ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

LBNL-4749E

A Framework for Comparative Assessments of Energy Efficiency Policy Measures

Helcio Blum, Barbara Atkinson, and
Alex Lekov

Energy Analysis Department
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

May 2011

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State, and Community Programs, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

DISCLAIMER

LAWRENCE BERKELEY NATIONAL LABORATORY

A Framework for Comparative Assessments of Energy Efficiency Policy Measures

Helcio Blum, Barbara Atkinson, Alex B. Lekov

Energy Efficiency Standards Group

Energy Analysis Department

Environmental Energy Technologies Division

When policy makers propose new policies, there is a need to assess the costs and benefits of the proposed policy measures, to compare them to existing and alternative policies, and to rank them according to their effectiveness. In the case of equipment energy efficiency regulations, comparing the effects of a range of alternative policy measures requires evaluating their effects on consumers' budgets, on national energy consumption and economics, and on the environment. Such an approach should be able to represent in a single framework the particularities of each policy measure and provide comparable results. This report presents an integrated methodological framework to assess prospectively the energy, economic, and environmental impacts of energy efficiency policy measures. The framework builds on the premise that the comparative assessment of energy efficiency policy measures should (a) rely on a common set of primary data and parameters, (b) follow a single functional approach to estimate the energy, economic, and emissions savings resulting from each assessed measure, and (c) present results through a set of comparable indicators. This framework elaborates on models that the U.S. Department of Energy (DOE) has used in support of its rulemakings on mandatory energy efficiency standards. In addition to a rigorous analysis of the impacts of mandatory standards, DOE compares the projected results of alternative policy measures to those projected to be achieved by the standards. The framework extends such an approach to provide a broad, generic methodology, with no geographic or sectoral limitations, that is useful for evaluating any type of equipment energy efficiency market intervention. The report concludes with a demonstration of how to use the framework to compare the impacts estimated for twelve policy measures focusing on increasing the energy efficiency of gas furnaces in the United States.

Contents

1. Introduction

When policy makers propose new policies, there is a need to assess the costs and benefits of the proposed policy measures, to compare them to existing and alternative policies (Bernstein et al, 2005), and to rank them according to their effectiveness. In the case of equipment[1] energy efficiency regulations, policy measures may include such command-and-control initiatives as mandatory energy efficiency standards, as well as market-based mechanisms, such as rebates, tax credits, labeling programs, or government purchases. In the assessment of these policy measures, costs refer to the greater initial end-user price and potentially greater installation, maintenance and repair costs usually associated with more energy-efficient devices, while benefits correspond to all energy-related savings resulting from the use of more efficient equipment. Evaluating the effects of a range of alternative policy measures on consumers' budgets and on the environment requires a comprehensive methodological approach. Such an approach should be able to represent in a single framework the particularities of each policy measure and provide comparable results.

The existing literature on energy efficiency provides methodologies and assessment studies related to market interventions aiming at reducing energy consumption. The methodologies range from general orientation on how to design, implement, and evaluate energy efficiency programs (IEA, 2000; Sebold et al, 2001; Wiel and McMahon, 2005) to specific guidance on assessing the potential impacts of these programs (Kintner-Meyer et al, 2003; Mosenthal and Loiter, 2007; CLASP, 2011a). The assessment studies present the potential for energy savings from a range of policy measures and/or programs.[2] Most of this body of literature, however, either (a) does not provide sufficient details on how to assess the impacts of the interventions or (b) focuses on assessing specific policy measures.

This report presents an integrated methodological framework to assess prospectively the energy, economic, and environmental impacts of energy efficiency policy measures. The framework builds on the premise that the comparative assessment of energy efficiency policy measures should (a) rely on a common set of primary data and parameters, (b) follow a single functional approach to estimate the energy, economic, and emissions savings resulting from each assessed measure, and (c) present results through a set of comparable indicators. This framework elaborates on models that the U.S. Department of Energy (DOE) has used in support of its rulemakings on mandatory energy efficiency standards.[3] In addition to a rigorous analysis of the impacts of mandatory standards, DOE compares the projected results of alternative policy measures to those projected to be achieved by the standards. The framework extends such an approach to provide a broad, generic methodology, with no geographic or sectoral limitations, that is useful for evaluating any type of energy efficiency market intervention.

---

[1] For the sake of simplicity, this paper uses the term *energy efficiency policy measure* to refer to policy measures promoting energy efficiency for *equipment* such as appliances, lighting, and other energy-consuming devices.
[2] See, for example, Rufo and Coito (2002), Itron et al (2006), McNeil, Letschert and Wiel (2006), McNeil, Van Buskirk and Letschert (2006), Ramos et al (2006), Rosenquist et al (2006), GDS (2007), ICF (2007), Eldridge et al (2008), Summit Blue (2008), Granade et al (2009), Global (2010), Itron (2010), Letschert, McNeil and Zhou (2010), Mundaca et al (2010), and KEMA (2011).
[3] The framework elaborates particularly on the *Integrated NIA-RIA* models (US DOE, 2011c; US DOE, 2011d) developed by the Energy Efficiency Standards Group (efficiency.lbl.gov) in the Environmental Energy Technologies Division (eetd.lbl.gov), Lawrence Berkeley National Laboratory (www.lbl.gov).

The report is organized into the following five sections: Section 2 presents the framework with its general procedure and formulation to assess and compare the effects of energy efficiency policy measures; Section 3 describes a range of energy efficiency policy measures and delineates how their specific impacts can be fit to the framework's general calculation procedure; Section 4 describes how to compare individual results from each policy measure assessed; Section 5 provides a simple demonstration of how to apply the framework to assess measures impacting gas furnaces in the U.S.; and Section 6 concludes with the benefits of the framework. Appendices A and B detail methodological issues.

2. Framework Description

When a government agency plans a new energy efficiency policy, the goal is to reduce the overall impacts resulting from the use of energy-consuming devices. Several alternative policy measures can help to achieve such a goal. Each measure may provide different benefits and impose different costs and, therefore, needs to be compared to the others. Comparing a range of policy measures intended to comprise an energy efficiency policy requires – for the sake of comparability – that the analysis of all candidate measures use a common set of input data and express the benefits of the measures through the same results indicators.

The input data typically describe the existing and potential technology from the engineering, operational, economic, and market perspectives. These data, after being analyzed, lead to estimates of the expected results of a policy measure, specifically the changes in market share of devices with different levels of energy efficiency and the resulting energy consumption, consumers' investments and operating costs, and pollutant[4] emissions that are expected to occur within a given timeframe. Depending on the input data, such estimates can be generated for a business-as-usual (*base case*) scenario – a scenario with no changes in the existing policies – or a scenario in which a certain policy measure is implemented (*policy measure case*).

Five indicators can be used to express the benefits of an energy efficiency policy measure, as compared to the base case scenario. These indicators account for energy and resource usage, consumer and social economic values, and emissions to the environment resulting from a new vintage of equipment marketed under the influence of the policy measure. The indicators are: (a) *Total*[5] *Energy Savings* (TES) and *Total Water Savings* (TWS); (b) total *Consumers Net Present Value* (cNPV) and *Social Net Present Value* (sNPV); and (c) *Total Emissions Reduction* (TER). The total savings and total emissions reduction indicators quantify, in physical units, the estimated amount of avoided energy (TES) and water (TWS) use, as well as of avoided emissions (TER), achieved by implementing the policy measure. The cost

[4] This may include greenhouse gas emissions and any other pollutant discharges to the environment.
[5] The framework has no geographic or sectoral constraints. Therefore, totals may refer to any: (a) geographical scope like a state, (sub-national) region, nation, group of nations, or even the world; (b) sectoral scope, from one or more specific economic sectors to a whole economy.

effectiveness indicators reflect the estimated aggregate net monetary benefits enjoyed by consumers (cNPV) and the wider society[6] (sNPV) resulting from the policy measure.

Each of these five indicators can be used by itself to assess comparatively the impacts in one realm of a group of proposed efficiency measures. However, these estimates also can be used to assess required tradeoffs between the energy, economic, and environmental goals of a policy. One typical tradeoff is between efficiency improvements and their corresponding costs. Because more energy-efficient models tend to rely on new technologies which are usually more expensive than the technologies employed in the models that would be purchased by consumers in the base case scenario, a policy measure that bans inefficient models from the market will reduce energy costs to consumers, but it is also likely to impose higher investment costs on them. Hence, when evaluating energy efficiency policy measures, it is necessary to understand and be able to compare all of the expected results of each measure, including the potential tradeoffs among energy, economic, and environmental impacts. In Section 4, we will elaborate on a method for comparing potential tradeoffs.

2.1 Framework Structure

Figure 1 presents the framework's general procedure for assessing the impacts of any energy efficiency policy measure. The blue shaded boxes represent the tasks in which the required equipment-related parameters are developed. The *Engineering Analysis* provides the (unit) annual energy (and sometimes water) consumption and pollutant emissions for each considered energy efficiency design option.[7] The *Cost Analysis* provides, for each energy efficiency design option, the end-user price, installation costs, and lifetime maintenance, repair, and operating costs. (For policy measures that do not provide any financial incentive, results from the *Cost Analysis* for the base case and the policy measure case scenarios will be the same.)

The red shaded boxes correspond to the forecast of annual shipments in the base case and policy measure case scenarios. Each of these forecasts produces a time-series of shipments per energy efficiency design option, within the same timeframe. The difference between the two time-series reflects the extent to which the measure is expected to transform the market by fostering the purchase of more efficient units of the targeted equipment.

The gray shaded boxes refer to the task in which, based on the equipment's engineering and economic parameters and on the shipments forecast, the total consumption of energy (and sometimes water), total

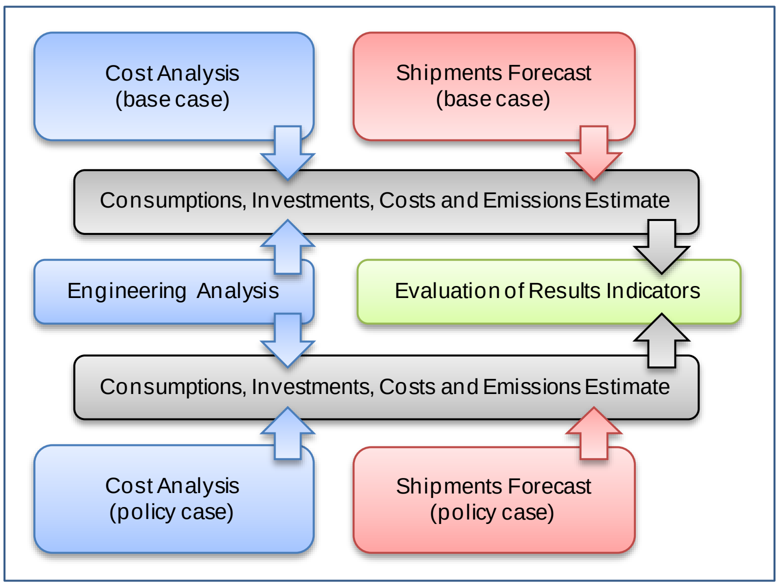
[6] The net benefits for society builds upon the consumers' benefits, removing any financial incentive provided by the policy measure and including the monetized benefits from emissions reduction. They do not account, however, for any industry and government investments and operational costs necessary to support the policy. These costs have been proven negligible when compared to the benefits of some policy measures. For example, a study of the impacts of the U.S. appliance standards program estimated the cumulative (1988 – 2030) net present value of standards (in place or scheduled to take effect) to be about a thousand times greater than the amount of taxpayer funds used to support DOE's residential appliance standards program over the prior 20 years (Meyers, McMahon and Atkinson, 2008).

[7] *Energy efficiency design options* refer to a set of representative technology options with similar consumer utility but different energy performance. This set may include both existing and potential technology options.

consumers' investments and operating costs and total emissions is calculated. The way that consumption, investments, costs, and emissions are accounted for is exactly the same for both the base case and the policy measure case scenarios. The results, however, will vary according to the inputs provided.

Finally, the green shaded box refers to the evaluation of the results indicators that express the impacts of the policy measure being assessed. The impacts are calculated by assessing the differences in consumption, investments, costs, and emissions associated with the policy measure case and the base case scenarios.

Figure 1: General procedure to assess the impacts of energy efficiency policy measures



Calculating these results indicators for a specific energy efficiency policy measure requires:

i. estimating the effects that the measure will have on consumer purchases, or how the shipments forecast will change for the policy case;

ii. accounting for energy and resource consumption, consumers' costs, and (direct and indirect) emissions resulting from the measure; and

iii. calculating the differences between the results from (ii) and the corresponding estimates for the base case scenario.

An energy efficiency policy measure will affect markets by changing the market penetration of the various energy efficiency design options while the policy measure is in effect.[8] Estimates of market

[8] An energy efficiency policy measure could ultimately lead to a sustainable market transformation. After fostering the purchase of more energy-efficient models for some time, the relative prices of these devices are likely to

penetration can be expressed by a time series of annual shipments per energy efficiency design option that will be driven by the policy measure. For each policy measure, these annual shipments will differ from shipments in the base case scenario in their total quantity and distribution across design options.

For each policy measure, the annual amounts of shipments per design option will determine the resulting estimates of total energy (and sometimes water) consumption, total consumers' investments and operating costs, and total emissions. These estimates, after being compared to their corresponding estimates for the base case scenario, ultimately establish the benefits of the measure. Hence, understanding how an energy efficiency policy measure affects shipments is paramount to assessing its effectiveness. A policy measure's impact on shipments is, therefore, the core of this framework. Once a policy analyst understands this relationship, the remaining evaluation of any policy measure is straightforward.[9]

2.2 Calculating Results Indicators

As mentioned previously, calculating the results indicators (the green shaded box in Figure 1) for a specific policy measure depends first on the calculation of how the policy measure affects shipments. Section 3 details, for selected energy efficiency policy measures, how to estimate shipments (the policy case *Shipment Forecast* box in Figure 1). Once the effect on shipments has been determined, calculating the results indicators is fairly straightforward and is described here.[10]

Let dev_i ($i = 1, \ldots, \mathrm{N}$) represent the i-th energy efficiency design option of the equipment targeted by an energy efficiency policy (energy efficiency of dev_i increases with i); t ($t = 1, \ldots, \mathrm{T}$) represent the sequence of years in a T-year assessment period[11]; and:

$prc_i(t)$	End-user price of the units represented by dev_i shipped in t (the t-th year of the assessment period)
$inst_i(t)$	Total installation costs of the units represented by dev_i shipped in t
$mnt_i(t)$	Lifetime maintenance costs of the units represented by dev_i shipped in t

decrease and make them more attractive to consumers. Also, the larger the penetration of those models into the market, the higher their acceptance by consumers. However, such (and any other) post-policy impacts are not (explicitly) taken into account in our approach. The policy analyst should, therefore, represent any post-policy effects that a policy measure may have on the market through dynamic prices, dynamic shipments, or any other appropriate variable.

[9] The indicator cNPV also will be affected by any monetary incentive provided by the policy measure. This should be accounted for when calculating the total investment (Equation [4]).

[10] The equipment economic parameters in the policy measure case scenario (the policy case *Cost Analysis* box in Figure 1) will be either: (a) given, for financial incentive measures; or (b) the same as the ones used for the base case otherwise. Further, the estimate of equipment engineering parameters (the *Engineering Analysis* box in Figure 1), as well as of equipment economic parameters and shipments for the base case scenario (respectively, the base case *Cost Analysis* and *Shipment Forecast* boxes in Figure 1), is out of the scope of this report and therefore not described here.

[11] The length of the assessment period may vary with the purposes of the study, but will typically cover at least one full equipment lifetime period.

$rpr_i(t)$	Lifetime repair costs of the units represented by dev_i shipped in t
$energy_{f,i}$	Annual energy consumption of fuel f by units represented by dev_i
$water_i$	Annual water consumption of units represented by dev_i
$emission_{g,i}$	Annual emissions of pollutant g by units represented by dev_i
$shp_i(t)$	Shipments forecast of the units represented by dev_i.

The total lifetime energy and water consumption, emissions, and equipment[12] and energy costs of units of all energy efficiency design options shipped in the t-th year of the assessment period can be calculated from:

$$Energy(t) = \sum_i \big(shp_i(t) \cdot \sum_f \big(energy_{f,i} \cdot \sum_{j=1,LF_i} pSurv_i(j)\big)\big) \quad [1]$$

$$Water(t) = \sum_i \big(shp_i(t) \cdot water_i \cdot \sum_{j=1,LF_i} pSurv_i(j)\big) \quad [2]$$

$$Emission_g(t) = \sum_i \big(shp_i(t) \cdot qEmission_{g,i} \cdot \sum_{j=1,LF_i} pSurv_i(j)\big) \quad [3]$$

$$qCost(t) = \sum_i \Big(shp_i(t) \cdot \big(prc_i(t) + inst_i(t) + mnt_i(t) + rpr_i(t) - v_i(t) + wExp_i(t)\big)\Big) \quad [4]$$

$$eCost(t) = \sum_i \big(shp_i(t) \cdot eExp_i(t)\big) \quad [5]$$

and:

$$eExp_i(t) = \sum_f \big(energy_{f,i} \cdot \sum_{j=1,LF_i} \big(pSurv_i(j) \cdot fPrice_f(t + j - 1) \cdot (1 + dRate)^{1-j}\big)\big) \quad [6]$$

$$qEmission_{g,i} = emission_{g,i} \cdot \sum_{j=1,LF_i} pSurv_i(j) \quad [8]$$

where:

$v_i(t)$	Monetary incentive provided by the policy measure[13]
$eExp_i(t)$	Present value in t of lifetime consumers' expense with energy
$wExp_i(t)$	Present value in t of lifetime consumers' expense with water
LF_i	Maximum lifetime of units represented by dev_i
$pSurv_i(j)$	Survival probability[14] of a unit represented by dev_i on its j-th year of operation
$dRate$	Social discount rate.

[12] Equipment costs include all non-energy-related consumers' expenses.
[13] See Section 3.2 for details on financial incentive policy measures.
[14] Survival probability refers to the probability that a device will be functioning on its j-th year of operation.

The cumulative (energy and water) consumption and emissions over the assessment period,[15] and the present values of the total investments and operating costs for the same period are given by:

$$cumEnergy = \sum_t Energy(t) \quad [9]$$

$$cumWater = \sum_t Water(t) \quad [10]$$

$$cumEmission_g = \sum_t Emission_g(t) \quad [11]$$

$$pvEquip = \sum_t (qCost(t) \cdot (1 + dRate)^{1-t}) \quad [12]$$

$$pvEnergy = \sum_t (eCost(t) \cdot (1 + dRate)^{1-t}) \quad [13]$$

Expressions [9] to [13] can be evaluated for the base case scenario and for the policy measure case scenario associated with each measure being assessed.[16] Based upon these results, the assessment indicators for each policy measure pol can be evaluated from:[17,18]

$$TES_{pol} = [cumEnergy]_{bc} - [cumEnergy]_{pol} \quad [14]$$

$$TWS_{pol} = [cumWater]_{bc} - [cumWater]_{pol} \quad [15]$$

$$TER_{pol,g} = \left[cumEmission_g\right]_{bc} - \left[cumEmission_g\right]_{pol} \quad [16]$$

---

[15] These are site consumptions and emissions. To estimate the corresponding amounts of energy and water that need to be produced, as well as to account for emissions across the whole supply-chain of energy and water, Equations [9] and [11] should be evaluated as:

$$cumEnergy = \sum_t \big(Energy(t) \cdot \sigma_e(t)\big) \quad [9a]$$

$$cumWater = \sum_t \big(Water(t) \cdot \sigma_w(t)\big) \quad [10a]$$

$$cumEmission_g = \sum_t Emission_g(t) + \sum_t \Big(Energy(t) \cdot \theta_{e,g}(t)\Big) + \sum_t \Big(Water(t) \cdot \theta_{w,g}(t)\Big) \quad [11a]$$

where:
- $\sigma_e(t)$ dynamic energy end-use-to-primary conversion factor
- $\sigma_w(t)$ dynamic water site-to-source conversion factor
- $\theta_{e,g}(t)$ dynamic emission factor of pollutant g in the energy supply chain
- $\theta_{w,g}(t)$ dynamic emission factor of pollutant g in the water supply chain.

[16] Equations [9] to [13] depend on Equations [1] to [5], where shipments are part of the evaluation. Some policy measures affect equipment price and, depending on the price-elasticity and the elasticity of substitution used (see Section 3), may consequently affect the total amount of shipments. When working with elasticities different than zero, for the sake of comparability of results, one should adjust the total shipments in the base case to reflect the effects that the elasticities might have on the total shipments in the policy measure case scenario. Alternatively, one can also evaluate Equations [1] to [5] on unitary basis, in which case the indicators calculated from Equations [9] to [13] will provide results at the *consumer level* rather than *totals* (see footnote 5 for the meaning of *totals*).

[17] One could add, respectively, to TES_{pol} and TWS_{pol} the energy savings resulting from water savings, and the water savings associated with energy savings. Also, when emissions from different pollutants can be converted to a common unit of measurement, the various $TER_{pol,g}$ can be summarized into a single TER_{pol}.

[18] Results for TES_{pol}, TWS_{pol} and $TER_{pol,g}$ refer to site savings. See footnote 15 to estimate savings of primary energy and source water, as well as to account for emissions across the whole energy and water supply chains.

$$cNPV_{pol} = [pvEquip]_{bc} + [pvEnergy]_{bc} - [pvEquip]_{pol} - [pvEnergy]_{pol} \quad [17]$$

$$sNPV_{pol} = cNPV_{pol} - v_{pol} + \sum_g mEmission_g \quad [18]$$

where:

$$mEmission_g = \sum_t \left([cumEmission_g(t)]_{bc} - [cumEmission_g(t)]_{pol} \right) \cdot gPrice_g(t) \cdot (1 + dRate)^{1-t}$$

and:

v_{pol}	Present value of monetary incentives provided by the policy measure[19]
$mEmission_g$	Present value of the monetized annual emissions reduction of g provided by measure pol
$gPrice_g(t)$	Market value of reducing one unit of emission of g in t.

3. Energy Efficiency Policy Measures

Several policy measures can foster purchase or production of energy-efficient equipment and contribute to an improvement in the overall energy efficiency of an economy. They range from mandatory standards to market-based policy approaches targeting both the supply- and demand- sides of the market. In this study we classify these measures as: energy efficiency standards; financial incentives; informational incentives; and government purchases. This section describes the measures and how they impact the market. It also outlines a methodology to estimate the effects of each type of policy measure on shipments of the equipment targeted by the policy.

3.1 Energy Efficiency Standards

Standards for the minimum energy efficiency of appliances in the United States first came into effect during the energy crisis of the mid-1970s, when high prices and increased environmental concerns drove many states to consider ways to cut the growing energy demand. Energy efficiency standards were implemented at the national level when a collaboration of manufacturers and energy efficiency advocates prompted the passage of the 1987 National Appliance Energy Conservation Act (Gillingham, 2006). Today, mandated efficiency standards are employed worldwide as a mechanism to reduce energy consumption and the consequent emissions of greenhouse gases (IEA, 2000; Nadel, 2002; CLASP, 2011b).

---

[19] Monetary incentives are not accounted for in the $sNPV_{pol}$ indicator (Equation [18]) because consumers benefit from the incentives at the expense of taxpayers. For more details on financial incentive policy measures see Section 3.2.

Mandated energy efficiency standards for a given product or group of products impact the total shipments of the targeted equipment and its distribution across energy efficiency design options.[20] The latter will be affected by the assumption that models with a rated energy efficiency that is less than the mandated *minimum efficiency performance standard* (*meps*) would no longer be marketed. Shipments of these devices would then be substituted by shipments of models with an energy efficiency level equal to the mandated *meps*.[21] This substitution, however, may be affected by the higher costs of the more efficient *meps*-compliant devices. Higher costs may reduce consumers' willingness to purchase or induce switching to other compatible types of equipment. These effects can be estimated from the *price-elasticity of demand*. Hence, for this policy case scenario, the shipments per energy efficiency design option can be estimated from:

$$shp_{pol,i}(t) = \begin{cases} 0, i < i^* \\ shp_{bc,i}(t) + \sum_{j<i}\left(shp_{bc,j}(t) + \Delta shp_{p,j}(t)\right), i = i^* \\ shp_{bc,i}(t), i > i^* \end{cases} \qquad [19]$$

where:

$$\Delta shp_{p,j}(t) = shp_{bc,j}(t) \cdot \varepsilon_{p,j} \cdot \left(\frac{qCost_{i^*}(t) - qCost_j(t)}{qCost_j(t)}\right) \qquad [20]$$

$$qCost_k(t) = prc_k(t) + inst_k(t) + mnt_k(t) + rpr_k(t) \qquad [22]$$

and:

$shp_{pol,i}(t)$ Shipments forecast of dev_i in t for the policy case scenario

$shp_{bc,i}(t)$ Shipments forecast of dev_i in t for the base case scenario

i^* Energy efficiency design option corresponding to the mandated *meps*

$\varepsilon_{p,j}$ Price-elasticity of demand for devices comprising the design option *j*

$qCost_k(t)$ Total non-energy costs[22] of units represented by dev_k shipped in t.

Energy efficiency standards may also arise when government and industry engage in negotiations to establish new voluntary, non-mandated levels of *meps* (Nadel, 2002). Manufacturers generally choose to participate in such a *self-regulation* approach to prevent the implementation of mandatory government regulations which they concern could be more onerous (OECD, 2002). Shipments, in this case, can be

[20] We assume a mandatory energy efficiency standard will apply to all models targeted by the policy measure. Full compliance with appliance energy efficiency standards is also assumed by policy makers in the United States. However, the assumed coverage of the standards could also apply to certain products on the market or to an average of all the products in a given market or sold by a given manufacturer. (IEA, 2000)

[21] We assume that consumers seeking to purchase a device with an energy efficiency level below the *meps* in the base case will not be willing to buy a more expensive equipment than one with an energy efficiency level that meets the *meps*.

[22] It should include, when applicable, consumers' expenses with water consumption.

estimated in a similar way as they are for mandated standards, yet assuming that not all shipments would meet the negotiated *meps*.[23] A modified version of Equation [19] should then be used:

$$shp_{pol,i}(t) = \begin{cases} (1-\kappa)\cdot shp_{bc,i}(t), i < i^* \\ shp_{bc,i}(t) + \kappa \cdot \sum_{j<i} shp_{bc,j}(t)\,, i = i^* \\ shp_{bc,i}(t), i > i^* \end{cases} \quad [19a]$$

where κ is the share of the base case shipments of design options with energy efficiency lower than the negotiated *meps* that would not meet the standard.

3.2 Financial Incentives

Government agencies have used financial incentives to attempt to increase the market penetration of energy-efficient equipment. Policy measures typically involve consumer rebates,[24] consumer and manufacturer tax credits, and early replacement programs.[25] (Nexus and RLW, 2005; SEEARP, 2009; DSIRE, 2011; US DOE, 2011a; TIAP, 2011a; TIAP, 2011b) Monetary incentives to consumers may include reductions, refunds, or deferred payments of part or the entire purchase price of more efficient models.[26] Concerning manufacturers, monetary incentives usually include tax reductions for the production of more energy-efficient models. Such incentives reduce the total ownership cost of energy-efficient equipment to consumers, making these devices more attractive when compared to the lower-cost, less efficient alternatives.

Consumer rebates typically offer direct price reductions with an immediate or fairly quick discount to the consumer. Consumer tax credits benefit the consumer when taxes are filed and hence have an implicit time delay, making them less attractive to consumers than a rebate. Manufacturer tax credits are assumed to be passed through to the consumer in the form of a reduced end-user price, but consumers may be unaware of the program and thus have lower participation.

For most policy approaches, this analysis methodology assumes that consumers are replacing inefficient equipment at the same time as they would be replacing it in the base case scenario (at the end of its service life). However, some consumers may replace their equipment earlier if a financial incentive is attractive enough. Therefore, a financial incentive designed to stimulate early replacements may shorten the time at which participating consumers make their purchases, effectively increasing the replacement rate for a certain period of time.

[23] We keep open the possibility that, even under a wide industry agreement, some manufacturers might not fully implement the negotiated *meps*.
[24] Utilities have also used consumer rebates as part of their demand-side management (DSM) programs (Reed, 2010; ADM, 2008; DSIRE, 2011).
[25] While rebate and tax credit programs focus on consumers shopping for new units, early replacement incentives aim to remove from the stock older inefficient models in operation.
[26] Monetary incentives could also target installation costs, or any other costs that would make the commodity covered by the policy measure less costly to consumers.

Reducing the cost to consumers of energy-efficient equipment is likely to increase its shipments. Three effects of a financial incentive will contribute to an increase in shipments of models meeting the *target* (efficiency) *level*[27] required by the policy measure:

(a) substitution of less efficient models from the same product class by any model covered by the measure;

(b) substitution of models from other (compatible) product classes by any model covered by the measure; and

(c) early replacement of existing devices from the same or from any other (compatible) product class by any model meeting the target level.[28]

The first effect can be estimated from the potential increase of the market penetration of models covered by the incentive as a response to the policy measure. The second effect will be proportional to the *price-elasticity of substitution* of devices from other product classes to which the one targeted by the policy can be an alternative. The third effect can be estimated either from historical data or any analytical approach representative of the decisions made by owners of devices of the targeted and other compatible equipment. Considering these three effects, shipments for this policy measure case scenario are estimated from:

$$shp_{pol,i}(t) = shp_{bc,i}(t) + \begin{cases} -\Delta shp_{m,i}(t), i < i^* \\ \Delta shp_{m,i}(t) + \Delta shp_{s,i}(t) + \Delta shp_{r,i}(t), i \geq i^* \end{cases} \qquad [23]$$

where:[29]

$$\Delta shp_{m,i}(t) = m(t) \cdot shp_{bc,i}(t) \cdot \begin{cases} \dfrac{\sum_{j \geq i^*} shp_{bc,j}(t)}{\sum_{j < i^*} shp_{bc,j}(t)}, i < i^* \\ 1, i \geq i^* \end{cases} \qquad [24]$$

[27] *Target level* refers to a minimum efficiency level stipulated by a policy measure.
[28] An early replacement policy measure restricts these effects to the third one.
[29] When, in the base case, the shipments forecast in t for all design options eligible to receive the incentive is zero ($\sum_{j \geq i^*} shp_{bc,j}(t) = 0$): (a) the increase in shipments due to the substitution of less efficient equipment by the ones eligible to the incentive ($\Delta shp_{m,i}(t)$) should be estimated using a different approach than the one proposed in this section (*e.g.* equipment utility-based market shares (ICF, 2007)); (b) the increase in shipments due to early replacements should be (conservatively) allocated only to the eligible design option with the lowest efficiency level (i^*). Consequently, equations [24] and [26] should be replaced by:

$$\Delta shp_{m,i}(t) = z_i(t) \cdot \sum_j shp_{bc,j}(t) \qquad [24a]$$

$$\Delta shp_{r,i}(t) = \begin{cases} repl(t) \cdot stock(t), i = i^* \\ 0, i > i^* \end{cases} \qquad [26a]$$

where $z_i(t)$ is the market share of dev_i in t estimated from the alternative method.

$$\Delta shp_{s,i}(t) = shp_{bc,i}(t) \cdot \varepsilon_s \cdot \left(\frac{-v(t)}{qCost_i(t)}\right) \qquad [25]$$

$$\Delta shp_{r,i}(t) = repl(t) \cdot stock(t) \cdot \frac{shp_{bc,i}(t)}{\sum_{j \geq i^*} shp_{bc,j}(t)} \qquad [26]$$

$$stock(t) = \sum_i \sum_{j=1,LF_i} \left(shp_{bc,i}(t-j+1) \cdot pSurv_i(j)\right) \qquad [27]$$

and:

$shp_{pol,i}(t)$ Shipments forecast of dev_i in t for the policy case scenario

$shp_{bc,i}(t)$ Shipments forecast of dev_i in t for the base case scenario

i^* Energy efficiency design option corresponding to the lowest energy efficiency level covered by the policy measure

$\Delta shp_{m,i}(t)$ Shipments of units represented by dev_i transferred in t to/from another energy efficiency design option eligible/non-eligible to receive the monetary incentive

$\Delta shp_{s,i}(t)$ Shipments of units from other product classes transferred in t to an energy efficiency design option covered by the policy measure

$\Delta shp_{r,i}(t)$ Shipments of units sold to early replace existing units

$v(t)$ Financial incentive given to consumers of all dev_i covered by the policy measure and shipped in t

$m(t)$ Market penetration increase resulting from the policy measure

ε_s Price-elasticity of substitution of products from other product classes that are substituted by a model of one of the energy efficiency design options covered by the policy measure

$repl(t)$ Early replacement rate in t fostered by the policy measure

$stock(t)$ Stock of units of all dev_i in t.[30]

The shift of shipments from less to more efficient models of the targeted product class ($\Delta shp_{m,i}(t)$) may not be straightforward, even in the presence of a financial incentive, due to market barriers[31] that are likely to prevent the full realization of the policy measure. Rufo and Coito estimated the potential electricity savings from energy efficiency measures in California (Rufo and Coito, 2002). As part of their

---

[30] We assume, for each design option i, the availability of shipments data for a period of $LF_i - 1$ years before the first year of the assessment period.

[31] A market barrier, in this context, is a mechanism that deters decisions or actions that appear to be both economically and energy efficient. Market barriers, by definition, discourage investments in cost-effective energy-efficient technologies. (Sorrel, 2004)

methodology, they developed a means of estimating customer acceptance of energy efficiency measures. In the study, they use a functional form to estimate market implementation rates according to the benefit/cost ratios of equipment with and without incentives and the estimated level of market barriers. The report presents five reference market *implementation curves* that vary according to the level of market barriers to technology penetration. These curves provide a framework to evaluate the penetration of energy-efficient equipment as a response to financial incentives, yet require matching the studied market to the curve that best represents it.[32] The approximate matching can introduce some inaccuracy to the analysis. More precise estimates can be reached from a market implementation function developed from interpolating between the five reference curves. Appendix A presents a functional form for such a function.[33]

The market implementation function $imp(b, bc)$ presented in Appendix A provides an estimate of the market penetration of devices with a certain efficiency level according to their benefit/cost ratio to consumers (bc) and the level of market barriers to its dissemination (b).[34] In the benefit/cost ratio, benefit refers to the energy cost savings that consumers will enjoy from using an energy-efficient device, and cost includes the likely greater purchase costs, and possibly installation and non-energy-related operational costs, associated with the energy-efficient equipment. A financial incentive will reduce the higher cost and thus increase the benefit/cost ratios of models covered by the policy measure. With a higher benefit/cost ratio, the market penetration of those devices will increase. The dynamic increase in market penetration $m(t)$ can be estimated from:[35]

$$m(t) = \lambda(t) \cdot \left(imp\left(b^*, bc_{pol}(t)\right) - imp\left(b^*, bc_{bc}(t)\right) \right) \quad [28]$$

where:

$$bc_{pol}(t) = \frac{incB(t)}{incC_{pol}(t)} = \frac{incB(t)}{incC_{bc}(t) - v(t)} \quad [29]$$

$$bc_{bc}(t) = \frac{incB(t)}{incC_{bc}(t)} \quad [30]$$

$$incB(t) = \frac{1}{\sum_{i \geq i^*} shp_{bc,i}(t)} \cdot \sum_{i \geq i^*} \left(shp_{bc,i}(t) \cdot eCost_i(t) \right) - eCost_1(t) \quad [31]$$

---

[32] Such curves have been used by DOE in the rulemakings for appliance energy efficiency standards (US DOE, 2007a; US DOE, 2007b; US DOE, 2009; US DOE, 2010) to estimate market share increases in response to rebate programs and tax credits for consumers and manufacturers.

[33] DOE has used this interpolation method to estimate the market penetration of financial incentives in more recent rulemakings (US DOE, 2011c; US DOE, 2011d).

[34] Alternative methods for predicting consumer response to financial incentives offered toward the purchase of energy-efficient equipment estimate adoption rates from: payback period and equipment utility-based market shares (ICF, 2007), incentive level as a percent of total project cost (Mosenthal and Wickenden, 1999), market data (Richey, 1998; Global, 2010), and experts' judgment (Kintner-Meyer et al, 2003).

[35] See Appendix B for how to calculate $m(t)$ when the level of market barriers of the studied market is below/above the lowest/highest barrier levels considered in Appendix A.

$$incC_{bc}(t) = \frac{1}{\sum_{i \geq i^*} shp_{bc,i}(t)} \cdot \sum_{i \geq i^*} shp_{bc,i}(t) \cdot \left(qCost_i(t) + wCost_i(t)\right) - \left(qCost_1(t) + wCost_1(t)\right) \quad [32]$$

and:

b^* Market barriers level, estimated such that $imp\left(b^*, bc_{bc}(t)\right) = \frac{\sum_{i \geq i^*} shp_{bc,i}(t)}{\sum_i shp_{bc,i}(t)}$

$bc_{pol}(t)$ Policy case scenario average benefit/cost ratio of models covered by the policy measure and shipped in t

$bc_{bc}(t)$ Base case scenario average benefit/cost ratio of models covered by the policy measure and shipped in t

$incB(t)$ Shipments weighted average incremental energy costs savings of all dev_i covered by the policy measure and shipped in t

$incC_{bc}(t)$ Shipments weighted average incremental non-energy-related costs, in the base case scenario, of all dev_i covered by the policy measure and shipped in t

$\lambda(t)$ Adjusting factor[36] ($0 < \lambda(t) \leq 1$).

The early replacement effect on shipments ($\Delta shp_{r,i}(t)$) can be estimated either from historical rates of anticipated replacements of the targeted and other compatible equipment in response to financial incentive programs, or from any analytical decision-making approach (e.g. repair *versus* replace) representative of the decisions made by owners of devices from these product classes.[37] Either approach should define a dynamic early replacement rate $repl(t)$ expressing the share of the stock of the equipment targeted by the program that is likely to be replaced in t because of the policy measure.

3.3 Informational Incentives

Informational incentives aim at allowing individuals and businesses to make informed decisions. As an energy efficiency policy measure, informational incentives can promote energy-efficient equipment by disclosing and highlighting their life-cycle economic benefits to increase consumers' willingness to overlook the equipment's greater initial costs and, eventually, to purchase more energy-efficient devices.

[36] In its rulemaking analyses DOE has considered the market penetration due to rebate programs to be the same as the implementation rate resulting from the interpolation method ($\lambda(t) = 1$). For tax credit programs, DOE estimates that the market penetration of more efficient equipment induced by consumer tax credits will be 60% of the market increase estimated from the interpolated curves ($\lambda(t) = 0.6$), and 30% in the case of manufacturer tax credits ($\lambda(t) = 0.3$) (US DOE, 2011c; US DOE, 2011d). The lower penetration rates for consumer tax credit programs occur because of the deferred nature of the discount to the consumer. For manufacturer tax credits, the lower implementation rate occurs because the consumer receives an indirect benefit via the assumed manufacturer pass-through of the financial incentive, but receives no incentive of direct information at the consumer level.

[37] We consider only the early replacements encouraged by a decrease in the cost of higher energy-efficient equipment. Early replacements motivated by any other reason without an adequate financial incentive would actually put upward demand pressure on the market and, in the short term, increase the price of more efficient models for consumers.

By informing consumers on the existence and the benefits of higher efficient equipment, informational programs provide free publicity to these products and distinguish their manufacturers. Firms are increasingly recognizing the value of taking voluntary initiatives or joining a voluntary initiative led by industry associations or government, as a means to enhance their reputations and increase sales (OECD, 2002). As a consequence, a greater share of the equipment being marketed will be composed of more energy-efficient equipment. Therefore, government agencies and utilities have used informational incentives to attempt to increase the market penetration of energy-efficient equipment (IEA, 2000; CLASP, 2011c).[38] Policy measures involve endorsement and comparative labeling programs[39] (FTC, 2011; US EPA and US DOE, 2011), best-in-the-market awards, media campaigns, and educational programs.

Increasing consumers' willingness to purchase more energy-efficient models is likely to increase shipments of these devices. The extent to which the more efficient models will penetrate into markets can be estimated based upon program goals or from historical data on the results of other similar programs. In the latter case, the expected increase in market penetration due to the policy measure under study can be estimated to be proportional to the penetration associated with the programs used as a reference.

Another way to understand the market transformation caused by earlier similar programs is estimating the extent to which they overcame the existing market barriers of the markets that they were targeting. This transformation can be evaluated from the same market implementation function used to estimate the market penetration of financial incentives. In this case, however, rather than working with different (*ex-ante* and *ex-post* policy) benefit/cost ratios over a single implementation curve, representative of the market under study, we analyze, across different market barrier curves, how the level of market barriers has evolved in that market concerning the models covered by the program. For each year y' for which historical market penetration data is available, the relative change in market barriers level $b'_{w/wo}(y')$ can be estimated from the ratio between the levels of market barriers *with* and *without* the earlier program:

$$b'_{w/wo}(y') = \frac{b'_w(y')}{b'_{wo}(y')} \qquad [33]$$

where $b'_{wo}(y')$ and $b'_w(y')$ are such that:

$$imp\left(b'_{wo}(y'), bc'(y')\right) = \frac{shp'_{wo}(y')}{shp'_{tot}(y')} \qquad [34]$$

$$imp\left(b'_w(y'), bc'(y')\right) = \frac{shp'_w(y')}{shp'_{tot}(y')} \qquad [35]$$

and:

[38] Informational programs are also carried out by industry trade and other associations (AHAM, 2011; NEMA, 2011) and non-governmental organizations (CEE, 2011; FYP, 2011).

[39] Endorsement labeling programs promote the most energy-efficient models to consumers. Comparative labeling programs give consumers important information about equipment energy use.

$b'_{w/wo}(y')$ Relative change in the level of market barriers in year y' due to the earlier program[40]

$b'_{wo}(y')$ Market barriers level in year y' without the earlier program

$b'_{w}(y')$ Market barriers level in year y' with the earlier program in place

$bc'(y')$ Benefit/cost ratio in year y' of models covered by the earlier program

$shp'_{wo}(y')$ Shipments in year y' of models covered by the earlier program without the program

$shp'_{w}(y')$ Shipments in year y' of models covered by the earlier program with the program in place

$shp'_{tot}(y')$ Total shipments in year y' of units from the product classes covered by earlier program.

The historical change in market barriers expressed by $b'_{w/wo}(y')$ can be used to estimate a pattern in the market transformation that the policy measure under study is likely to promote. Let $\mathcal{M}(t) = f\left(t, b'_{w/wo}(y')\right)$ be a function that transforms the historical market barrier changes led by the earlier program into market barrier changes forecast for the policy measure under study. Shipments resulting from the new policy measure can be estimated from:

$$shp_{pol,i}(t) = shp_{bc,i}(t) + \begin{cases} -\Delta shp_{m',i}(t), i < i^* \\ \Delta shp_{m',i}(t), i \geq i^* \end{cases} \quad [36]$$

where:

$$\Delta shp_{m',i}(t) = m'(t) \cdot \sum_k shp_{bc,k}(t) \cdot shp_{bc,i}(t) \cdot \begin{cases} \dfrac{1}{\sum_{j<i^*} shp_{bc,j}(t)}, i < i^* \\ \dfrac{1}{\sum_{j \geq i^*} shp_{bc,j}(t)}, i \geq i^* \end{cases} \quad [37]$$

$$m'(t) = imp\left(b_{pol}(t), bc(t)\right) - imp\left(b_{bc}(t), bc(t)\right) = imp\left(\mathcal{M}(t) \cdot b_{bc}(t), bc(t)\right) - imp\left(b_{bc}(t), bc(t)\right) \quad [38]$$

and:

$\Delta shp_{m',i}(t)$ Shipments of units represented by dev_i transferred in t from/to another energy efficiency design option not covered/covered by the policy measure

$m'(t)$ Market penetration increase fostered by policy measure

$bc(t)$ Average benefit/cost ratio of models covered by policy measure and shipped in t

$b_{bc}(t)$ Base case scenario market barriers level in t

$b_{pol}(t)$ Policy case scenario market barriers level in t.

[40] We assume the existence of market barriers in the market targeted by the earlier program ($b'_{wo}(t') > 0$).

3.4 Government Purchases

Government can use its purchasing power to increase the demand for more energy-efficient equipment (McGrory et al, 2002; Harris et al, 2005; McGrory et al, 2006).[41] The expected consequence is that stimulating manufacturers to increase the production of more energy-efficient equipment will reduce the prices of these devices relative to the less efficient ones, and eventually induce a shift in the larger non-government market.

Government can establish energy-efficient procurement policies that set lower bounds for the efficiency of equipment purchased by governmental agencies (US DOE, 2011b). Such a measure will require government agencies to adhere to these procurement specifications when they purchase energy-consuming products. Massive government purchases may avail government of a discounted quantity price. The shipments increase from government purchases can be estimated the same way as it is estimated for mandated energy efficiency standards, yet assuming the scope of the affected market would be restricted to government purchases.[8]

Government agencies can also replace their existing stock of energy-consuming devices early, whenever the life-cycle cost benefits of such an initiative are attractive. In this case, shipments can be estimated from qualitative (e.g. vintage, efficiency) and quantitative characteristics of the government-owned fleet of the targeted equipment.

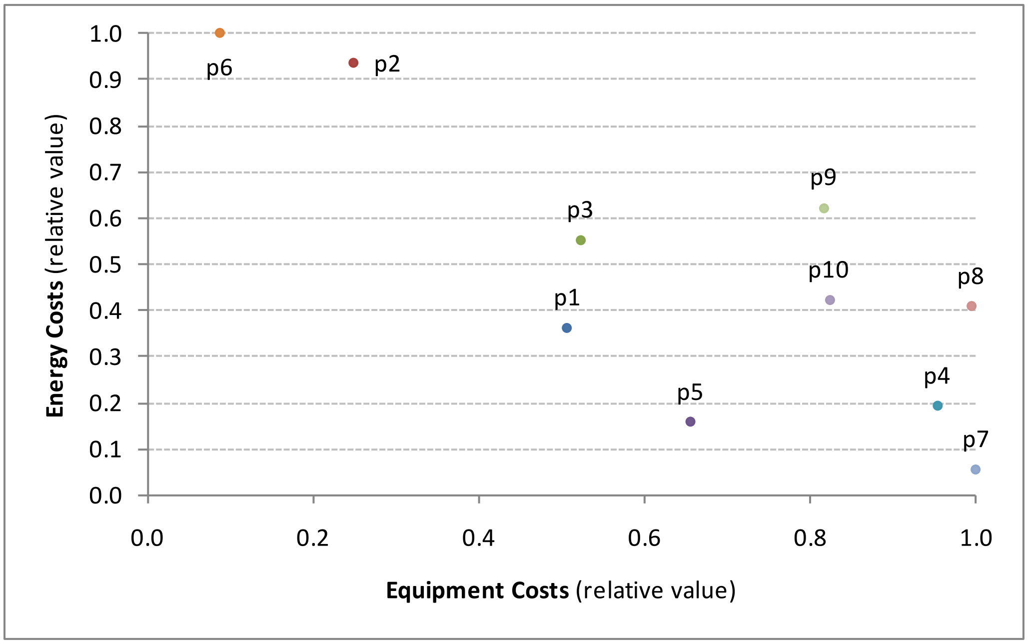
4. Comparative Assessments

In Section 2 we introduced a set of indicators to compare the estimated results of a group of policy measures comprising an energy efficiency policy. As a first comparative assessment approach, the policy measure results can be contrasted across individual indicators. This will provide an initial view on how their potential savings compare to each other. This approach does not emphasize, however, the tradeoffs between energy-related amounts (energy consumption, energy costs or emissions) and non-energy-related costs of each policy measure that could affect the decisions of policy makers.

An alternative approach to comparatively assessing the effects of various policy measures is to plot their results in such a way that the joint equipment costs and energy-related results for each measure can be compared, in what we are calling a *trade-off chart*.[42] A *trade-off chart* is drawn by picking any variable associated with energy consumption (for example $cumEnergy$, $cumEmission$ or $pvEnergy$) and the variable that expresses the total consumers' expenses with equipment as the axis of a two-dimensional chart. The policy measure results are then plotted in the chart according to their (absolute or relative[43]) values for each indicator selected for the axis. Figure 2 presents an example of a trade-off chart using relative values for a set of ten hypothetical policy measures.

[41] See PEPS (2011) for an extensive list of international public sector energy-efficiency programs.
[42] A trade-off chart can also be useful when comparing results from sets of combined policy measures.
[43] A trade-off chart based on relative values can present, for each variable, results indexed to: (a) the highest value of the variable; or (b) the value of the variable in the base case.

Figure 2: Example of an energy costs trade-off chart (relative values)



One of the benefits of a trade-off chart is that it helps with comparing the benefits from saving energy and the corresponding equipment costs. The chart also reveals the subset of measures, namely the ones closest to the origin (like measures p6, p1, p5, and p7 in Figure 2), that dominates the whole set of alternatives and defines the *frontier of savings* for the policy under assessment.

5. Assessing Energy Efficiency Policy Measures for Gas Furnaces in the U.S.

In this section, we demonstrate how to use the framework to compare the impacts estimated for twelve policy measures focusing on increasing the energy efficiency of gas furnaces in the United States. We rely on engineering and shipment data from the *Technical Support Document* (TSD) that was developed for the current energy efficiency standards rulemaking (US DOE, 2011d). Table 1 presents energy consumption and cost data for the available technologies across five energy efficiency design options, each one representing a certain value of the *annual fuel utilization efficiency* (AFUE). Table 2 reports the shipments forecasted for selected years in all scenarios.[44]

The policy measures assessed refer to the following policy mechanisms targeting, alternatively, each of the design options:

(a) Energy efficiency standards set at the efficiency level of each design option except the current

[44] We assume zero price-elasticity and zero elasticity of substitution. Therefore, the only effect that the policy measures have on shipments is on their distribution across design options.

baseline technology, which has an AFUE of 0.80 (Std 0.90, Std 0.92, Std 0.95, Std 0.98);[45]

(b) Consumer rebates that would offset 75% of the incremental equipment retail price (in reference to equipment price of the baseline technology), for each energy efficiency design option except the current baseline technology (Reb 0.90, Reb 0.92, Reb 0.95, Reb 0.98);

(c) Government purchase standards set at the level of each energy efficiency design option except the current baseline technology (Gov 0.90, Gov 0.92, Gov 0.95, Gov 0.98).

Table 1: Energy consumption and cost data

	Energy Efficiency (AFUE)				
	0.80	*0.90*	*0.92*	*0.95*	*0.98*
Annual gas consumption (MMBtu)	38.09	33.95	33.23	32.21	30.92
Annual electricity consumption (kWh)	313.47	290.34	284.40	275.93	365.26
Total installed cost ($)	1714.09	2356.36	2417.42	2560.71	2820.10
Equipment cost	839.91	1042.28	1103.34	1246.63	1493.55
Installation cost	874.18	1314.08	1314.08	1314.08	1326.56
Lifetime* maintenance and repair costs** ($)	721.10	723.21	723.84	725.34	727.91

* Maximum lifetime: 26 years

** Discount rate: 3%.

Table 2: Shipments forecast

	Energy Efficiency (AFUE)					*Total*
	0.80	*0.90*	*0.92*	*0.95*	*0.98*	
2010	1.225	0.254	0.628	0.429	0.011	2.547
2015	1.371	0.284	0.702	0.481	0.013	2.851
2020	1.366	0.465	0.777	0.532	0.014	3.155
2025	1.226	0.687	0.812	0.556	0.014	3.295
2030	1.060	0.918	0.840	0.574	0.015	3.407
2035	0.881	1.163	0.868	0.594	0.015	3.521

Table 3 presents the total energy consumption and the present values (at a 3% discount rate) of consumers' expenses for equipment and energy. Table 4 summarizes the result indicators for each policy-case scenario. Figure 3 presents a trade-off graph, covering all policy measures assessed and confronting base case-indexed energy costs with their corresponding equipment costs.

[45] The baseline technology refers to the energy efficiency design option composed of commonly marketed equipment, usually with energy efficiency at the level mandated by the current efficiency standard.

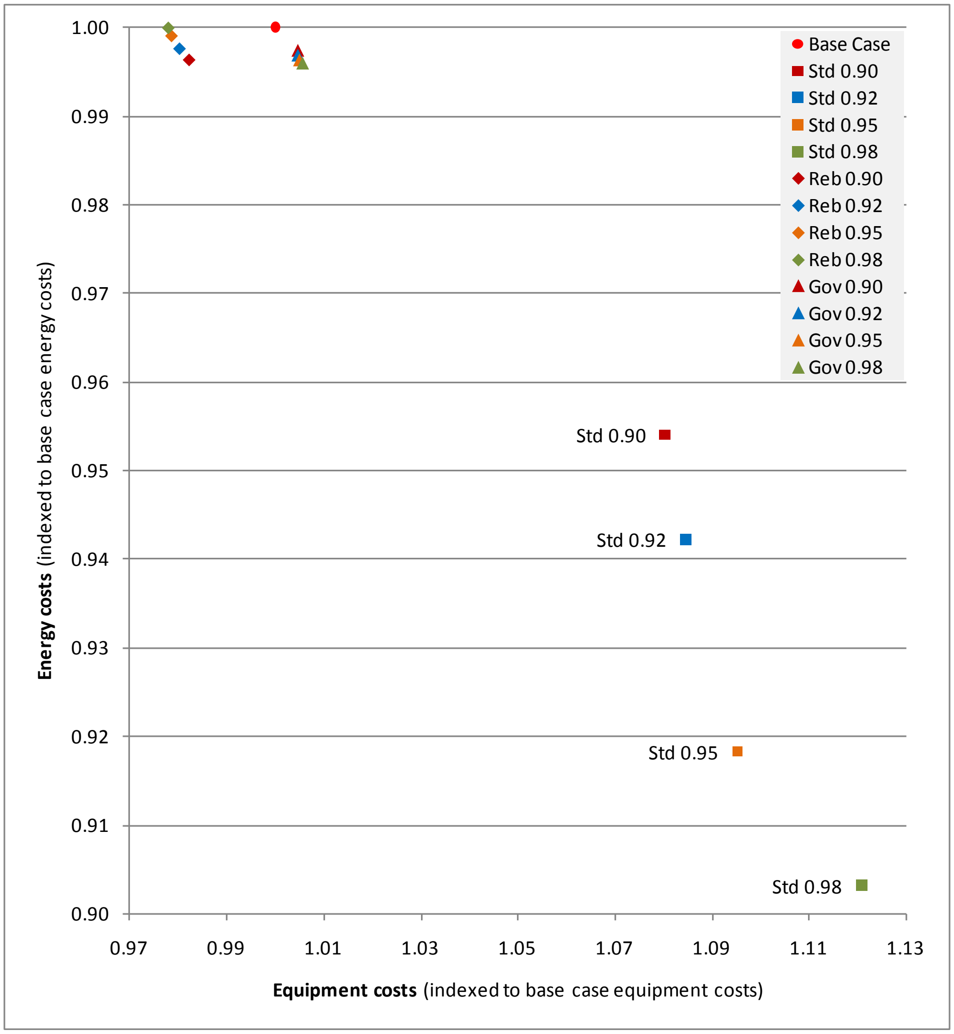
Table 3: Energy consumption and consumers' expenses

Scenario		Energy Consumption (quad)	Costs (billion $)		
			Equipment	Energy	Total
Base Case		83.6	157.2	581.1	738.3
Efficiency Standards	Std 0.90	79.9	169.9	554.4	724.3
	Std 0.92	78.9	170.5	547.6	718.1
	Std 0.95	76.9	172.2	533.6	705.8
	Std 0.98	75.2	176.2	524.9	701.1
Rebates	Reb 0.90	83.3	154.5	579.0	733.4
	Reb 0.92	83.4	154.2	579.8	733.9
	Reb 0.95	83.6	153.9	580.6	734.4
	Reb 0.98	83.6	153.8	581.1	734.9
Government Purchases	Gov 0.90	83.4	157.9	579.6	737.5
	Gov 0.92	83.4	158.0	579.3	737.3
	Gov 0.95	83.3	158.0	579.0	737.0
	Gov 0.98	83.3	158.1	578.8	736.9

Table 4: Results indicators

Policy Measures		TES (quad)	cNPV (billion $)
Efficiency Standards	Std 0.90	3.8	14.0
	Std 0.92	4.7	20.3
	Std 0.95	6.7	32.5
	Std 0.98	8.4	37.3
Rebates	Reb 0.90	0.3	4.9
	Reb 0.92	0.2	4.4
	Reb 0.95	0.1	3.9
	Reb 0.98	0.0002	3.5
Government Purchases	Gov 0.90	0.2	0.8
	Gov 0.92	0.3	1.0
	Gov 0.95	0.3	1.4
	Gov 0.98	0.3	1.5

Figure 3: Energy costs trade-off chart (values relative to base case results)



The analysis demonstrates that the four rebate policy measures (Reb 0.98, Reb 0.95, Reb 0.92 and Reb 0.90), along with the two more stringent efficiency standard measures (Std 0.95 and Std 0.98), comprise the frontier of savings of the policy. All other alternative measures lie in the upper-right side of the curve defined by these measures and are likely to promote less cost-effective energy savings.

6. Conclusions

This report presents an integrated methodological framework to assess prospectively the energy, economic, and environmental impacts of energy efficiency policy measures. Comparing a range of policy measures requires that the analysis of all candidate measures use a common set of input data and express the benefits of the measures through the same results indicators. We show how to use the integrated framework to estimate the expected results of a policy measure, specifically the changes in market share of devices with different levels of energy efficiency and the resulting energy consumption, consumers' investments and operating costs, and pollutant emissions that are expected to occur within a given timeframe. We also show how to further compare the effects of various policy measures by plotting their expected results in such a way that, for example, the joint equipment costs and energy-related results for each measure can be compared, in what we are calling a *trade-off chart.* Finally, we demonstrate how to apply the framework methodology by using it to compare the impacts estimated for twelve candidate policy measures focusing on increasing the energy efficiency of gas furnaces in the United States.

The methodology should be a useful tool for policy analysts and policy makers when considering which policy measure can most cost effectively achieve a policy target. With its open framework, this methodology can be applied to any geographical scope—be it a state, sub-national region, nation, group of nations, or the whole world. It can also be applied to any sectoral scope, including a specific sector, group of sectors, or the whole economy. The framework can be extended to accomplish an analysis of any type of policy measure, as long as it is possible to specify how the measure will affect shipments of more efficient equipment, or essentially how it will transform a given market. Future work to further extend the utility of this framework would include addressing uncertainties and assessing the effects of combined policy measures.

References

ADM et al (2008): *Evaluation Study of the 2004-05 Statewide Residential Appliance Recycling Program*: *2004-2005 Programs #1114, #1157, #1232 and #1348*. ADM Associates, Athens Research, Hiner & Partners, Innovologie. <http://www.calmac.org/publications/EM&V_Study_for_2004-2005_Statewide_RARP_-_Final_Report.pdf>

AHAM (2011): "Energy Saving Tips for Consumers." In *AHAM Consumer Information*, Association of Home Appliance Manufacturers (AHAM), Washington, DC, USA. <http://www.aham.org/consumer/>

Bernstein, P M et al (2005): *When Cost Measures Contradict*. Charles River Associates.

CEE (2011): "Qualifying Products." In *Resource Library*, Consortium for Energy Efficiency, Boston, MA, USA. <http://www.cee1.org/resrc/qualprod-main.php3>

CLASP (2011a): *Methodology Description for the Policy Analysis Modeling System* (*PAMS*). Collaborative Labeling and Appliance Standards Program (CLASP), Washington, DC, USA.

CLASP (2011b): *Worldwide Summary of S&L Programs*. Collaborative Labeling and Appliance Standards Program (CLASP), Washington, DC, USA. <http://www.clasponline.org/clasp.online.worldwide.php>

CLASP (2011c): *Label Designs around the World*. Collaborative Labeling and Appliance Standards Program (CLASP), Washington, DC, USA. <http://www.clasponline.org/clasp.online.resource.php?label=1>

DSIRE (2011): *Database of State Incentives for Renewables and Efficiency* (DSIRE). North Carolina Solar Center and the Interstate Renewable Energy Council (IREC). <http://www.dsireusa.org/>

Eldridge, M et al (2008): *Energy Efficiency: The First Fuel for a Clean Energy Future - Resources for Meeting Maryland's Electricity Needs*. Report Number E082, American Council for an Energy-Efficient Economy, Washington, DC, USA.

FTC (2011): *The ENERGYGUIDE: What Is It*? U.S. Federal Trade Commission, Washington, DC, USA. <http://www.ftc.gov/bcp/conline/edcams/eande/contentframe_appliance_guide.html>

FYP (2011): *Efficient Appliances*. Flex Your Power, San Francisco, CA, USA. <http://www.fypower.org/res/efficient-appliances/>

GDS (2007): *Vermont Electric Energy Efficiency Potential Study - Final Report*. Report prepared for the Vermont Department of Public Service, GDS Associates, Marietta, GA, USA.

Gillingham, K et al (2006): "Energy Efficiency Policies: A Retrospective Examination." *Annual Review of Environment and Resources* (31: 161-192).

Global (2010): *AmerenUE Demand Side Management (DMS) Market Potential Study*, *Volume 2*: *Market Research*. Report Number 1287-2. Global Energy Partners, Walnut Creek, CA, USA. <http://www.ameren.com/sites/aue/Environment/Renewables/Documents/AmerenUEVolume2MarketResearchReport2.pdf>

Granade, H C et al (2009): Unlocking Energy Efficiency in the U.S. Economy. McKinsey Global Energy and Materials. <http://www.mckinsey.com/en/Client_Service/Electric_Power_and_Natural_Gas/Latest_thinking/Unlocking_energy_efficiency_in_the_US_economy.aspx>

Harris, J et al (2005): *Public Sector Leadership*: *Transforming the Market for Efficient Products and Services*. In *Proceedings of the 2005 ECEEE Summer Study: Energy savings: What works & who delivers?* Mandelieu, France.

ICF (2007): *Arizona Public Service Energy Efficiency Baseline and Market Potential Study*. ICF International, Fairfax, VA, USA.

IEA (2000): *Energy Labels and Standards*. International Energy Agency, Paris, France.

Itron et al (2006): *California Energy Efficiency Potential Study* (Volume 1). CALMAC Study PGE0211.01. Report submitted to Pacific Gas & Electric, San Francisco, CA, by Itron (San Diego, CA), KEMA (Oakland, CA), RLW Analytics (Sonoma, CA) and Architectural Energy (Boulder, CO), USA.

Itron (2010): *Incremental Impacts of Energy Efficiency Policy Initiatives Relative to the 2009 Integrated Energy Policy Report Adopted Demand Forecast* (Attachment A: Technical Report). Prepared for the California Energy Commission, Itron, Oakland, CA, USA.

KEMA (2011): *Missouri Statewide DSM Market Potential Study - Final Report*. Prepared for the Missouri Public Service Commission, Jefferson City, MO, by KEMA, Burlington, MA, USA.

Kintner-Meyer, M et al (2003): *Final Report for the Energy Efficient and Affordable Small Commercial and Residential Buildings Research Program. Project 6.6 – Development of the Assessment Framework*. Report PNNL-14343. Pacific Northwest National Laboratory, Richland, WA, USA. <http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14343.pdf>

Letschert, V, M A McNeil, N Zhou (2010): *Residential Electricity Demand in China – Can Efficiency Reverse the Growth?* LBNL Paper LBNL-2321E, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

McGrory, L V W et al (2002): "Market Leadership by Example: Government Sector Energy Efficiency in Developing Countries." In *Proceedings of the ACEEE 2002 Summer Study on Energy Efficiency in Buildings*. American Council for an Energy-Efficient Economy, Washington, DC, USA.

McGrory, L V W et al (2006): "Two Paths to Transforming Markets through Public Sector Energy Efficiency: Bottom Up versus Top Down." In *Proceedings of 2006 ACEEE Summer Study on Energy Efficiency in Buildings*: *Less is More -- En Route to Zero Energy Buildings.* American Council for an Energy-Efficient Economy, Washington, DC, USA.

McNeil, M, R D Van Buskirk, V E Letschert (2006): *The Value of Standards and Labelling*: *An International Cost-Benefit Analysis Tool for Standards & Labeling Programs with Results for Central America Countries*. Collaborative Labeling and Appliance Standards Program (CLASP), Washington, DC, USA. <http://www.clasponline.org/files/4260_paper_McNeil_final.pdf>

McNeil, M A, V E Letschert, SWiel (2006): *Reducing the Price of Development*: *The Global Potential of Efficiency Standards in the Residential Electricity Sector*. International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL), London, UK.

Meyers, S, J E McMahon, B Atkinson (2008): *Realized and Projected Impacts of U.S. Energy Efficiency Standards for Residential and Commercial Appliances.* LBNL Report 63017. Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Mosenthal, P H and Michael Wickenden (1999): "The Link between Program Participation and Financial Incentives in the Small Commercial Retrofit Market." In *1999 International Energy Program Evaluation Conference*, Denver, CO, USA.

Mosenthal, P and J Loiter (2007): *Guide for Conducting Energy Efficiency Potential Studies*. Prepared for the National Action Plan for Energy Efficiency, Optimal Energy, Bristol, VT, USA.

Mundaca, L et al (2010): *Evaluating Energy Efficiency Policies with Energy-Economy Models*. LBNL Report 79375, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Nadel, S (2002): "Appliance and Equipment Efficiency Standards." *Annual Review of Energy and the Environment* (27):159–192.

NEMA (2011): *Energy Efficiency*. National Electrical Manufacturers Association, Rosslyn, VA, USA. <http://www.nema.org/gov/energy/efficiency/>

Nexus and RLW (2005): *Impact, Process, and Market Study of the Connecticut Appliance Retirement Program*: *Overall Report.* Report submitted to Northeast Utilities – Connecticut Light and Power and the United Illuminating Company. Nexus Market Research and RLW Analytics, Cambridge, MA, USA. <http://www.ctsavesenergy.org/files/Appliance%20Retirement%2012-05.pdf>

OECD (2002): *Regulatory Policies in OECD Countries*: *From Interventionism to Regulatory Governance*. Organization for Economic Co-operation and Development, Paris, France.

PEPS (2011): *International Programs*. Promoting an Energy-Efficient Public Sector. <http://www.pepsonline.org/programs.html>

Ramos, I S et al (2006): Assessment of the Impacts of Standards and Labeling Programs in Mexico (Four Products). Report No. 12933 ITF FN LBNL 001, Insituto de Investigaciones Eléctricas, Cuernavaca, Morelos, Mexico.

Reed, J et al (2010): *Process and Market Evaluation of Southern California Edison's Appliance Recycling Program*, *2006 – 2008*. Report Number SCE0281.01. Innovologie, Rockville, MD, USA. <http://calmac.org/publications/scearpfinal041410.pdf>

Richey, C (1998): "Methodology for Tax Rebate Analysis." In *Analysis of Tax Credits for Efficient Equipment*. Lawrence Berkeley National Laboratory, Berkeley, CA, USA. <http://enduse.lbl.gov/Projects/TaxCredits.html>

Rosenquist, G et al (2006): "Energy efficiency standards for equipment: Additional opportunities in the residential and commercial sectors." *Energy Policy* 34 (17) 3257–3267.

Rufo, M and F Coito (2002): *California's Secret Energy Surplus*: *The Potential for Energy Efficiency*. Prepared for The Energy Foundation and The Hewlett Foundation. XENERGY Inc., CA, USA. <http://www.ef.org/documents/Secret_Surplus.pdf>

SEEARP (2009): *State Energy Efficient Appliance Rebate Program* (*SEEARP*). Funding Opportunity Number DE-FOA-0000119, American Recovery and Reinvestment Act, U.S. Government, Washington, DC, USA. <http://www.grants.gov/search/search.do?mode=VIEW&oppId=48463>

Sebold, F D et al (2001): *A Framework for Planning and Assessing Publicly Funded Energy Efficiency*. Study PG&E-SW040. Pacific Gas and Electric Company, CA, USA.

Sorrel, S (2004): “Understanding Barriers to Energy Efficiency.” In *The Economics of Energy Efficiency*: *Barriers to Cost-Effective Investment* by Steve Sorrel, Eoin O’Malley, Joachim Schleich and Sue Scott. Edward Elgar Publishing Inc. MA, USA.

Summit Blue (2008): *Energy Efficiency Potential Study for the State of Kansas*: *Final Report*. Prepared to the Kansas Energy Council, Summit Blue Consulting, Boulder, CO, USA.

TIAP (2011a): *Consumer Tax Incentives*: *Home Heating & Cooling Equipment*. Tax Incentives Assistance Project (TIAP). <www.energytaxincentives.org/consumers/heating-cooling.php>

TIAP (2011b): *Manufacturers Incentives*. Tax Incentives Assistance Project (TIAP). <http://energytaxincentives.org/builders/appliances.php>

US DOE (2007a): “Regulatory Impact Analysis” (Reports). In *Technical Support Document: Energy Efficiency Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers*. U.S. Department of Energy - Energy Efficiency & Renewable Energy. Washington, DC, USA. <http://www1.eere.energy.gov/buildings/appliance_standards/residential/fb_tsd_0907.html>

US DOE (2007b): “Regulatory Impact Analysis” (Report 2). In *Technical Support Document: Energy Efficiency Program for Commercial and Industrial Equipment: Electrical Distribution Transformers*. U.S. Department of Energy - Energy Efficiency & Renewable Energy. Washington, DC, USA. <http://www1.eere.energy.gov/buildings/appliance_standards/commercial/distribution_transformers_fr_tsd.html>

US DOE (2009): “Chapter 17: Regulatory Impact Analysis.” In *Final Rule Technical Support Document: Residential Dishwashers, Dehumidifiers, and Cooking Products, and Commercial Clothes Washers*. U.S. Department of Energy - Energy Efficiency & Renewable Energy. Washington, DC, USA. <http://www1.eere.energy.gov/buildings/appliance_standards/residential/cooking_products_final_rule_tsd.html>

US DOE (2010): “Regulatory Impact Analysis” (Chapter 15). In *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment*, *Residential Water Heaters, Direct Heating Equipment, and Pool Heaters*. U.S. Department of Energy - Energy Efficiency & Renewable Energy. Washington, DC, USA. <http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr_tsd.html>

US DOE (2011a): “Rebates, Tax Credits & Financing.” In *Energy Savers*, Energy Efficiency & Renewable Energy, U.S. Department of Energy, Washington, DC, USA. <http://www.energysavers.gov/financial/>

US DOE (2011b): *Procuring Energy-Efficient Products*. Federal Energy Management Program, Energy Efficiency & Renewable Energy, U.S. Department of Energy, Washington, DC, USA. <http://www1.eere.energy.gov/femp/technologies/procuring_eeproducts.html>

US DOE (2011c): “Regulatory Impact Analysis” (Chapter 17). In *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment*, *Residential Clothes Dryers and Room Air Conditioners.*. U.S. Department of Energy - Energy Efficiency & Renewable Energy. Washington, DC, USA. <http://www1.eere.energy.gov/buildings/appliance_standards/residential/residential_clothes_dryers_room_ac_direct_final_rule_tsd.html>

US DOE (2011d): “Regulatory Impact Analysis” (Chapter 17). In *Technical Support Document: Energy Conservation Standards for Residential Furnaces and Residential Central Air Conditioners and Heat Pumps*. U.S. Department of Energy - Energy Efficiency & Renewable Energy. Washington, DC, USA. (forthcoming)

US EPA and US DOE (2011): *Find ENERGY STAR Products*. Energy Star Program, U.S. Environmental Protection Agency and U.S. Department of Energy, Washington, DC, USA. <http://www.energystar.gov/index.cfm?c=products.pr_find_es_products>

Wiel, S and J E McMahon (2005): *Energy-Efficiency Labels and Standards*: *A Guidebook for Appliances, Equipment, and Lighting* (2nd Edition). Collaborative Labeling and Appliance Standards Program (CLASP), Washington, DC, USA.

Appendix A: Market Implementation Function

A.1 Market Implementation Function and Curves

Rufo and Coito (2002) employ the following functional form to estimate the "percentage of the informed market[46] that will accept each [energy-efficiency] measure based on the participant's benefit/cost ratio":

$$imp(bc) = \frac{max}{\left(1 + e^{-\ln\left(\frac{bc}{4}\right)}\right) \cdot \left(1 + e^{-fit \cdot \ln(mid \cdot bc)}\right)} \qquad [A.1]$$

where:

imp	implementation rate
bc	benefit/cost ratio
max	maximum annual acceptance rate for the technology
mid	inflection point of the curve
fit	parameter that determines the general shape (slope) of the curve.

In a more recent approach (US DOE, 2010; US DOE, 2011c; US DOE, 200d) Equation [A.1] has been slightly modified, with the constant value 1/4 replaced by a parameter *r*. By introducing this parameter in Equation [A.1] and rewriting it without the exponential and logarithmic operators, the market implementation rate can be evaluated using the following equation:

$$imp(bc) = \frac{max}{\left(1 + \frac{1}{r \cdot bc}\right) \cdot \left(1 + (mid \cdot bc)^{-fit}\right)} \qquad [A.2]$$

Rufo and Coito (*ibid.*) use Equation [A.1] to generate five primary (reference) market implementation curves. These curves produce "base year program results that are calibrated to actual measure implementation results associated with major [utility] efficiency programs." Different curves, generated using distinct values for parameters *max*, *mid*, *fit,* and *r*, reflect different levels of market barriers for different efficiency measures. The market barrier levels characterized by the five reference curves are: *No Barriers*, *Low Barriers*, *Moderate Barriers*, *High Barriers,* and *Extremely High Barriers*. Figure A.1 presents the five reference curves. They build on the following functional form:

$$imp(b_d, bc) = \frac{max_d(b_d)}{\left(1 + \frac{1}{r_d(b_d) \cdot bc}\right) \cdot \left(1 + (mid_d(b_d) \cdot bc)^{-fit_d(b_d)}\right)} \qquad [A.3]$$

[46] The *informed market* refers to the portion of the market aware and informed about the energy efficiency measure.

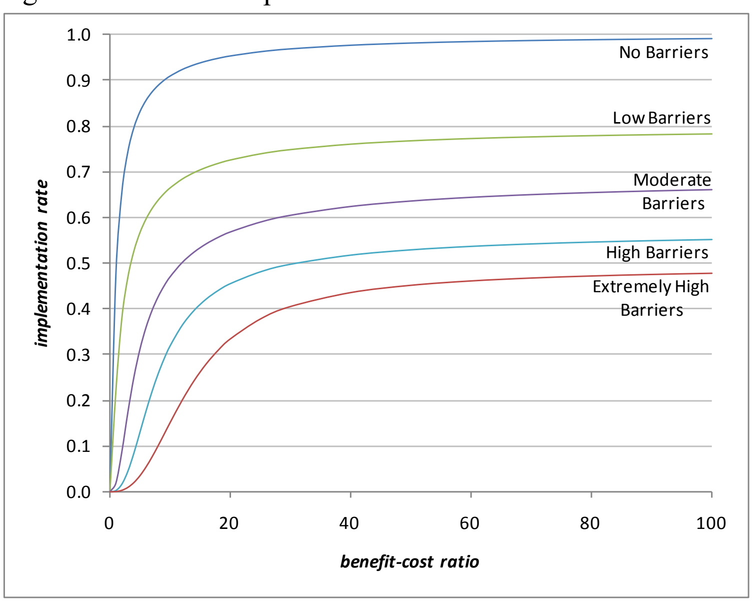
where b_d is the market barrier level, and $max_d(b_d)$, $mid_d(b_d)$, $fit_d(b_d)$, and $r_d(b_d)$ are as shown in Table A.1 (and presented in Figure A.2).

To estimate the barrier level of a given market, based on the reference curves, one should seek for the curve that most closely represents the pair (benefit/cost ratio, market share) for the product and market under evaluation. The effect of a financial incentive on the penetration of more energy-efficient devices can then be estimated to be proportional to the effect that increasing the benefit/cost ratio of the equipment would have in a market represented by the selected reference curve.

Table A.1: Parameter values for the reference curves

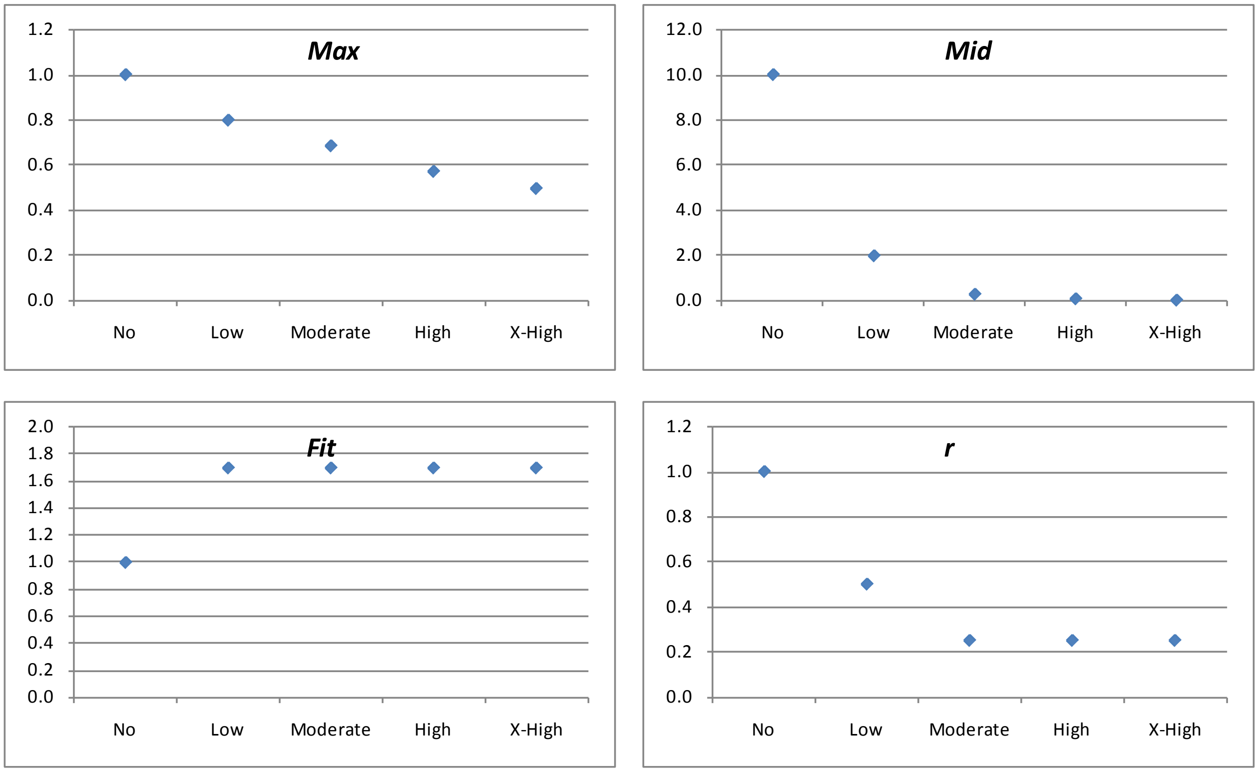
	Market Barriers Level				
	No Barriers	*Low Barriers*	*Moderate Barriers*	*High Barriers*	*Extremely High Barriers*
max_d	1.0	0.8	0.7[47]	0.6[47]	0.5[47]
mid_d	10	2	0.3	0.1	0.04
fit_d	1	1.7	1.7	1.7	1.7
r_d	1	0.5	0.25	0.25	0.25

Figure A.1: Market implementation curves for the five reference levels of market barriers



[47] DOE adopted these parameters after consultation with the authors of the implementation curve methodology (US DOE, 2011c; US DOE, 2011d). In the *Regulatory Impact Assessment* (RIA) for the rulemakings for cooking products, commercial clothes washers, and heating products the *max* value adopted by DOE for the *moderate barriers* and *high barriers* market barrier levels was 0.5 (US DOE, 2009; US DOE, 2010). RIAs developed during prior rulemakings for furnaces and boilers (US DOE, 2007a) and distribution transformers (US DOE, 2007b) adopted a *max* value of 0.8 for all but the *no barriers* curve, based on the original penetration curve values from Rufo and Coito (*ibid.*).

Figure A.2: Discrete-value functions of the parameters driving the shape of the implementation curve



A.2 Calibrating the Market Implementation Rate Function

The procedure described above lacks accuracy when the studied market penetration point based on the actual benefit/cost ratio does not lie close to one of the reference curves. Interpolation can eliminate such inaccuracy. The interpolation process presented below provides intermediate, continuous values for the four parameters (*max*, *mid*, *fit,* and *r*) driving the market implementation curves. These intermediate values are obtained after linear interpolation of their corresponding reference values.

The four parameters (*max*, *mid*, *fit,* and *r*) were previously defined as discrete-value functions ($max_d(b_d)$, $mid_d(b_d)$, $fit_d(b_d)$, and $r_d(b_d)$) of the market barriers level (Table A.1, Figure A.1). To facilitate the interpolation, it is necessary to transform the four discrete-value functions into continuous functions, the latter being thus capable of associating each of the four parameters to a real number denoting the market barrier level ($b_c \in \mathbf{R}$). A numeric, continuous scale for the market barriers level is proposed, ranging from 0 to 5 ($b_c \in [0,5]$). The correspondence between the discrete-values of market barrier levels and b_c are shown in Table A.2.

Based on the continuous-value market barriers levels, the parameters *max*, *mid*, *fit,* and *r* are interpolated using the following functions:

$$max_c(b_c) = \propto_{max}(b_c) \cdot b_c + \beta_{max}(b_c) \qquad \text{[A.4a]}$$

$$mid_c(b_c) = \propto_{mid}(b_c) \cdot b_c + \beta_{mid}(b_c) \quad \text{[A.4b]}$$

$$fit_c(b_c) = \propto_{fit}(b_c) \cdot b_c + \beta_{fit}(b_c) \quad \text{[A.4c]}$$

$$r_c(b_c) = \propto_r(b_c) \cdot b_c + \beta_r(b_c) \quad \text{[A.4d]}$$

where $\propto_x(b_c)$ and $\beta_x(b_c)$ are given by Table A.3. (Figure A.3 presents the four continuous-value functions.)

The continuous-value functions defined for *max*, *mid*, *fit,* and *r*, as expressed by Equations [A.4a]-[A.4d], are then substituted in Equation [A.3], leading to the following functional form for the market implementation rate of a financial incentive program:

$$imp(b_c, bc) = \frac{max_c(b_c)}{\left(1 + \frac{1}{r_c(b_c) \cdot bc}\right) \cdot \left(1 + (mid_c(b_c) \cdot bc)^{-fit_c(b_c)}\right)} \quad \text{[A.5]}$$

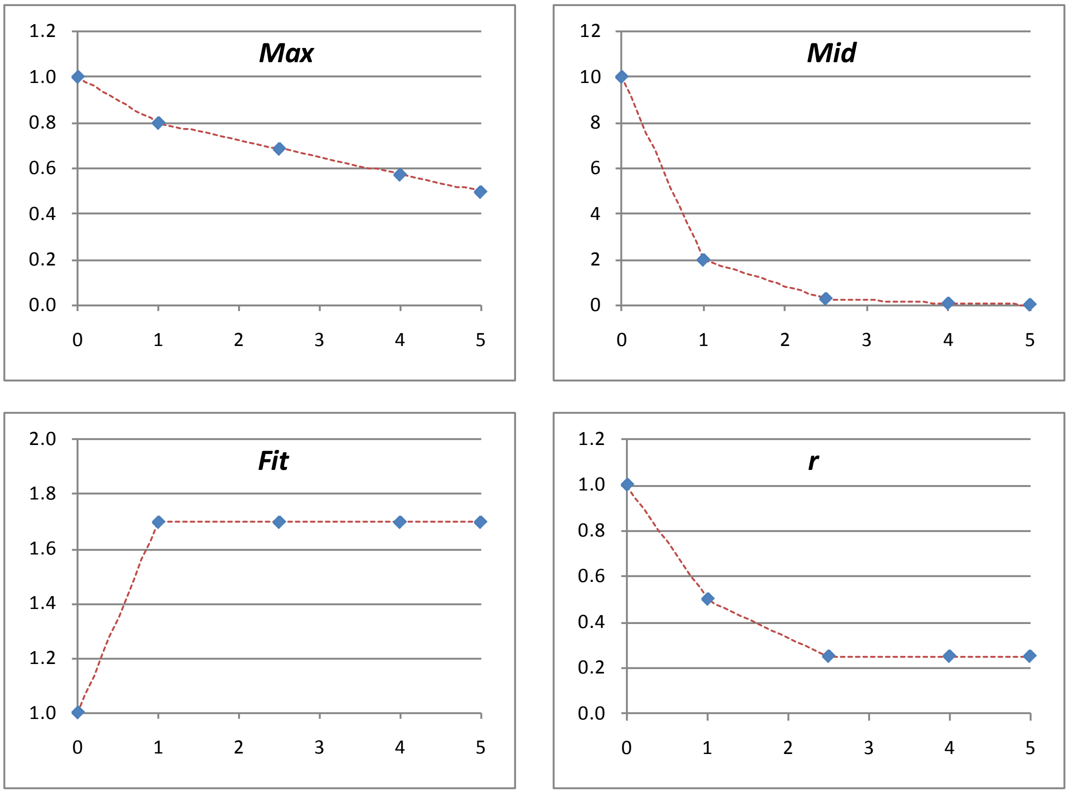
Table A.2: Correspondence between discrete and continuous values of market barrier levels

	Market Barriers Level				
	No Barriers	*Low Barriers*	*Moderate Barriers*	*High Barriers*	*Extremely High Barriers*
b_c	0.0	1.0	2.5	4.0	5.0

Table A.3: Coefficients of the continuous-value functions of *max*, *mid*, *fit,* and *r*

	Market Barriers Level Intervals			
	No-Low Barriers	*Low-Moderate Barriers*	*Moderate-High Barriers*	*High-Extremely High Barriers*
	$b\in[0,1]$	$b\in[1,2.5]$	$b\in[2.5,4]$	$b\in[4,5]$
max				
$\propto_{max}(b_c)$	-0.200	-0.075	-0.075	-0.075
$\beta_{max}(b_c)$	1.000	0.875	0.875	0.875
mid				
$\propto_{mid}(b_c)$	-8.000	-1.133	-0.133	-0.060
$\beta_{mid}(b_c)$	10.000	3.133	0.633	0.340
fit				
$\propto_{fit}(b_c)$	0.700	0.000	0.000	0.000
$\beta_{fit}(b_c)$	1.000	1.700	1.700	1.700
r				
$\propto_r(b_c)$	-0.500	-0.167	0.000	0.000
$\beta_r(b_c)$	1.000	0.667	0.250	0.250

Figure A.3: Continuous-value functions of the parameters driving the shape of the implementation curve



Hence, estimating the market effects of such a program relies on finding the custom implementation curve that best represents the studied market. In other words, it involves finding b_c such that the pair (bc, $imp(b_c,bc)$) equals the pair (benefit/cost ratio, market share) for the product and market under evaluation. Once the appropriate value of b_c is found (e.g. $b_c = \mathrm{b}_\mathrm{c}^*$), the market penetration of more energy-efficient models under a financial incentive program can be estimated from the following equation:

$$imp(\mathrm{b}_\mathrm{c}^*, \mathrm{bc}^*) = \frac{max_c(\mathrm{b}_\mathrm{c}^*)}{\left(1 + \frac{1}{r_c(\mathrm{b}_\mathrm{c}^*) \cdot \mathrm{bc}^*}\right) \cdot \left(1 + (mid_c(\mathrm{b}_\mathrm{c}^*) \cdot \mathrm{bc}^*)^{-fit_c(\mathrm{b}_\mathrm{c}^*)}\right)} \qquad \text{[A.6]}$$

where:

b_c^* market barriers level corresponding to the studied market, and
bc^* benefit/cost ratio with financial incentive.

A.3 Final Remarks

The approach presented in this Appendix increases the accuracy of the estimate of the market implementation rate resulting from a financial incentive program. Consequently, it improves the analysis of the market effects of those programs. However, whereas it is feasible to develop interpolated implementation curves between the former reference ones, there is no empirical support to extrapolate them beyond the *No Barriers* and the *Extremely High Barriers* curves. Nevertheless, a market penetration increase for markets with barrier levels beyond these boundary curves can be estimated to be proportional to the market increase that the financial incentive would promote in a market represented by these curves. (See Appendix B for a discussion of this estimation method.)

Appendix B: Estimating Market Penetration Increase

The market penetration increase (m) of more energy-efficient equipment due to a financial incentive can be estimated from the market implementation function:

$$m = imp(b, bc_{pol}) - imp(b, bc_{bc}) \quad [B.1]$$

where:

$imp(b, bc)$	Market implementation function (See Appendix A),
b	Level of market barriers of the market under evaluation,
bc_{pol}	Policy case scenario average benefit/cost ratio of models covered by the policy measure, and
bc_{bc}	Base case scenario average benefit/cost ratio of models covered by the policy measure.

The level of market barriers is associated with the market penetration curve that best represents the market being analyzed. When such a curve lies beyond the space bounded by the curves of the *No Barriers* and the *Extremely High Barriers* markets, there is no numerical value to describe its corresponding barriers level.[48] Consequently, in these cases, the market implementation function cannot be used to calculate the market penetration increase that would result from an increase in the benefit/cost ratio of the equipment targeted by the policy measure under assessment.

One way to estimate such an increase is to consider that it will be proportional to the increase that would occur if the same benefit/cost ratio change were applied to the market represented by the implementation curve that is the closest to the one associated with the market being analyzed.[49] The latter refers to either the *No Barriers* or the *Extremely High Barriers* curves, depending on whether the market share of more energy-efficient equipment in the base case is greater than the market share for the same benefit/cost ratio in the *No Barriers* curve, or lower than the corresponding one in the *Extremely High Barriers* curve. The proportionality applies to the decrease in the distance between the base case implementation rate and the maximum implementation rate of each curve that the change in the benefit/cost ratio would promote.

[48] In this case, the numerical value for the market barriers level would be out of the domain defined in Appendix A ($0 \le b \le 5$).

[49] Notice the implementation curve associated with the market being analyzed is hypothetical, since the range of market barriers is lower/upper limited by the barriers corresponding to the *No Barrier*/*Extremely High Barrier* markets.

Let mkt represent the market under analysis, and rep the one associated with an existing implementation curve used as representative of mkt. The market penetration increase (m_{mkt}) resulting from a change in the benefit/cost ratio in the market under evaluation can be estimated from:

$$m_{mkt} = imp_{mkt,pol} - imp_{mkt,bc} \qquad \text{[B.2a]}$$

$$imp_{mkt,pol} = M_{rep} - \left(M_{rep} - imp\left(b_{rep}, bc_{pol}\right)\right) \cdot \frac{M_{rep} - imp_{mkt,bc}}{M_{rep} - imp\left(b_{rep}, bc_{bc}\right)} \qquad \text{[B.2b]}$$

where:

$imp_{mkt,s}$	Implementation rate in market mkt for scenario s
M_{rep}	Highest implementation rate in market rep (See parameter ***max*** in Table A.3)
$imp(b, bc)$	Implementation rate function (See Appendix A)
b_{rep}	Level of market barriers in market rep
bc_s	Benefit/cost ratio for scenario s.

Notice the expressions above are valid for any market mkt and can be used, generically, to estimate the market penetration increase for markets with any level of market barriers. When mkt can be represented by an existing implementation curve, $imp\left(b_{rep}, bc_{bc}\right)$ is equal to $imp_{mkt,bc}$ and, consequently (from Equation [B.2b]), $imp_{mkt,pol}$ equals to $imp\left(b_{rep}, bc_{pol}\right)$ which corresponds to $imp\left(b_{mkt}, bc_{pol}\right)$.