).

The components of (9a) are essentially analogous to those for the gasoline tax in (7a), except that terms reflecting the contribution of non-CO₂ externalities, and non-internalized lifecycle costs, are summed across the two electricity durables, and other externalities vary with all changes in energy use rather than just those from changes in product use.

The marginal cost of the efficiency standard ($MC_E^{e_R}$), applied to the regulated durable, and its associated shadow price, are almost analogous to those for the auto efficiency standard in (8a and b)—see Appendix A for the formula. The only difference is that EXT_E varies in proportion (rather than less than in proportion) to changes in energy use, and cost components apply to the covered electricity durables only.

(iii) *Reducing (nationwide) CO₂ emissions.* The marginal costs of energy taxes and efficiency standards are easily expressed in costs per ton of (economy-wide) CO₂ reduced, by dividing the above expressions by CO₂ per gallon, or CO₂ per kWh of electricity, as follows:

$$(10) \quad MC_{CO_2}^{t_G} = \frac{MC_G^{t_G}}{z_{CO_2}^A}, \quad MC_{CO_2}^{e_G} = \frac{MC_G^{e_G}}{z_{CO_2}^A}, \quad MC_{CO_2}^{t_E} = \frac{MC_E^{t_E}}{z_{CO_2}^E}, \quad MC_{CO_2}^{e_R} = \frac{MC_E^{e_R}}{z_{CO_2}^E}$$

The marginal cost of the CO₂ emissions tax, denoted $MC_{CO_2}^{t_{CO_2}}$, can be expressed (see Appendix A):

$$(11a) \quad MC_{CO_2}^{t_{CO_2}} = \alpha_{CO_2}^G \cdot MW_{CO_2}^{t_G} + \alpha_{CO_2}^E \cdot MC_{CO_2}^{t_E} + (\alpha_{CO_2}^{z^E} + \alpha_{CO_2}^I) \cdot t_{CO_2}$$

$$(11b) \quad \alpha_{CO_2}^G = (z_G^{CO_2})^2 \frac{dG/dt_G}{dCO_2/dt_{CO_2}}, \quad \alpha_{CO_2}^E = (z_E^{CO_2})^2 \frac{dE/dt_E}{dCO_2/dt_{CO_2}},$$

$$\alpha_{CO_2}^{z^E} = E \frac{dz_{CO_2}^E/dt_{CO_2}}{dCO_2/dt_{CO_2}}, \quad \alpha_{CO_2}^I = \frac{d(z_{CO_2}^I \cdot I)/dt_{CO_2}}{dCO_2/dt_{CO_2}},$$

$$\alpha_{CO_2}^G + \alpha_{CO_2}^E + \alpha_{CO_2}^{z^E} + \alpha_{CO_2}^I = 1$$

$\alpha_{CO_2}^G$, $\alpha_{CO_2}^E$, $\alpha_{CO_2}^z$, and $\alpha_{CO_2}^I$ are the share of the marginal, tax-induced reduction in nationwide CO₂ emissions that comes from reduced gasoline use, reduced electricity consumption, reductions in CO₂ per unit of electricity, and reductions from the industrial sector, respectively. The marginal cost of reducing a ton of CO₂ through fuel switching in the power sector, or from reducing industrial sources, is simply the CO₂ tax rate, as there are no broader market failures relevant to these two margins of behavior.

(iv) *Should efficiency standards supplement energy taxes?* For any given level of (prevailing or optimal) energy or emissions taxation, an efficiency standard that further reduces gasoline by amount \hat{G} , or electricity by \hat{E} , is fully efficient if the marginal cost curves, MC_G^{eG} and MC_E^{eR} , have negative intercepts, and are exactly zero, when evaluated at these reductions and prior tax levels. From these conditions, it is straightforward to obtain “iso-market failure” curves that indicate combinations of CO₂ (or energy security) externalities and misperceptions failures required to justify efficiency standards of different stringencies.

(v) *The distinction between cap-and-trade versus emissions taxes.* We show, in Appendix A, that the marginal cost formulas MC_G^{tG} , MC_G^{eG} , MC_E^{tE} , and MC_E^{eR} change in one regard when CO₂ emissions are fixed by a binding cap-and-trade system rather than taxed. The terms in $EXT_{CO_2} - t_{CO_2}$ simply drop out, because any reduction in CO₂ emissions in one sector is exactly offset by an increase in emissions in the other sector.

(vi) *Potential value of energy information programs.* As shown in Appendix A, the marginal cost of information programs, per unit reduction in gasoline, electricity, or CO₂ emissions, is analogous to the marginal cost of the relevant energy efficiency standards (hence we do not illustrate separate results for information programs). Information programs increase energy efficiency, just like standards, though this is achieved indirectly through raising the perceived private benefits from higher efficiency. The effects of these programs may be limited if ρ is already close to zero. However, information programs avoid the risk of excessively increasing energy efficiency, in the sense of pushing the incremental costs of energy efficiency improvements beyond the point at which they are justified by discounted energy savings.

(vii) *To what extent can a broad combination of standards mimic CO2 pricing?* <to be completed>

3. Parameter Values

Here we comment briefly on data assumptions for our baseline simulations, as summarized in Table 1, which is representative of year 2008 or thereabouts. Alternative parameter assumptions with possible significance for our results are discussed later. Appendix B provides additional documentation of data sources and estimation procedures. Parameters for the transportation sector are taken (and updated where appropriate) from prior literature, while for the power sector we construct estimates by grouping and aggregating products in regulated and unregulated sectors.

A. Basic Transportation Data

We assume the average fuel economy of the (on-road) vehicle fleet is 23 miles per gallon (BTS 2009, Table 4.23). This implies fuel intensity is 43.5 gallons per 1000 miles. From Parry and Small (2005), we take the combined federal and (average) state gasoline tax to be \$0.40/gal. And, based on the average price between 2003 and 2008, and we assume a pre-tax gasoline price of \$2.15/gal.¹⁰ Initial fuel use is taken to be \$135 billion gallons (BTS 2009, Table <>).

Based on the widely cited work by Small and Van Dender (2006), we assume the (long-run) own-price elasticity of gasoline is -0.4, with half of the response due to changes in fuel economy, and a quarter each from reduced miles per vehicle and reduced vehicle demand. Thus, the gasoline demand elasticity is -0.2 in the presence of binding fuel economy standards. We further assume the mileage response is split equally between changes in the vehicle stock and miles per vehicle—this implies a rebound effect of 10 percent (for a given vehicle stock) which again is approximately consistent with Small and Van Dender (2006).

B. Basic Electricity Data

¹⁰ See http://tonto.eia.doe.gov/dnav/pet/hist/mg_tco_usA.htm.

Ours is the first attempt to divide up electricity-using goods into those that are and are not subject to efficiency standards. The major groups in the former category include most major appliances, lighting and heating and cooling equipment, while other electricity uses, like smaller appliances and audio and entertainment equipment, are grouped into the latter. We assume that the standards are binding for those products subject to them. However, they are minimum standards, and therefore they are not binding for all produced goods. According to our assessment, about 60 percent of nationwide electricity consumption (in the residential, industrial and commercial sectors) are in categories that are, or are potentially, subject to efficiency standards.

The average electricity price in 2007 is 10.7 cents/kWh, which is inclusive of state taxes that average to 0.4 cents/kWh (EIA 2009a) over all end users. Total electricity consumption was about 4,176 million MWh in 2007 (EIA 2009b). There are relatively few recent estimates of the electricity elasticity of demand in the United States (for a survey, see Sanstad and McMahon, 2008). We use the long-run own-price elasticity of demand of -0.4 estimated by Paul et al. (2008). We assume that the short-run estimate of the household demand elasticity from Paul et al. (2008), -0.13, represents the share of the long run elasticity attributable to reduced intensity of durable use (although in the long run as replacement durables are purchased this implied share would be lower). We further assume increased energy efficiency accounts for half of the elasticity and reduced durable demand 17 percent.

C. Externalities

A gallon of gasoline combustion produces 0.0088 tons of CO₂. Given the prevailing fuel mix, the average emissions intensity of power generation is 0.0006 tons of CO₂ per kWh. We assume that efficiency standards reduce emissions at this average rate. However, efficiency standards may more likely reduce generation from marginal sources of production which often use natural gas. The average emissions intensity from natural gas production in 2007 was 0.00045 tons of CO₂ per kWh, although for the less-efficient peaking units the rate is higher.

We consider a benchmark value of \$20/ton for CO₂ damages (based on a recent inter-agency recommendation), thus CO₂ damages amount to 18 cents/gallon and 1.2 cents/kWh. Given that the treatment of extreme catastrophic risks and the intergenerational discount rate are

so contentious, we adopt a range of \$0-\$100/ton for CO₂ damages in the sensitivity analysis (see Appendix B for more discussion).

As regards energy security externalities from dependence on gasoline, a review by Brown and Huntington (2009) put the external costs due to macroeconomic disruptions from world oil price volatility at equivalent to about 10 cents per gallon. However, perhaps more important, dependence on an oil market under the influence of hostile regimes might impose constraints on the ability of the United States to freely pursue foreign policy goals. Given that these broader geo-political costs are difficult to define, let alone quantify, we simply infer the implicit values for energy security benefits needed to justify different efficiency standards for automobiles.

Based on Small and Verhoef (2007), we assume local pollution damages from autos of \$0.01/mile. For marginal congestion costs, we update Parry and Small (2005)'s figure by 30 percent to \$0.045/mile to account for growth in the value of travel time and congestion between 2000 and 2008 (based on CEA 2009, Table B 47 and Schrank and Lomax 2009, Table 4). For marginal accident externalities, we increase Parry and Small (2005)'s estimate by 16 percent to \$0.035/mile, based on the value of a statistical life now assumed by the US Department of Transportation (\$5.8 million). Thus other externalities amount to \$0.09/mile for autos.

For electricity generation we account for local pollution externalities, but not for energy security nor externalities associated with the intensity of consumption. For local pollution we focus on the damages from direct particulate matter emissions less than 2.5 micrograms (PM_{2.5}) as they are associated with increased mortality, and thus yield the highest damages per kWh of the local air pollutants associated with electricity production. The average PM_{2.5} emissions intensity from the electricity sector is 3.84×10^{-5} pounds/kWh. Using an average PM_{2.5} cost per ton from Fann et al. 2009, the average cost is 1.3 cents/kWh, although there is significant heterogeneity in this cost across the United States (see Appendix B). The majority of direct PM_{2.5} is from baseload coal-fired generation, so using this value likely overstates the reduced PM_{2.5} that would arise from energy efficiency standards. The major sources of indirect PM_{2.5}, sulfur and nitrogen oxides, are controlled by cap-and-trade programs. The allowance prices for these programs are currently quite low given legal uncertainties surrounding them.

There is no analogous energy security externality as both the total and marginal sources of generating fuel are produced domestically. There are no similar accident or congestion externalities as the amount of one's use of electricity does not impose a safety risk on others, nor

limit the service of energy supply to another customer. That said, there is congestion in the delivery of electricity given the limited scale and access rules for the transmission grid. A more complete accounting of the externalities associated with electricity use should perhaps account for transmission congestion.

D. Misperceptions

Appendix B briefly reviews empirical literature on implicit discount rates and possible explanations of why they exceed market interest rates. We consider two bounding cases, one in which there is no misperceptions market failure ($\rho_i = 0$), that is, differences between implicit and social discount rates are entirely explained by hidden costs, and another where the entire difference is due to misperceptions over the benefits of energy efficiency. In the latter case, based on the common assumption that consumers only consider fuel saving benefits from higher efficiency over the first three years of a vehicle life, $\rho_A = 0.65$. There are no recent empirical estimates of the level of misperceptions that consumers have for electricity durables in general, but older analyses estimate implicit discount rates for energy efficiency from 20 to 800 percent (Hausman, 1979, Dubin and McFadden, 1984; Gately, 1980; Ruderman et al., 1987). Few studies found implicit rates at the higher end of this range, but rates around 20-25 percent were common. Using a 25% discount rate, ρ_A would be .45 if the average product lifespan was about 12 years. As this is a bounding exercise, we assume that consumers only consider the benefits of increased efficiency of electricity durables over the first three years of use following the observation in vehicle markets that consumers do the same. Using an average product-lifespan of 12 years for electricity-consuming durables this implies $\rho_A = 0.62$ (which is equivalent to assuming a 50 percent discount rate).

4. Quantitative Results

This section first discusses the welfare effects of energy efficiency standards and energy taxes, with and without misperceptions failures. Conditions under which efficiency standards of differing stringencies are warranted are then identified. We then compare the marginal costs of reducing economy-wide CO₂ emissions under all policies, including CO₂ taxes and emissions standards for power generation, and a combination of regulatory approaches. Finally, our results are related to prior literature.

A. Welfare Comparison of Efficiency Standards and Energy Taxes

(i) Transportation sector

Figure 1(a) indicates the marginal cost of reducing gasoline use under fuel taxes and efficiency standards with no misperceptions failure. The marginal cost curve under the standard is about twice as steep as the marginal cost under the tax, given that half of the fuel reduction under the tax comes from reduced vehicle miles and half from fuel economy improvements. This assumes efficiency standards do not bind under the tax, which is relaxed below.

For both policies, the pre-existing gasoline tax contributes 40 cents/gallon to the intercept of the marginal cost curves. However, this is partly offset by CO₂ externality benefits of 18 cents per gallon.

Moreover, under the gasoline tax there is a substantial gain of \$1.04/gallon due to the reduction in mileage-related externalities. Overall, the marginal cost curve under the gasoline tax therefore has an intercept of 81 cents/gallon. Furthermore, the marginal cost is negative up to a fuel reduction of 11.0 percent—this corresponds to the fuel reduction under the optimal gasoline tax, which is \$1.26/gallon.

In contrast, mileage increases under the fuel economy standard, and the resulting increase in congestion and other externalities raises the overall intercept of the marginal cost under this policy by 21 cents to 43 cents/gallon (i.e., climate externality benefits are neutralized by the rebound effect). Thus (at least under our benchmark assumptions) a misperceptions failure is required to justify fuel economy standards. Moreover, this failure must be large enough to shift the marginal cost curve down so it has a negative intercept, given current fuel taxes. And if there were no constraints on fuel taxes, the downward shift must be large enough to make the intercept *below* the intercept of the marginal cost under fuel taxes (given that it has a steeper slope).

Figure 1(b) illustrates the bounding case that allows for the possibility of such a misperceptions market failure.

The marginal cost under the gasoline tax is shifted down substantially further—now the intercept is -\$1.64 per gallon, the optimal fuel tax (in the absence of standards) rises to \$3.08/gallon, and the fuel reduction under the optimized tax is 25.0 percent. However, the downward shift in the marginal cost curve is much larger under the fuel economy standard as all, rather than a fraction, of the reduction in fuel use comes from improved fuel economy. The

intercept for this curve is now \$1.65 per gallon, essentially the same as for marginal costs under the fuel tax. In fact, if fuel taxes are fixed at current levels, a standard that cut fuel use by 7.5 percent would be optimal.

However, if there are no constraints on fuel taxes, fuel economy standards would not be warranted as (aside from the first increment) the marginal cost for the tax is always lower than for the standard. Importantly, this result would apply even under much larger damage assumptions for CO₂ (or oil dependence) as these assumptions shift both marginal cost curves by the same amount.

(ii) Power sector

Figure 2(a) shows the marginal cost of reducing electricity use under the efficiency standard and electricity tax with no misperceptions. The slope of the marginal cost curve under the efficiency standard is about 2.5 times that under the electricity tax. This again reflects the failure of the standard to exploit reductions in product demand. However in addition, unlike the electricity tax, the standard fails to exploit electricity savings (through reduced product use and energy intensity) in the unregulated sector.

Again, accounting for prior electricity taxes shifts up both curves (by 1.1 cents/kWh), but in this case prior taxes are more than offset by the CO₂ and local pollution benefits from reduced electricity use (1.0 and 1.3 cents/kWh respectively). And there is no analog to the mileage-related externalities. Thus, overall both curves have the same intercept, -1.3 cents/kWh, and are both potentially welfare improving, even with no misperceptions failures. However, potential welfare gains are relatively modest, as indicated by the optimal electricity reductions—5.0 percent under the electricity tax and only 1.7 percent under the standard.

Figure 2(b) allows for the misperceptions market failure, again taking the bounding case. For the same reason as before (namely all of the behavioral response is from efficiency improvements) the downward shift in the marginal cost is much greater for the efficiency standard—the intercept for this curve is -9.5 cents/kWh compared with -4.5 cents for the electricity tax. As a result, even if electricity taxes could be optimized, efficiency standards are still potentially welfare improving.

B. Necessary Conditions to Warrant Different Levels of Efficiency Standards <to be completed>

C. Role of Efficiency Standards in CO₂ Mitigation<to be completed>

D. Relation to Other Studies <to be completed>

5. Conclusion <to be completed>

We emphasize a number of caveats to the analysis.

First, the model assumes the full turnover of energy capital within a single period. A dynamic model that distinguishes capital of different vintages could explore the inefficiencies from new product standards resulting from the uneven treatment of new and pre-existing capital. However, such inefficiencies are transitory, and a dynamic formulation, requiring numerical simulation, would result in considerable loss of transparency.

Second, the model assumes homogenous firms and goods within a product classification. Relaxing these assumptions would allow us to examine inefficiencies from differences in marginal compliance costs across firm and product types. However, at least in the context of fuel economy standards for automobiles, the efficiency losses stemming from variation in marginal compliance costs across firms seem to be relatively modest program (Austin and Dinan 2005, other findings?). Moreover, the issue would become moot if policymakers were to allow credit-trading provisions.

Third, the model also assumes marginal-cost pricing. In practice, prices deviate from marginal costs because of cost-of-service regulation of power generation in many states and limited use of time-of-day pricing. However, it is difficult to make general statements about the economy-wide implications of these deviations (even with regard to their sign let alone magnitude), given that they are highly specific to region and time of day.

Appendix A. Analytical Derivations <to be completed>

Appendix B. Additional Documentation for Parameters

CO₂ Damages

Some studies (e.g., Nordhaus 2008) value CO₂ damages at about \$10/ton, while others value it at about \$80/ton (e.g., Stern 2007). One reason for the different estimates is that—due to long atmospheric residence times and the gradual adjustment of the climate system—today’s emissions have very long range impacts and their discounted damages are therefore highly sensitive to assumed discount rates. Some analysts (e.g., Heal 2009) argue against discounting the utility of future generations on ethical grounds (i.e., to avoid discriminating against people just because they are born in the future), while others (e.g., Nordhaus 2007) view market discounting as essential for meaningful policy analysis (i.e., to avoid highly perverse policy implications in other contexts, like dramatic reductions in current consumption).

The second reason for different CO₂ damage assessments has to do with the treatment of extreme catastrophic risks, such as the possibility of an unstable feedback mechanism in the climate system leading to a truly catastrophic warming destroying the planet as we know it. In particular, it is possible that the marginal damages from CO₂ emissions are arbitrarily large if the probability distribution over future climate damages has “fat tails”, that is, the probability of increasingly catastrophic outcomes falls more slowly than marginal utility rises (with diminished consumption) in those outcomes (Weitzman 2009). Others (e.g., Nordhaus 2009) have critiqued the fat tails hypothesis on the grounds that we can head off a future catastrophic outcome by radical mitigation measures, and possibly geo-engineering, in response to future learning about the seriousness of climate change.

Following an inter-agency agency recommendation (US DOE 2009, pp. 44,947-44,949), we begin with a benchmark value of \$20 per ton and we use a range of \$10-\$100 for sensitivity analysis.

Non-CO₂ external costs from electricity generation

As described in the body text we focus on damages from PM_{2.5} as the key externality associated with electricity generation. Total filterable PM_{2.5} emissions from the electricity sector in 2005 was about 117 thousand short tons (U.S.EPA, 2009) while total electricity generation was about 3.9 billion kWh (EIA, 2009). The average direct PM_{2.5} emissions intensity from the sector is thus about 5.84×10^{-5} pounds/kWh. Fann et al. 2009 report an average cost per ton of PM_{2.5} emissions of about \$460,000 (2007 \$). This yields an approximate cost of direct PM_{2.5} emissions of 1.3 cents/kWh.

Energy efficiency misperceptions

There is a substantial body of evidence, from studies examining consumer purchases of a wide range of domestic appliances and other energy-related investments, indicating that consumers have very high implicit discount rates for energy efficiency.¹¹ While the presence of these high implicit discount

¹¹ Hausman (1979), examining household purchases of room air conditioners, found implicit discount rates of around 20 percent, where these rates vary inversely with the level of household income. Later studies found comparable, and in some instances, much higher rates. Dubin and McFadden (1984), for example, in a study of space heating and water heating investments, also found implicit discount rates around 20 percent. But Gately (1980) found much higher discount rates of 45 to 300 percent in his study of consumer purchases of refrigerators. Likewise, Ruderman et al. (1987) calculated implicit discount rates ranging all the way from 20 to 800 percent on residential purchases of heating and cooling equipment and appliances. Little (1984) and Berkovec et al. (1983) report implicit discount rates of 32 for thermal shell investments and 25 percent for space heating systems, respectively.

rates seems reasonably well established, whether they reflect market failures or hidden costs is much less clear.

Market failure explanations may reflect the basic problem of the costly acquisition and processing of information. Many consumers may not know what the relevant cost savings are. Furthermore, consumers may believe that the prospective cost-savings are exaggerated.¹² On the other hand, high implicit discount rates may instead reflect hidden costs like reductions in other product attributes as a result of higher energy efficiency. Moreover, rational consumers may hold back on what may be largely “irreversible investments” with uncertain returns (Hassett and Metcalf 1993) due to risk aversion or liquidity constraints.

If high implicit discount rates reflect real information problems, consumers are largely unaware of the potential costs savings from more energy-efficient technologies and this corresponds to a positive value for ρ_i . In contrast, if these high rates reflect hidden or other costs, this corresponds to a positive value for $u_{\mu_i} \mu'_i$, which does not enter the welfare formulas as it is an internalized cost. We therefore consider two “extreme” cases meant to cover the range of possibilities, one where the difference between implicit and social discount rates reflects a misperceptions market failure (i.e., $\rho_i > 0$) and another where it is explained entirely by hidden costs (i.e., $\rho_i = 0$).

For automobiles, empirical literature on implicit discount rates is thin.¹³ We follow one scenario explored by NRC (2002) where consumers value fuel economy improvements by considering (undiscounted) fuel savings over the first three years of a vehicle life.¹⁴ Using their assumptions for vehicle life and declining vehicle usage with age, and a social discount rate of 5 percent, this implies $\rho_A = 0.65$ if there are no hidden costs.

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¹² There is, in fact, some evidence to support this claim: Metcalf and Hassett (1995) found, after accounting for all the costs, that the realized return to attic insulation (i.e., 9.7 percent) was well below that promised by engineers and manufacturers.

¹³ One study, by Dreyfus and Viscusi (1995), finds a discount rate of 11-17 percent. However, the average new car loan interest rate was 12.6 percent in their sample, suggesting that car buyers may have been liquidity constrained rather than myopic.

¹⁴ This case is consistent with the Energy Information Administration’s National Energy Modeling System where new auto buyers are assumed to use payback periods of 3-5 years.

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Table 1. Baseline Data
(assumes currently prevailing policies)

	Autos	Electricity Durables	
		Regulated	Non-regulated
Basic data for energy-using products			
Energy intensity, gal./1000 miles, kWh/hour	43.5	0.73	0.48
Initial energy tax, \$/gal., \$/kWh	0.40	0.011	0.011
Initial pre-tax energy price, \$/gal., \$/kWh	2.15	0.096	0.096
Initial quantity of fuel/energy, bn gallons, billion kWh	135	2,506	1,670
Price elasticities (standards non-binding)			
elasticity with respect to own price of energy	-0.40	-0.40	-0.40
fraction of elasticity from:			
reduced usage per product	0.25	0.33	0.33
reduced demand for product	0.25	0.17	0.17
reduced fuel intensity per unit of use	0.50	0.50	0.50
External costs			
CO ₂ emissions intensity, tons/gal., tons/kWh	0.009	0.0005	0.0005
CO ₂ damages, \$/gal., \$/kWh	0.18	0.010	0.010
Other external costs, \$/mile, \$/kWh	0.09	0.013	0.013
Non-internalized fraction of lifecycle energy costs in misperceptions scenario	0.65	0.62	0.62

Source. See text and Appendix B.

Figure 1. Cost Comparison for Fuel Taxes and Efficiency Standards

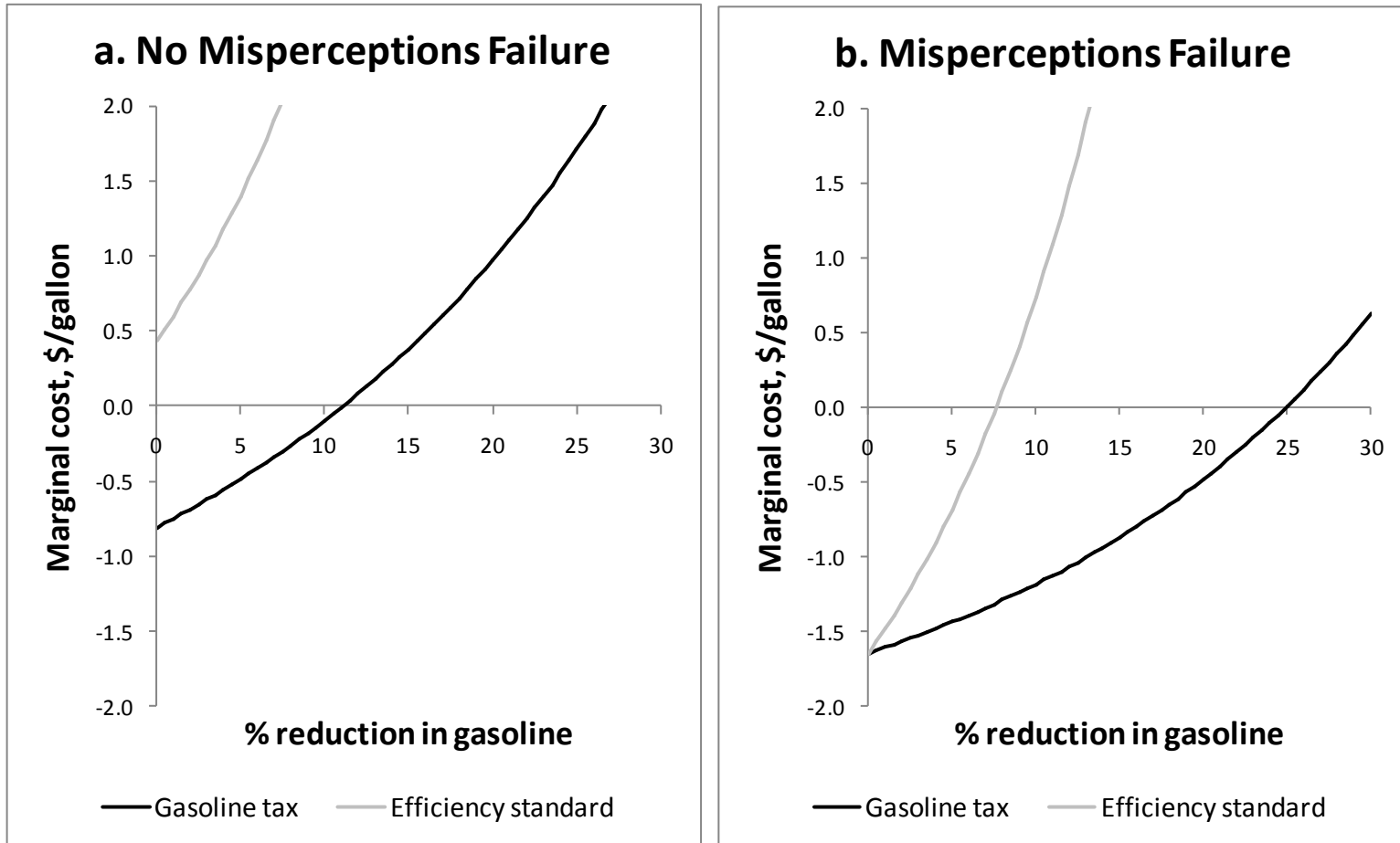


Figure 2. Cost Comparison for Electricity Taxes and Efficiency Standards

