Shareholder Incentives for Utility-based Energy Efficiency Programs in California*

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ABSTRACT

Energy efficiency is increasingly being recognized as a preferred resource warranting aggressive public investment. The State of California has committed an unprecedented sum of $2.2 billion in ratepayer funds to utility-based energy efficiency programs from 2006 through 2008; the State finalized in 2007 the determination of the shared-savings incentive mechanism for the 2006-2008 programs and beyond. This study seeks to examine whether the adopted incentive mechanism would ensure an efficient delivery of the programs, and what reforms, if any, could be proposed to meet this end. I develop a game theory model for the implementation of the programs, in which a regulator adopts an energy savings target and a shared-savings incentive mechanism before a utility firm proposes program funding, gets the proposal authorized, and begins to manage the programs. The study reveals that each firm requires a minimum level of incentive rate, in order for the mechanism to encourage the firm to achieve the adopted energy savings target, eventually bringing non-negative bill savings to its customers. It also reveals that a higher-than-minimum incentive rate could achieve not only a greater net social benefit but also greater bill savings for customers. Model-based analysis of California energy efficiency programs suggests that a higher-than-adopted incentive rate is warranted and that social efficiency would be improved by customizing incentive mechanisms for individual utilities and updating them on a regular basis.

Keywords: Energy efficiency; utility regulation; shareholder incentives; shared-savings incentive mechanism; ratepayer funds

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1. INTRODUCTION

Energy efficiency is increasingly being recognized as a preferred resource warranting aggressive public investment. For policy makers, escalating energy costs reflected in the economy, mounting concerns over global warming and associated regulatory demand for mitigation measures, and increasing energy dependency on politically unstable regions all contribute to a heightened awareness of the need for increased energy efficiency. For utilities, particular concerns are rising fuel prices; increasing uncertainty about cost-recovery for "steel-in-the-ground" investments; and intimidating environmental costs, in particular, potential carbon emission reduction costs. Improving energy efficiency is one of the most cost-effective ways to positively address these challenges.

As a necessary first step to justify a substantial expansion of energy efficiency programs, particularly of those administered by investor-owned utilities, many utility regulators are currently taking a serious look at a variety of utility shareholder incentives for energy efficiency programs that are being considered or are already in place in many states in the U.S. Along with the interest in shareholder incentives, the state of California has committed the unprecedented sum of $2.2 billion in ratepayer funds to utility-based energy efficiency programs from 2006 through 2008 and finalized in 2007 the determination of its shared-savings incentive mechanism for the 2006-2008 programs and beyond (CPUC 2007). A rigorous scrutiny of California energy efficiency programs and the associated incentive mechanism could assist the state in delivering energy efficiency more effectively, while ensuring political support for the programs.

This research focuses on California energy efficiency programs, which employ the shared-savings incentive mechanism. The incentive mechanism, by definition, specifies how large a share of the net monetary benefits created by program implementation the utility shareholders would be allowed to acquire. This paper aims to examine whether the adopted shared-savings incentive mechanism can ensure an efficient delivery of the energy efficiency programs, and what reforms, if any, could be proposed to meet this end. The crucial question is whether the adopted incentive rate for the mechanism is appropriate not only to prompt utility managers to commit their resources to the achievement of the energy savings targets adopted by the California Public Utilities Commission (CPUC) but also to maximize net social benefits.

Versions of shared-savings incentive mechanisms adopted by several states vary in their specification of an incentive rate. Eto, et al. (1998) report that, before the market restructuring, shared-savings incentive payments to seven electric utilities in states such as California, New York, and New Jersey accounted for from 8% to 27% of the net benefits derivable from demand-side management programs. Most of these incentive rates are more aggressive than the one adopted by California, which ranges up to 9-12%. Unfortunately, there is no evidence that serious scrutiny has been given to the establishment of those incentive rates. The CPUC also admitted that "Establishing the level of earnings opportunity for a shareholder risk/reward incentive mechanism is ultimately a judgment call that the Commission must make, and not a precise science" (CPUC 2007).

There is no consensus in the literature either. On the basis of a simplified shared-savings incentive model, Stoft, et al. (1995) propose that the incentive rate of 100% is efficient because then the utilities' profit would equal the net social benefits.[1] However, their suggestion is not appropriate for the energy efficiency programs in California because their study presumes that (i) unlike in the California case, regulators do not have any preset

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[1] This proposal is consistent with the one made earlier by Loeb and Magat (1979) that, in utility regulation, it is efficient to allow the utility to name its own service price and to subsidize the utility on a per unit basis equal to the consumer surplus at the price.

performance targets and only care about the net social benefits and (ii) there is no strategic interaction between utilities and regulators, which is likely to be prevalent in program funding proposals and authorization. More importantly, the proposition made by Stoft, et al. is not politically feasible because the incentive mechanism would then guarantee the monopoly position of utilities in the delivery of energy efficiency. While they advise the imposition of a lump-sum charge on utilities, none of the reported mechanisms has offered an incentive rate close to 100% along with such a lump-sum charge (Eto, et al. 1998).

Considering a more general setting, called the "sharecropping" model, several authors provide some insights into the landlord-worker relationship, which appears to be similar to the CPUC-utilities relationship in California's energy efficiency programs. Hurwicz and Shapiro (1978) find that a 50% split is optimal for a broad class of reward schemes to maximize the landlord's residual gain, namely, the part of output net of reward payment to the worker. Based on the model in which a random state of nature as well as actions taken by the worker determines an overall gain, Holmstrom (1979) shows that, without removing an efficiency loss due to the risk-averse nature of the worker, the performance-based sharing policy adopted by the risk-neutral landlord could encourage the worker to take costly action that produces the greatest possible *ex-ante* residual gain for the landlord. These sharecropping models, however, do not apply to the California case. In addition to the same problems that arise with the proposal of Stoft, et al. (1995), the models suffer from the reality that what is to be maximized in the California case is the net social benefit, not necessarily the customers' bills savings as in the models, and that the utility expenditures are funded by the customers themselves, not by the utilities. To my knowledge, no study has investigated the efficient design of a shared-savings incentive mechanism in connection with landlord-funded programs that are in place to accomplish the maximum net social benefit while ensuring the achievement of preset performance targets.

It is also useful to note that the California case allows us to relate efficiency implications of performance-based incentives, which have been intensively studied in the literature, to their allocative implications, which have mostly been underemphasized therein. A possible reason for the lack of this connection in the literature is the researchers' practice of constructing a generic model based on simplifying assumptions, which may enable them to derive qualitative requirements for social efficiency but often keep them from extracting useful allocative insights from the model. Other reasons may be that there is no objective basis for assigning particular weights for the welfare of different stakeholders, or that welfare allocation has not, in fact, been perceived as a critical issue. However, in the California case, the welfare allocation issue must be seriously taken into account. In fact, how much earnings the utilities should be allowed to garner in comparison with their customers' bill savings has been one of the most debated issues throughout the rulemaking process of designing the shared-savings incentive mechanism. This paper answers the questions, (i) how would the welfare allocations to the stakeholders vary with the specifications of the mechanism? and (ii) how would the program efficiency be affected accordingly?

The entire paper is organized as follows: Section 2 presents background of the research by reviewing the proceedings on California's energy efficiency programs. Section 3 builds an economic model and analyzes the implementation of the programs. Section 4 then shows numerical analysis results drawn from the economic model and discusses policy implications. Finally, Section 5 reviews the important findings presented in this paper.

2. BACKGROUND OF THE STUDY

Under traditional ratemaking practices, no utility has an incentive to deliver energy efficiency even if the utility's costs are guaranteed to be reimbursed. This is primarily because once rates are set, the utility earns extra return if *ex-post* sales exceed projected sales, but loses if *ex-post* sales fall below the projection. It follows that the utility would have incentives to be in favor of supply-side investment even if cost-effective energy efficiency measures were available. To reconcile the conflict between utilities' interest in higher sales and increasing public interest in energy efficiency, many Public Utilities Commissions (PUCs) have authorized or are considering revenue decoupling mechanisms for electric or natural gas utilities. The term revenue decoupling refers to a rate adjustment mechanism that simply ensures that utilities' approved costs, including an allowed rate of return, are recovered regardless of the *ex-post* fluctuation of retail sales.

It should be noted, however, that revenue decoupling is necessary but not sufficient for encouraging utilities to deliver energy efficiency (Bachrach, et al., 2004). In effect, under most ratemaking structures with revenue decoupling, utility shareholders' earnings opportunities are restricted to a return on supply-side investments that can be added to the rate base. Thus utility managers who aim to first and foremost consider shareholder value in their business activities have a clear incentive to promote supply-side resources, rather than energy efficiency.

Shareholder incentives are a commonly used approach for states that have a regulatory commitment to utility-based energy efficiency which goes beyond addressing problems of lost revenue. As of 2007, eighteen states have provided various types of energy efficiency program incentives to investor-owned utilities (Kushler, et al. 2006; National Action Plan for Energy Efficiency 2007). Among these shareholder incentives, shared-savings incentives are receiving the greatest attention because they explicitly account for both the benefits and the costs of energy efficiency programs and can therefore guarantee an economically efficient delivery of energy efficiency. By 1998, shared-savings incentives had been adopted by utilities in at least sixteen states (Eto, et al. 1998) and versions of the incentives are currently in place in six states including the state of California (National Action Plan for Energy Efficiency 2007).

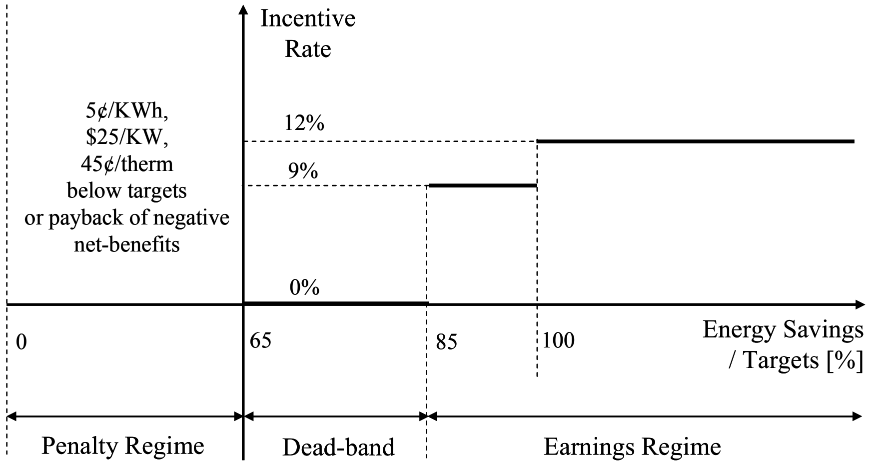

Figure 1 California's shared-savings incentive mechanism (Source: CPUC (2007))

Figure 1 illustrates the shared-savings incentive mechanism adopted by the CPUC in 2007. The figure indicates that the adopted mechanism is, in effect, a "letter-graded" system: (i) utilities start to receive tiers of reward over the threshold percentage savings of 85% relative to the CPUC-adopted energy savings targets; (ii) utilities are penalized under the threshold percentage savings of 65%; and (iii) utilities receive neither reward nor penalty over the dead-band between the two thresholds. The CPUC estimates that, once the targets are *precisely* met, the 2006-2008 programs based on the incentive mechanism will create a net benefit of $2.7 billion ($2.4 billion ratepayer savings and $0.3 billion shareholder earnings) from a $2.2 billion investment in energy efficiency (CPUC 2007). The CPUC has made it clear that the adopted incentive mechanism will be in effect over the 2006-2008 programs and subsequent program cycles until further notice (CPUC 2007).

The letter-graded mechanism makes utilities' earnings dependent not only on the net program benefits produced by energy efficiency program implementation, but also on their *ex-post* energy savings. This characteristic of the incentive mechanism is consistent with the CPUC's goals for energy efficiency programs, namely, maximizing net social benefits *and* meeting preset energy savings targets, as pointed out in the Energy Efficiency Policy Manual: "The Commission's overriding goal guiding its energy efficiency efforts is to pursue all cost-effective energy efficiency opportunities over both the short- and long-term…The Commission translated this policy into specific annual and cumulative numerical goals for electricity and natural gas savings by utility service territory" (CPUC 2005b).

In theory, the purpose of any regulatory incentive is to encourage its agents to achieve certain regulatory objectives in the most efficient manner. It is expected that these objectives will ultimately maximize social welfare. When it comes to energy efficiency programs, such regulatory objectives have often taken the form of "dual goals": to attain the greatest possible net social benefits while ensuring the achievement of preset targets. With this dual-goals approach, utilities potentially earn nothing and may even lose money if they fail to accomplish the targets, despite having created substantial net benefits from energy efficiency program implementation.

There are two potential reasons why the incentive mechanisms for utility-based energy efficiency programs pursue a dual-goals approach rather than that of single net-benefit maximization. First, policy makers can elicit a greater net social benefit by deploying a series of energy efficiency programs, guided by particular energy savings targets, which can be updated when necessary. In doing so, the policy makers can advance energy efficiency in accordance with the resolution of a variety of market uncertainties that may affect the cost-effectiveness of pursuing energy efficiency. These uncertainties include unpredictable energy demands, utilities' effectiveness in delivering energy efficiency, and technological changes. This rationale is consistent with the CPUC's Decision 04-09-060, which established its energy savings targets for 2006 and beyond, permitting possible updates of these targets. Decision 04-09-060 reads: "…today's adopted savings goals reflect the expectation that energy efficiency efforts in their combined service territories should be able to capture on the order of 70% of the economic potential and 90% of the maximum achievable potential for electric energy savings over the 10-year period, based on the most up to date study of that potential…updates of these goals will be considered for the PY2009-PY2011 program cycle, based on updated savings potential estimates, accomplishment data and other evaluation studies, as appropriate" (CPUC 2004).

The second possible reason for policy makers to take the dual-goals approach concerns the funding for energy efficiency programs. Even in the absence of the abovementioned uncertainties, ratepayers may not support a substantial amount of energy efficiency funding, which increases their rates in the short-run, until they perceive significant bill savings over time. This, in turn, leaves utilities open to the risk of not recovering all of their program expenditures, which might lead to "window-dressing" efforts by the utilities in energy efficiency programs. It is, therefore, preferable that the policy makers authorize a series of energy savings targets as a means of restricting ratepayer funding for individual program cycles, thus, assuring the complete recovery of the program funding. Indeed, this strategy is being employed by the CPUC, as stated in its Decision 04-09-060: "In submitting proposed energy efficiency program plans and funding levels to meet the savings goals adopted by the Commission, the programs administrator(s) shall demonstrate that their proposed level of electric and natural gas energy efficiency program activities and funding is consistent with the Commission's-adopted electric and natural gas savings goals…Today's adopted goals take into consideration the practical limits to effectively increasing program funding and ramping up programs to capture the full economic potential of energy efficiency in the near term" (CPUC 2004).

Note, however, that while the letter-graded nature of the shared-savings incentive mechanism is necessary to accomplish the dual regulatory goals, the establishment of the mechanism itself may not be sufficient to align shareholder interests and ratepayer interests. To achieve the alignment of these interests, the incentive mechanism must provide sizeable earnings opportunities to utility shareholders. In this regard, it is crucial to recognize that predicted shareholder earnings from energy efficiency programs must be no less than utilities' opportunity costs associated with the management of the programs, which are not apparent to regulators and thus not reimbursed.[2] Such opportunity costs may include (i) hidden costs associated with paying managerial attention and reallocating limited organizational resources to the effective management of energy efficiency programs and (ii) costs associated with utility businesses foregone by the pursuit of energy efficiency, including shareholder earnings from supply-side projects that are displaced by energy efficiency programs (Stoft, et al. 1995).

It is also important to note that utilities' earnings opportunities suggested by a particular shared-savings incentive mechanism must take into account a dynamic process of energy efficiency program implementation, in which different entities strategically interact with each other. As discussed, California's energy efficiency programs will be implemented in such a way that, given the CPUC-adopted energy savings targets, individual utilities propose their own program plans and funding levels to meet the targets, get the proposals authorized by the CPCU, and begin to manage the programs. In this process, strategic interaction is likely to occur between utilities seeking to receive the greatest possible program funding and the CPUC seeking to authorize the least possible funding that will ensure the achievement of the targets.

Based on these considerations, I construct a game theory model, in which both a regulator who establishes a shared-savings incentive mechanism and a utility firm facing the opportunity costs of program management behave optimally at any stage of the implementation of energy efficiency programs. Because a higher level of abstraction will not offer rich insights into the model, I instead choose non-generic functions that allow for a close examination of the California case while permitting moderate loss of generality.

This research is by its nature applied. The main focus is not to obtain the first-best optimal regulatory process or mechanism for the delivery of public-funded programs in general, but rather to investigate the shared-savings incentive mechanism that has been adopted by the CPUC under its dual regulatory goals for the energy efficiency

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[2] The CPUC admitted the existence of such opportunity costs. The CPUC writes, "We concur with NRDC, SCE and others that all levels of management and personnel throughout the company, and not just within the energy efficiency division, need to be motivated to view energy efficiency as a core business activity in order to achieve the aggressive energy efficiency and environmental goals of the state" (CPUC 2007). In the same proceedings, the CPUC also made it clear that the incentive decision supports the 2003 Energy Action Plan, which requires regulatory actions to offer demand-side management rewards comparable to the return on supply-side investment, by stating "We conclude that supply-side comparability should be one, among other relevant considerations, in establishing the earnings potential under the incentive mechanism we adopt today."

programs. Many of the normative suggestions from the economic analyses that will follow are provided in the context of California's programs and its incentive mechanism. This more realistic approach is, nonetheless, inherently different from what is used for the *ex-post* assessment of program delivery and impacts. With the approach taken by this research, I can describe and predict how the energy efficiency programs will be delivered under the incentive mechanism and how the changes in a variety of market circumstances will affect the effectiveness of the programs. This paper starts with this perspective and direction.

3. THE ECONOMIC MODEL

The economic model presented here analyzes California's shared-savings incentive mechanism, which aims to achieve the dual goals of utility-based energy efficiency programs, that is, to achieve the greatest possible net social benefit while ensuring the achievement of preset energy savings targets. Note that successful implementation of the programs can be impeded by potential information asymmetry that may exist between utilities and their regulators. In particular, the regulators may not have complete information about how effective the utilities will be in the management of the programs, and the utilities may want to exploit the regulators' incomplete information (Baron and Myerson 1982; Joskow and Schmalensee 1986). The accommodation of information asymmetry could allow the analysts of the regulatory process to achieve more realistic insights into the implementation of energy efficiency programs.[3]

However, a benchmark analysis performed in the absence of information asymmetry is valuable because ignoring utilities' strategic behavior based on asymmetric information allows for a more focused look at the implications that the shared-savings incentive mechanism itself has for the implementation of energy efficiency programs. In this paper, I present an economic model by presupposing information symmetry according to which utilities, customers, and regulators all have the same information. Consistent with the California case, the entire process of program implementation is structured as follows:

- **Stage 1:** The regulator, given an energy savings target of $t \in (0, \infty)$, chooses an incentive rate of $r \in (0, 1]$ for the incentive mechanism.
- **Stage 2:** The firm with program management efficiency, $\theta \in (0, \infty)$, proposes funding[4] $K \in (0, \infty)$, which will be used for energy efficiency activities directed toward a customer base of size β. Then the regulator authorizes the proposal as long as K is no greater than the funding level that the fully-informed regulator estimates in order for the firm to achieve t.
- **Stage 3:** Once K is authorized, the firm manages the programs in such a way that it produces an energy savings level of $x \in [0, \infty)$ with an energy savings productivity of $e \in [0, \infty)$.

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[3] For a detailed analysis of utility-based energy efficiency programs under asymmetric information, see Eom (2008).

[4] Funding for energy efficiency programs will cover the so called Program Administration Costs (PAC), which consists of customer incentives and rebates, installation costs, operating costs, and marketing/outreach costs. The PAC differs from the Total Resource Costs (TRC), which also includes the costs paid by participants. Note that the incentive mechanism adopted by the CPUC employs the Performance Earning Basis (PEB) as its earnings basis, which is defined as the sum of 2/3 of the TRC-based net benefit and 1/3 of the PAC-based net benefit. The PAC-based net benefit, which is employed as the earnings basis in this study, is an overestimation of the PEB.

I will analyze the equilibrium of the model, in which the regulator and the utility firm behave optimally at any stage. Before going further, here are the definitions of key functions that will be used for the analysis.

• The Incentive Mechanism:

There is a shared-savings incentive mechanism by which earnings of the utility firm begin to accrue at a uniform incentive rate [5] of $r\ (> 0)$ if the firm's *ex-post* energy savings x meets or surpasses adopted target t. That is, if x is greater than or equal to t, for every dollar of net benefits, the firm appropriates r and the consumers take the rest, $1 - r$, whereas if x is lower than t, the firm acquires no earnings. Incentive mechanism R is then represented as follows:[6]

$$R = \begin{cases} r, & \text{if } x \geq t \\ 0, & \text{if } x < t. \end{cases} \tag{1}$$

This representation indicates that the marginal incentive rate is zero over $0 \leq x < t$, which is called the dead-band region, but surges to infinity at $x = t$. Therefore, the firm with this mechanism would have no incentives to increase *ex-post* energy savings x within the dead-band region, but would have substantial incentives to move at least to the upper-end of this region.

• The Gross Benefit of Energy Savings:

The determination of incentive payments to the firm based on the shared-savings incentive mechanism requires precise assessment of the gross benefit of energy savings produced by the energy efficiency programs for utility customers. This gross benefit is equivalent to the total avoided costs to the firm – supply-side generation, transmission, distribution, and environmental costs avoided by the energy savings. The gross benefit, denoted as B, can be a function of produced energy savings x and marginal energy savings benefit $\eta \in (0, \infty)$. Marginal energy savings benefit η refers to the change of total avoided costs to utility customers arising when produced energy savings change by one unit. η allows for the variation across different program cycles or different utility service territories. I assume that η is constant over x, that is, that the size of the supply-side investments avoided by the firm increases proportionately with its energy savings achievement.[7] I get, then

$$B = \eta\, x. \tag{2}$$

• Energy Savings:

The utility firm produces energy savings x from program funding K with an energy savings productivity of e. Energy savings productivity e increases with customer-oriented activities associated with (i) pursuing potential avenues for cost-effective energy savings opportunities throughout a program cycle and (ii) paying more attention to efficiently incorporating new information about individual customers' behavior in program portfolios in such a

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[5] For the welfare impacts of introducing another tier into the incentive rate, see Eom (2008).

[6] In fact, the CPUC-adopted shared-savings incentive mechanism shown in Figure 1 is more sophisticated than the mechanism (1). However, the simplified incentive mechanism can be valid for the analysis of the California case (i) if r is set high enough for the firm to always be encouraged to accomplish t and (ii) if there is no significant uncertainty associated with forecasting customers' participation and associated load impacts. If these assumptions hold, the firm will achieve at least t and thus appropriate r for every dollar of net program benefit because regulatory provision ensures that program funding will be developed to achieve t (CPUC 2004). I presuppose that the assumptions are fulfilled throughout this paper.

[7] To be precise, the proportionality assumption may not hold if the avoided costs depend on the time when any energy savings occur. In fact, in the 2006 Avoided Cost Update (CPUC 2006), the CPUC adopted correction factors to adjust the avoided costs during peak hours.

way that more energy savings can be elicited from authorized funding. For instance, having learned how to facilitate the penetration of high-potential measures into the customer base at lower costs, the firm may implement such measures on a larger scale by replacing some high-cost and low-potential measures, resulting in a decrease in the *ex-post* average cost of energy savings.[8]

To keep the analysis mathematically tractable, I assume that *ex-post* energy savings x are proportional to public funding K and that the marginal return of the fund is equivalent to the firm's energy savings productivity e, represented as follows:

$$x = e\,K. \tag{3}$$

• The Opportunity Costs of Managing Energy Efficiency Programs:

Utilities' energy efficiency activities incur sizeable opportunity costs, which may not be apparent to utility regulators and thus are not reimbursed through program funding. The opportunity costs include the hidden costs associated with energy efficiency program management and potential foregone shareholder earnings[9] from supply-side projects that are displaced by energy efficiency (Stoft, et al. 1995).

It is assumed that these opportunity costs associated with energy efficiency are increasing and convex with the firm's energy savings productivity e. The convexity assumption is sensible because the firm can only enhance energy savings productivity e with the adjustment of its organizational and financial resources, which are generally constrained, so that greater productivity incurs disproportionately higher costs to the utility firm. To keep the problem tractable without losing much generality, I chose a quadratic opportunity cost function, which is as follows:

$$\psi(e;\beta,\theta) = \frac{\beta}{2\theta}e^2, \tag{4}$$

Here, θ is the firm's program management efficiency, which contributes to lowering ψ, and β is the size of the firm's customer base, which raises ψ proportionately. That is, to achieve the same level of e, a firm will lose less when it has higher θ and a smaller β.

The variation in program management efficiency θ across utilities is attributable to their differences in codified or even tacit knowledge of program management, which has been acquired from prior implementation and evaluation of the programs. Such a knowledge asset can be embodied in well-established communication channels with the programs' participants, such as customers and subcontractors, and agility in incorporating information about energy savings opportunities into program designs. It would be fair to suppose that the individual utilities' program management efficiency is an idiosyncratic resource and that precise information about it may be inaccessible to other parties.[10]

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[8] The implementation process of energy efficiency programs determined by the CPUC allows individual utilities to enhance their energy savings productivity regarding the authorized programs. In fact, the funding for 2006-2008 includes funding for market penetration studies and process evaluations to assess which measures are working and which measures are not. On the basis of such information, the utilities can shift resources among budget categories within programs as well as across programs under the fund shifting rules (CPUC 2005c), providing the utilities with the flexibility to use their authorized funding to achieve even greater energy savings.

[9] Note that an economic interpretation of supply-side foregone earnings should account for the possibility that utility shareholders can put their investment money elsewhere, earning a return similar to the one they would have earned on the displaced supply-side investments.

[10] To lessen the extent to which utilities' informational advantage could impede efficient regulatory oversight, the CPUC ordered non-financially interested "Peer Review Groups" (PRGs) to be formed and review the utilities' proposed plans and funding proposals before they are submitted (CPUC 2005c).

Having stipulated the key functions, I now analyze the equilibrium of the model by employing the usual backward induction.

• Stage 3: The Firm's Program Management

In the pursuit of energy efficiency, the firm balances gross shareholder earnings (i.e., a share of a net program benefit) with the associated opportunity costs. To be precise, with the choice of energy savings productivity e, the firm maximizes its cost-adjusted earnings from energy efficiency program management or, equivalently, net earnings on energy efficiency. The maximum net earnings on energy efficiency are then represented as follows:

$$\begin{aligned} U &= \max_{e} \ R(B-K)_{+} - \psi \\ &= \max \left\{ \max_{e \geq \frac{t}{K}} r(\eta e K - K) - \frac{\beta}{2\theta} e^2, \quad \max_{e < \frac{t}{K}} - \frac{\beta}{2\theta} e^2 \right\}. \end{aligned} \tag{5}$$

As shown, a higher marginal energy savings benefit (i.e., higher η), a higher incentive rate (i.e., higher r), or greater program funding (i.e., higher K) enhances the firm's gross earnings, whereas higher program management efficiency (i.e., higher θ) or a smaller size of the customer base (i.e., lower β) reduces the firm's opportunity costs. For convenience, I will call the first group of changes (i.e., higher η, higher r, and higher K) the *earnings-enhancing factors*, and the latter group of changes (i.e., higher θ and lower β) the *cost-reducing factors*.

The right term in the brackets of (5) indicate the case in which the utility firm expects that no matter how productive it is in the management of the energy efficiency programs, the programs will result in a net cost (i.e., no earnings basis that can be shared between the firm and its customers); the firm then decides not to produce any energy savings, resulting in the net earnings of zero. The zero earnings can be thought of as reservation earnings for the firm, which are given regardless of its program performance.

However, if a sufficient level of net program benefit is expected, the firm will be encouraged to manage the energy efficiency programs with the following level of energy savings productivity:

$$e^* = \frac{\eta r \theta K}{\beta}. \tag{6}$$

I call this the *profitable-and-optimal* level of energy savings productivity, by which the firm can acquire the non-negative and maximum net earnings – the left term in the brackets in (5). Equation (6) establishes that both the earnings-enhancing factors (i.e., higher η, higher r, and higher K) and the cost-reducing factors (i.e., higher θ and lower β) prompt the firm to enhance its energy savings productivity.

Substituting (6) for (5) results in the firm's maximum net earnings with optimal energy savings productivity e^*, given as

$$U = \max \left\{ \frac{\eta^2 r^2 \theta}{2\beta} K \left(K - \frac{2\beta}{\eta^2 r \theta} \right), \quad 0 \right\}. \tag{7}$$

It follows that e^* is chosen by the firm only when the energy efficiency programs and the associated funding fulfill the following constraint:

$$K \geq \frac{2\beta}{\eta^2 r \theta}. \tag{8}$$

This is referred to as the *firm's participation constraint*, which ensures that the firm will produce energy savings by exhibiting profitable-and-optimal energy savings productivity e^*, rather than zero productivity for seeking the reservation earnings. Constraint (8) suggests that the earnings-enhancing factors and the cost-reducing factors can be compensated for by decreased program funding to ensure the firm's participation in program management.

• Stage 2: The Firm's Funding Proposal

Following the provision that requires any funding proposal to be developed to meet t, the regulator will expect K to be no greater than what the utility firm needs to just meet t with its profitable-and-optimal level of energy savings productivity e^*, so that

$$x^* = e^* K \leq t. \tag{9}$$

Then the firm will propose the greatest possible program funding $\tilde{K}$, such that constraint (9) is fulfilled. Plugging (6) into the equality form of (9) yields the firm's proposal

$$\tilde{K} = \left(\frac{\beta t}{\eta r \theta}\right)^{1/2}, \tag{10}$$

which I term the *justifiable funding level*. This equation indicates that the firm is required to propose a *lower* level of $\tilde{K}$ with either the earnings-enhancing factors (i.e., higher η and higher r) or the cost-reducing factors (i.e., higher θ and lower β).

The intuitive explanation for (10) is that, with the earnings-enhancing factors or the cost-reducing factors, the firm is encouraged to achieve a higher level of energy savings productivity e^*, as shown in (6). By utilizing the firm's motivation, the regulator can authorize lower program funding while still ensuring the achievement of its preset target t. It is obvious that higher t allows the firm to propose higher $\tilde{K}$.

Note that the equilibrium of program implementation is that the utility firm proposes $\tilde{K}$, gets the proposal authorized by the regulator, and yields e^* in program management to achieve t. Substituting (10) for (6) results in the firm's profitable-and-optimal level of energy savings productivity at equilibrium, given as

$$e^* = \left(\frac{\eta r t \theta}{\beta}\right)^{1/2}. \tag{11}$$

This equation, in comparison with (6), suggests that the productivity-augmenting effects of the earnings-enhancing factors (i.e., higher η and higher r) and the cost-reducing factors (i.e., higher θ and lower β) are, to some extent, mitigated by the regulator's incentive to exploit the augmented productivity in its funding authorization.

Moreover, the utility firm's opportunity costs at equilibrium are represented as

$$\psi(e^*; \beta, \theta)|_{K=\tilde{K}} = \frac{\eta r t}{2}, \tag{12}$$

establishing that the earnings-enhancing factors (i.e., higher η and higher r), not the cost-reducing factors (i.e., higher θ and lower β), affect the firm's opportunity costs. Note that the firm's cost-reducing factors, in effect, have nothing to do with its opportunity costs. The reason is that the direct effect of the cost-reducing factors on the opportunity costs is, at equilibrium, offset by the factors' indirect effect on the opportunity costs through an increase in e^*. Yet, the earnings-enhancing factors only raise the firm's opportunity costs in terms of raising e^*.

Equation (12) further indicates that the firm's opportunity costs at equilibrium are proportional to energy savings target t. This result is sensible for most utility-based energy efficiency programs because, as the programs expand, utilities' foregone earnings from supply-side investments and their hidden managerial costs are likely to increase proportionately.

• Stage 1: The Regulator's Incentive Decision

Now given the motivation of the regulator and the firm, I can derive a set of incentive rates to ensure that the firm exhibiting energy savings productivity e^* will achieve preset target t by utilizing justifiable funding $\tilde{K}$. Such a set is obtained by plugging the justifiable funding level (10) into the firm's participation constraint (8) and is represented as follows:

$$\frac{4\beta}{\eta^3\theta t} \le r \le 1. \tag{13}$$

I call this the *jointly sufficing constraint,* in the sense that any r fulfilling the constraint guarantees that the firm's management of the programs will achieve target t, while bringing non-negative net earnings to the firm and non-negative bill savings to the customers. It follows that as long as the programs fulfill (13), the programs pass not only the net program benefit criterion, namely, $\eta x - K \ge 0$, but also the net social benefit criterion, namely, $\eta x - K - \psi \ge 0$, which includes the firm's opportunity costs; the fulfillment of both of these criteria justifies the implementation of the programs. Put differently, the regulator must explicitly consider the jointly sufficing constraint in the design of an incentive mechanism since, otherwise, the mechanism might preempt the firm's incentive to produce energy savings, resulting in net costs to society, which completely eliminates political support for energy efficiency program implementation. This requirement is summarized as follows:

Proposition 1: *The regulator's choice of r must fulfill the jointly sufficing constraint, so that the firm's program management will make both the firm and its customers weakly better off.*

The jointly sufficing constraint (13) implies that the regulator can establish a lower incentive rate (i.e., lower r), given with a higher marginal energy savings benefit (i.e., higher η), higher program management efficiency (i.e., higher θ), and a higher per-customer energy savings target (i.e., higher t/β). The regulator can do so because all of these factors offer the firm opportunities to gain greater net earnings, which can be offset by lowering the incentive rate, while still ensuring the firm's participation in the programs.

For ease of terminology, I call any incentive rate fulfilling the jointly sufficing constraint (13) a *jointly sufficing rate*, and I call the lower bound of the constraint, $4\beta/\eta^3\theta t$, the *minimum sufficing rate*, which is denoted as r_{min}. Here I introduce a useful synthetic parameter, ξ, defined as

$$\xi\left(t, \eta, \beta, \theta\right) \equiv \frac{\eta^3\theta t}{4\beta} = \frac{1}{r_{min}}. \tag{14}$$

Then the jointly sufficing constraint (13) is rewritten as

$$1/\xi \le r \le 1. \tag{15}$$

I call the synthetic parameter, ξ, the *design flexibility* because it indicates how much earnings opportunities the programs can provide to the firm and thus represents the extent to which the regulator is flexible in its choice of a jointly sufficing rate. As indicated by (15), higher ξ broadens the range of jointly sufficing rates and thus offers a more *complete* set of design choices to the regulator.

Design flexibility ξ has important characteristics. First, ξ is determined by per-customer energy savings target t/β, marginal energy savings benefit η, and the firm's program management efficiency θ in a substitutive manner. For instance, for the same level of ξ, lower t/β can be compensated for by either higher η or higher θ. Thus the regulator may face the same set of jointly sufficing rates even under dissimilar regulatory or market circumstances exhibiting different t/β, η, or θ, as long as the parameters collectively allow for the same ξ. Second, if any working incentive mechanism is to exist, ξ must be greater than or equal to one. In other words, if some of the parameters were so low that the other parameters could not compensate in order to yield $\xi \ge 1$, no incentive rate would be workable for the incentive mechanism.

Having analyzed the equilibrium of the entire process of energy efficiency program implementation, I go back to the question of how the programs can accomplish the dual regulatory goals, namely, producing the greatest possible net social benefit while ensuring the achievement of preset energy savings targets. Under the scenario in which the regulator chooses a jointly sufficing rate, meeting target t is achieved through the equilibrium implementation of the programs. To be precise, given a jointly sufficing rate (at Stage 1), the firm proposes justifiable funding $\tilde{K}$, gets the proposal authorized by the regulator (at Stage 2), and manages the programs with the profitable-and-optimal level of energy savings productivity e^{*}, achieving energy savings target t, no more or less (at Stage 3).

What remains is the maximization of the *net social benefit* that is derivable from the energy efficiency program implementation. Let W represent the net social benefit. Let U and V be the firm's net earnings and the customers' bill savings, respectively. This research defines W as the sum of U and V. Thus what should be maximized through the program implementation is net social benefit W that includes the utility firm's opportunity costs of managing energy efficiency programs, not the one that precludes such costs.[11]

To derive conditions ensuring the maximization of the net social benefit, I first identify both the firm's net earnings and the customers' bill savings at equilibrium. Given r, t, and η, the utility firm with β and θ acquires the following net earnings on energy efficiency:

$$\begin{aligned} U(r;t,\eta,\beta,\theta) &= r(\eta t-\tilde{K})-\psi(e^{*},\beta,\theta)|_{K=\tilde{K}} \\ &= \frac{\eta rt}{2}-\left(\frac{\beta rt}{\eta\theta}\right)^{1/2}. \end{aligned} \tag{16}$$

As a result, the firm's customers receive, in the aggregate, the following bill savings:

$$\begin{aligned} V(r;t,\eta,\beta,\theta) &= (1-r)(\eta t-\tilde{K}) \\ &= (1-r)\left\{\eta t-\left(\frac{\beta t}{\eta r\theta}\right)^{1/2}\right\}. \end{aligned} \tag{17}$$

Again, as pointed out by Proposition 1, both $U(r;t,\eta,\beta,\theta)$ and $V(r;t,\eta,\beta,\theta)$ are non-negative as long as adopted incentive rate r fulfills the jointly sufficing constraint (15). The net social benefit are then given as

$$\begin{aligned} W(r;t,\eta,\beta,\theta) &= \eta t-\tilde{K}-\psi(e^{*},\theta)|_{K=\tilde{K}} \\ &= \eta t\left(1-\frac{r}{2}\right)-\left(\frac{\beta t}{\eta r\theta}\right)^{1/2}. \end{aligned} \tag{18}$$

Having specified the complete representation of the net social benefit, the incentive rate that will prompt the firm to produce the maximum net social benefit is obtained by solving the usual maximization problem for equation (18) subject to the jointly sufficing constraint (15). The socially efficient incentive rate is given by the following proposition:

Proposition 2: *The socially efficient incentive rate* r^{S*} *is given by*

$$r^{S*}=\begin{cases} (1/4\xi)^{1/3}, & \text{if } \quad \xi>2 \\ 1/\xi, & \text{if } 1\leq\xi\leq 2. \end{cases}$$

This proposition indicates that socially efficient incentive rate r^{S*} is piece-wise over the ranges of design flexibility ξ, where $\xi\geq 1$ must hold for the existence of any jointly sufficing rate. If $\xi>2$, it is socially efficient

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[11] The net benefit that precludes opportunity costs is a metric is called the net program benefit and is used in this paper as an earnings basis for the shared-savings incentive mechanism.

to adopt the interior solution, $r = (1/4\xi)^{1/3}$, instead of the corner solution, $r = 1/\xi \equiv r_{min}$. This is because such a sizeable level of ξ offers a complete set of design choices, within which the regulator can establish the interior solution that balances the marginal social benefit of adopting higher r (i.e., a decrease in justifiable funding $\tilde{K}$) and associated marginal social cost (i.e., an increase in opportunity costs ψ^*). In this case, the firm acquires strictly *positive* net earnings.

By contrast, if $1 \leq \xi < 2$, the corner solution, $r = 1/\xi$, must be chosen for social efficiency. The reason is that such a limited level of ξ already requires an r so high that no interior solution could produce a greater social net benefit. In this case, the firm, in effect, gains *nothing* from the program management because its gross earnings are exactly offset by its opportunity costs. Consequently, the level of ξ determines whether or not the corner solution, $r = 1/\xi$, should be established and whether or not the firm will eventually become better off with the program management.

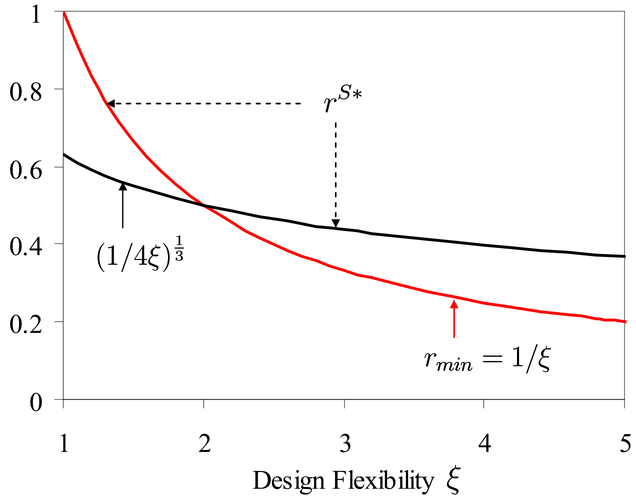

Figure 2 Socially efficient incentive rate r^{S*} with respect to ξ (≥ 1)

Figure 2 illustrates socially efficient incentive rate r^{S*} with respect to ξ (≥ 1), where r^{S*} corresponds to the upper envelope of the two crossing curves, $(1/4\xi)^{1/3}$ and $1/\xi$. The figure indicates that, regardless of the ranges of ξ, the higher the level of ξ, the lower the level of r^{S*}. This is represented as a simple corollary to Proposition 2**.**

Corollary: r^{S*} *decreases with* ξ (≥ 1)*, so that* $dr^{S*}/d\xi < 0$.

It is important to note that the relationship between ξ and r^{S*} holds even with $\xi > 2$. This is because, with a higher level of ξ, the marginal cost of adopting a higher incentive rate (i.e., an increase in ψ^*) rises faster than the associated marginal benefit (i.e., a decrease in $\tilde{K}$). In contrast, with a lower level of ξ, a higher incentive rate can be established because the associated marginal benefit (i.e., a decrease in $\tilde{K}$) will rise faster than the associated marginal cost (i.e., an increase in ψ^*).

The corollary has significance for an efficient design of a shared-savings incentive mechanism. The corollary indicates that, *ceteris paribus*, a lower incentive rate (i.e., lower r) is socially efficient for energy efficient programs with a higher per-customer energy savings target (i.e., higher t/β), for those managed by a firm with higher program management efficiency (i.e., higher θ), and for those implemented in utility service areas with a higher marginal energy savings benefit (i.e., higher η).

Emerging from the above analysis is the fact that the efficient incentive rate or any single incentive rate, in general, may not best represent the preferences of the utility firm and its customers. To illuminate the implications of any adopted incentive rate for the firm and its customers, I obtain their preferred incentive rates by solving the maximization problems for (16) and (17), both subject to (15), which leads to the following propositions:

Proposition 3: *The firm prefers to receive all of a net program benefit generated by its management of the programs. That is, the firm's preferred incentive rate* r^{F*} *is one.*

Proposition 4: *The customers' preferred incentive rate* r^{C*} *that will be provided to the firm is given by*

$$r^{C*} = \begin{cases} \rho^C(\xi), & \text{if} \quad \xi > 3 \\ 1/\xi, & \text{if } 1 \leq \xi \leq 3, \end{cases}$$

where $\rho^C(\xi)$ *is a function that is given by the first-order optimality condition for* (17).

While the firm's solution r^{F*} is straightforward, the customers' preferred incentive rate r^{C*} is piece-wise over the ranges of ξ, as is the socially-optimal incentive rate r^{S*}. Proposition 4 indicates that if $\xi > 3$, the customers prefer the interior solution, $r = \rho^C$, rather than $r = 1/\xi \equiv r_{min}$. The reason is that such a sizeable level of ξ offers a more complete set of design choices, within which the customers can find the interior solution that balances their marginal benefit of allowing higher r (i.e., an increase in a net program benefit due to a decrease in $\tilde{K}$) and the associated marginal cost (i.e., a decrease in the customers' share of the net program benefit). In this case, the customers' solution will permit the firm to acquire strictly positive net earnings.

By contrast, if $1 \leq \xi \leq 3$, the customers prefer the corner solution, $r = 1/\xi$. This preference is warranted because such a limited level of ξ already requires an r so high that no interior solution could produce greater bill savings to the customers. In this case, the firm's net earnings are exactly offset by the associated opportunity costs, and therefore the firm gains nothing from the program management. Consequently, the level of ξ determines whether or not the corner solution, $r = 1/\xi$, will be preferable for the customers and whether or not the customers' solution will allow the firm to be better off with the program management.

Propositions 2 through 4 collectively suggest that the regulator's choice of an incentive rate has different implications for the firm, its customers, and society as a whole. Figure 3 illustrates the firm's net earnings U, the customers' bill savings V, and net social benefit W as a function of adopted incentive rate r, which is jointly sufficing. These relationships are also shown under different circumstances, which can be represented by different ranges of design flexibility ξ, that is, $1 \leq \xi \leq 2$, $2 < \xi \leq 3$, and $\xi > 3$. Figure 3 indicates that U is convex and that both V and W are concave in r regardless of ξ (≥ 1). However, the first-order effects of r on V and W differ by the ranges of ξ: (a) for $1 \leq \xi \leq 2$, both V and W are monotonically decreasing in r; (b) for $2 < \xi \leq 3$, V is monotonically decreasing, but W is non-monotone in r; and (c) for $\xi > 3$, both V and W are non-monotone in r. These first- and second-order effects, along with Propositions 2 through 4, lead to the following proposition:

Proposition 5: *When there exists any jointly sufficing incentive rate, that is,* $\xi \geq 1$*, the socially efficient incentive rate* r^{S*} *lies between the customers' preferred incentive rate* r^{C*} *and the firm's preferred incentive rate* r^{F*}*, which is represented by*

$$\frac{1}{\xi} \leq r^{C*} \leq r^{S*} \leq r^{F*} = 1,$$

where the strict inequality $r^{S*} < r^{F*}$ *holds for* $\xi > 1$, $r^{C*} < r^{S*}$ *holds for* $\xi > 2$, *and* $1/\xi < r^{C*}$ *holds for* $\xi > 3$.

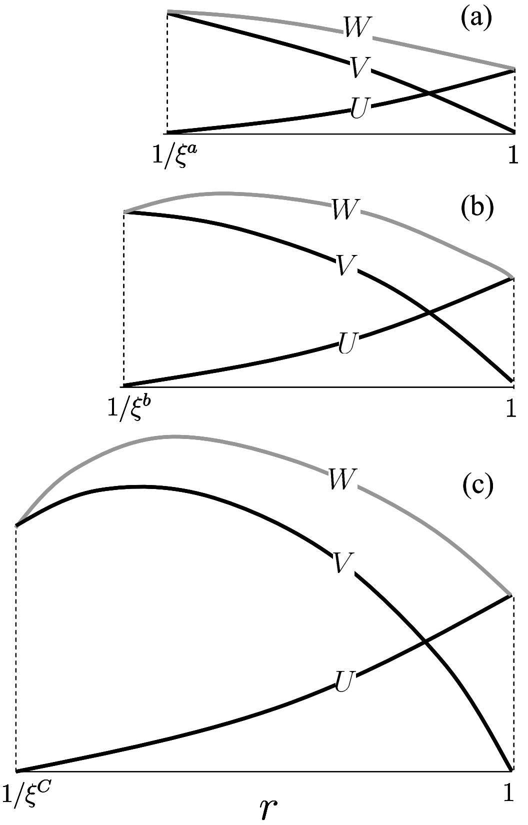

Figure 3 Impacts of jointly sufficing rate r on U, V, and W under different ranges of design flexibility ξ: (a) $1 \leq \xi \leq 2$, (b) $2 < \xi \leq 3$, and (c) $\xi > 3$

Proposition 5 enables us to answer the overarching question of whether or not an alignment of the utility firm's interests and its customers' interests regarding the implementation of energy efficiency programs would be *sufficient* to accomplish the maximization of net social benefit. The interests of these two parties can be said to be *aligned* if the adopted incentive mechanism ensures (i) the firm will view its management of the energy efficiency programs as one that can generate meaningful shareholder earnings – earnings that are greater than or equal to the firm's opportunity costs of managing the programs – and (ii) the customers expect that they will be protected against any financial losses on their investment. That is, the alignment of interests is guaranteed when the programs bring about a Pareto improvement relative to the status quo. In this regard, the above analysis makes it clear that such an alignment can be accomplished if the adopted incentive rate r is at least as high as the minimum sufficing rate, that is, if $r \geq 1/\xi \equiv r_{min}$.

However, Proposition 5 also suggests that the mere alignment of the interests of the utility firm and its customers may not be sufficient to generate the greatest possible net social benefit. Suppose, for instance, that the regulator adopts the minimum sufficing rate in an attempt to align the stakeholders' interests regarding energy efficiency program implementation, while avoiding potential backlash from the customers. Such an alignment maximizes net social benefit only if ξ is relatively limited such that $1 \leq \xi \leq 2$. If $\xi > 2$, however, a higher level of r is warranted for social efficiency.

Further insights are derived from the possible case when the regulator is concerned only about the customers' bill savings in the design of the incentive mechanism. Proposition 5 indicates that if $1 \leq \xi \leq 3$, the minimum sufficing rate, $r = 1/\xi$, will not only align the stakeholders' interests but also generate the greatest possible bill savings for the customers. If $\xi > 3$, however, a higher level of r must be established to achieve the greatest possible bill savings for the customers.

In sum, the level of design flexibility ξ determines whether or not the alignment of the stakeholders' interests with only the minimum sufficing rate, $r = 1/\xi$, will suffice to achieve the maximization of both net social benefit and the customers' bill savings and whether or not a higher incentive rate is warranted.

4. ENERGY EFFICIENCY PROGRAMS IN CALIFORNIA

The economic model developed in the past sections can be used to predict the performance of California energy efficiency programs over 2009-2011 and beyond, in that the implementation processes for each of those program cycles will be consistent with the timing of the model: the CPUC adopts energy savings targets and the share-savings incentive mechanism before utilities propose their energy efficiency program plans and associated funding levels, get the proposals authorized by the CPUC, and begin to manage the programs. Recognizing that each utility's production of energy savings will perforce be optimal under the incentive mechanism, the CPUC authorizes the utility's funding proposal as long as it is no greater than the level the CPUC estimates for the optimizing utility to meet its energy savings target. Then the CPUC-adopted energy savings targets are achieved by the equilibrium of program implementation: once the CPUC adopts a jointly sufficing incentive rate, each utility proposes the CPUC-projected level of program funding, gets the proposal authorized, and manages the programs with its optimal level of energy savings productivity. If the jointly sufficing rate is identical to the socially efficient incentive rate, the CPUC accomplishes the maximization of net social benefit as well.

The model-based prediction of program performance should be treated with caution because the model is built on several simplifying assumptions, which may be too restrictive to reflect practical features of California energy efficiency programs. First, the economic model does not consider the risk that, given *ex-ante* appropriate funding, utilities will fail to achieve preset energy savings targets. The utilities' risk of substandard performance may be attributable to uncertainties associated with forecasting the penetration of individual measures into the market and their associated energy savings impacts.[12] Second, utilities' supply of energy savings and their associated opportunity costs may not exhibit the nice properties assumed by the model. For instance, the linearity assumption made for program funding and resultant energy savings does not take into account the fact that, particularly with

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[12] This risk may not be significant in the California case not only because the utilities can manage the risk by diversifying their program portfolios, but also because the CPUC allows the utilities to shift resources within programs as well as across programs as they become more informed about which measures are working and which are not.

the considerable amount of program funding available in the California case, the program portfolios can comprise a broad range of energy efficiency measures of non-uniform cost-to-savings ratios. The simple quadratic opportunity cost assumption can constitute another source of inaccuracy by misrepresenting the extent to which each utility's energy efficiency activities impact its opportunity costs. Third, while our model defines an earnings basis for the incentive mechanism as the net program benefit based only on program administration costs (PACs: customer incentives and rebates, installation costs, operating costs, and marketing/outreach costs), the CPUC-adopted earnings basis metric reflects an additional two-thirds of participation costs paid by utility customers. Therefore, *ceteris paribus*, both the minimum sufficing rate and the socially efficient incentive rate for the CPUC-adopted incentive mechanism are likely to be *higher* than those suggested by the model. Fourth, the model cannot accommodate the feature that the CPUC evaluates the utilities' performance as an average of the percentage achievements of their cumulative targets[13] for electricity savings [GWh annual savings], peak savings [MW savings], and end-use natural gas savings [Mtherm annual savings] – all of which have different benefit impacts. This is because funding for the energy efficiency programs cannot be separated by the three types of energy savings. Subsequent numerical analysis thus assumes that electricity savings performance will vary proportionately with peak savings and natural gas savings, so that a utility's electricity savings performance is representative of the utility's overall program performance.

4. 1 Parameters for the Economic Model

Given these caveats, I calculate two important model parameters, which will be used to predict the performance of the 2009-2011 energy efficiency programs. One is the *marginal energy savings benefit* [$ / MWh annual savings], which refers to the lifetime avoided costs to the utility customers of an average energy efficiency measure producing one MWh annual savings.[14] The second model parameter is the utility's *program management efficiency* [MWh annual savings squared / $ cubed], which is a normalized measure representing how much less the utility would lose due to energy efficiency activities. The two model parameters are calculated by using information about the 2006-2008 programs, whose details are stipulated in the CPUC proceedings for energy savings targets and funding authorization.

According to the CPUC proceedings, (i) the three-year cumulative electricity savings targets[15] for the 2006-2008 programs are 2,826GWh for PG&E, 3,135GWh for SCE, and 850GWh for SDG&E, (ii) the authorized program administration costs[16] (PACs) over the program cycle are $959 million for PG&E, $661 million for SCE, and $266 million for SDG&E, and (iii) the gross benefit estimates[17] or, equivalently, lifetime avoided cost

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[13] Under the CPUC-adopted incentive mechanism, the utilities' energy savings performance of a three-year program cycle is assessed against their cumulative annual energy savings targets for that program cycle, so within the cycle, it does not make any difference when any particular measure is installed. However, total avoided costs (or, gross energy savings benefits), which are used to calculate an earnings basis, are of course based on the lifetime energy savings of any particular measure.

[14] Since the change in costs to the utility customers is equivalent to the change in net generation, transmission, distribution, and environmental costs, the marginal energy savings benefit is also the cost reduction to the utility avoiding those supply-side investments.

[15] CPUC (2004) established its energy savings targets for the 2006-2008 programs and beyond, permitting possible updates of these targets.

[16] See CPUC (2005c).

[17] CPUC (2005c) projected PAC benefit-cost-ratios (i.e., the ratios of lifetime avoided costs producible by installed measures to the total PAC expenditure) of 2.24 for PG&E's portfolios, 3.58 for SCE's, and 2.18 for SDG&E's. These figures, along with the utility-specific PACs, give the gross benefit estimates.

estimates for the program cycle are $2,148 million for PG&E, $2,366 million for SCE, and $579 million for SDG&E.

Dividing the gross benefit estimates by the electricity savings targets gives utility-specific estimates of marginal energy savings benefit regarding the 2006-2008 programs: 760 [$ / MWh annual savings] for PG&E's portfolios, 750 for SCE's, and 680 for SDG&E's. That is, an energy efficiency measure producing one MWh annual savings for each of its lifetime years is estimated to be worth, on average, $760 for PG&E, $750 for SCE, and $680 for SDG&E. The reduction in electricity sales – and thus in electricity generated and distributed – have similar values for PG&E and SCE, but slightly smaller values for SDG&E.

Moreover, the information from the CPUC proceedings suggests that the CPUC believed that PG&E would require, on average, $340 PACs[18] to induce its customers to install an energy efficiency measure producing one MWh annual savings; as noted, such a measure will create the benefit of $760 for PG&E customers over its lifetime. The counterpart numbers are $750 of benefits and $210 of PACs for SCE; $680 of benefits and $310 of PACs for SDG&E. Table 1 summarizes the impacts of an average energy efficiency measure producing one MWh annual savings over the 2006-2008 programs and the associated shareholder earnings under the CPUC-adopted incentive rate of 12%. As shown, SCE's shareholders are likely to gain the greatest earnings per one MWh annual savings largely due to its lowest average PACs.

Table 1 Average impacts of 2006-2008 energy efficiency measures

	Benefits / MWh annual savings	PACs / MWh annual savings	Net program benefits / MWh annual savings	Shareholder earnings / MWh annual savings (12% incentive rate)
PG&E	$760	$340	$420	$50
SCE	$750	$210	$540	$65
SDG&E	$680	$310	$370	$44

Consistent with the structure of the economic model,[19] we can interpret the inverse of the individual utilities' average PACs as their energy savings productivity over the 2006-2008 programs. The energy savings productivity is 2,940 [MWh annual savings / $million] for PG&E, 4,740 for SCE, and 3,190 for SDG&E. Seen from the fact that SCE was authorized to use relatively limited program funding ($661 million) for the accomplishment of its most ambitious target (3,135GWh), the CPUC could have believed that SCE would exhibit the greatest energy savings productivity in program management.

While the implementation process of the 2006-2008 programs has not been consistent with the timing of the economic model developed in this research,[20] the utilities' funding proposals and the above estimated levels of energy savings productivity could have reflected the utilities' optimizing behavior as suggested by the model, as long as the utilities and the CPUC had held the same belief of what an incentive rate would be like. I here conjecture that the utilities and the CPUC alike believed that an incentive rate for the incentive mechanism would

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[18] PG&E's average PACs, 340 [$ / MWh annual savings], are equivalent to paying annually $42 to avoid one MWh of electricity over average energy-efficiency measure life of 12 years (with the discount rate of 8%), which is far below the current price of electricity.

[19] Refer to Equation (3).

[20] The CPUC started, in April 2006, the rulemaking process of designing the incentive mechanism for the 2006-2008 and beyond. However, the funding authorization process for the 2006-2008 programs was finalized in September 2005.

range from 10 to 25%. This is a reasonable conjecture, in that shared-savings incentive payments to seven electric utilities before the market restructuring accounted for from 8% to 27% of the net benefits derivable from demand-side management programs (Eto, et al. 1998).

Assuming that the above estimated levels of energy savings productivity are *efficient* for the individual utilities, I now infer their program management efficiency. With the presumed incentive rate of 10~25% and the individual utilities' customer base,[21] the structure of the model returns the program management efficiency of 0.08~0.20 for PG&E, 0.18~0.45 for SCE, and 0.08~0.21 for SDG&E.[22] SCE appears to be most efficient in program management, whereas the efficiency of PG&E and SDG&E is about half that of SCE. These estimates of program management efficiency predict that, over the 2006-2008 programs, the opportunity costs incurred by the utilities if they all meet the energy efficiency targets will range from $255 to $510 million in aggregate: $106~264 million for PG&E, $117~294 million for SCE, and $32~80 million for SDG&E. It is useful to have these estimates because they establish the *minimum earnings requirement* that will induce the utilities to commit their organizational resources to the achievement of the energy savings targets.

Part of the utilities' opportunity costs associated with energy efficiency activities may be verified if one calculates the level of reduction in shareholder earnings from supply-side projects that are displaced by the 100% achievement of the energy savings targets. Such foregone shareholder earnings are referred to as "supply-side comparable earnings." The interpretation of supply-side comparable earnings as part of the utilities' opportunity costs can be reasonable because (i) the greater the energy savings that the utilities produce, the lower the returns that the utility shareholders will be authorized to earn from their supply-side investment and (ii) the utility managers are required to first and foremost consider the interests of their shareholders in their business activities. When the utilities' hidden costs of paying managerial attention to energy efficiency are also taken into account, the opportunity costs will surpass the supply-side comparable earnings.

It should be noted, however, that an economic interpretation of supply-side comparable earnings should account for the possibility that utility shareholders can put their investment money elsewhere, earning a return similar to the one they would have earned on the displaced supply-side investments. Then the supply-side comparable earnings that account for such alternative investment opportunities will be by far *less* than the returns that the utilities would be authorized to collect in rates if it were not for energy efficiency programs.[23] Nevertheless, the adjusted supply-side comparable earnings might not be zero. This is because the CPUC-adopted return on equity (ROE) is meant to be reasonable and adequate for utilities to maintain and support their financial credit ratings, so that the utilities can attract investors and thus fulfill their public service obligations.[24]

Table 2 shows (i) the model-based program management efficiency and the associated opportunity costs estimates and (ii) the projections for supply-side comparable earnings regarding the 2006-2008 programs that were submitted by the Utility Reform Network (TURN), the CPUC, and the three utilities. Because the shareholders' alternative investment opportunities were accounted for only by TURN, not by the utilities and the CPUC, the TURN-projected supply-side comparable earnings ($0~87 million) are by far lower than those of the

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[21] I assume the number of each utility's customers is representative of the size of its customer base: 5.00 million for PG&E, 4.67 million for SCE, and 1.32 million for SDG&E (Energy Sales and Prices in 2005, the Energy Commission, http://www.energy.ca.gov/electricity/)

[22] Refer to equation (6).

[23] In fact, this perspective has been maintained by customer advocacy groups like TURN and DRA throughout the incentive rulemaking process. Nonetheless, the CPUC decided not to account for the alternative investment possibilities.

[24] See CPUC (2005d). In the rulemaking process, a TURN witness also testified that TURN believes the CPUC establishes a return on equity that is greater than the cost of equity (CPUC 2007).

utilities ($646 million) and the CPUC ($428~664 million). The comparison between the TURN-projected supply-side comparable earnings, which I believe to be most appropriate, and the model-based opportunity costs ($256~638 million) reveals that, under the economic model, a significant portion of the utilities' opportunity costs could be attributed to hidden (and unobservable) managerial costs.

Table 2 Model-based opportunity costs and projected supply-side comparable earnings for the 2006-2008 programs

	Model-based program management efficiency	Model-based opportunity costs [$million]	†Supply-side comparable earnings [$million]		
			TURN's calculation	§CPUC's calculation	§Utilities' calculation
PG&E	0.20~0.08	106~264	0~36	177~275	272
SCE	0.45~0.17	117~294	0~41	201~312	312
SDG&E	0.21~0.08	32~80	0~10	50~77	62
Total	-	256~638	0~87	428~664	646

† Source: CPUC (2007)

§ Shareholders' alternative investment opportunities were *not* taken into account.

For ease of exposition, the subsequent numerical analyses employ the middle points of the ranges of model-based program management efficiency: 0.14 for PG&E, 0.31 for SCE, and 0.15 for SDG&E. The numerical analyses also presume that the marginal energy savings benefit of 750 [$ / MWh annual savings] is representative of the 2009-2011 programs,[25] regardless of the utility service territories. With uncertainties associated with the market for energy efficiency, however, these ballpark estimates may not represent the utilities' real levels of program management efficiency and marginal energy savings benefit over the 2009-2011 programs. Nevertheless, the estimates are a reasonable case from which to begin sensitivity analyses.

4. 2 Base Predictions for the 2009-2011 programs

Given the parameter estimates thus far, the economic model can be used to provide the implications of the CPUC-adopted incentive mechanism for the implementation of the 2009-2011 energy efficiency programs, whose energy savings targets have already been adopted, although their funding authorization is as yet to be given. The CPUC-adopted cumulative annual electricity savings targets for the 2009-2011 programs are 3,169 GWh for PG&E, 3,528GWh for SCE, and 818GWh for SDG&E.

Figure 4 depicts how the utilities' net earnings U, their customers' bill savings V, and the associated net social benefit W with regard to the 2009-2011 programs will vary with adopted incentive rate r for the incentive mechanism. Given the CPUC-adopted incentive rate, 12%, which will accrue once the utilities precisely meet their preset targets, PG&E will reap the net earnings of $8 million (with shareholder earnings of $151 million) from its justifiable funding of $1.1 billion, resulting in bill savings of $1.1 billion to its customers; SCE will produce the net earnings of $67 million (with shareholder earnings of $225 million) and its customers' bill savings of $1.7 billion by utilizing the justifiable funding of $0.8 billion; and SDG&E will produce the net earnings of $3 million (with shareholder earnings of $37 million) and its customers' bill savings of $0.3 billion by

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[25] With the marginal energy savings benefit, 750 [$/MWh annual savings], customers receive the annual bill savings of $92 from energy efficiency measure(s) that avoids annually one MWh of electricity over average measure lifetime of 12 years (with the discount rate of 8%).

utilizing the justifiable funding of \$0.3 billion. For the three utilities combined, the CPUC-adopted incentive rate is projected to create the net social benefit of \$3.1 billion out of the \$2.2 billion investment in energy efficiency, creating \$78 million utility net earnings (with \$413 million shareholder earnings) and \$3.0 billion ratepayer savings.

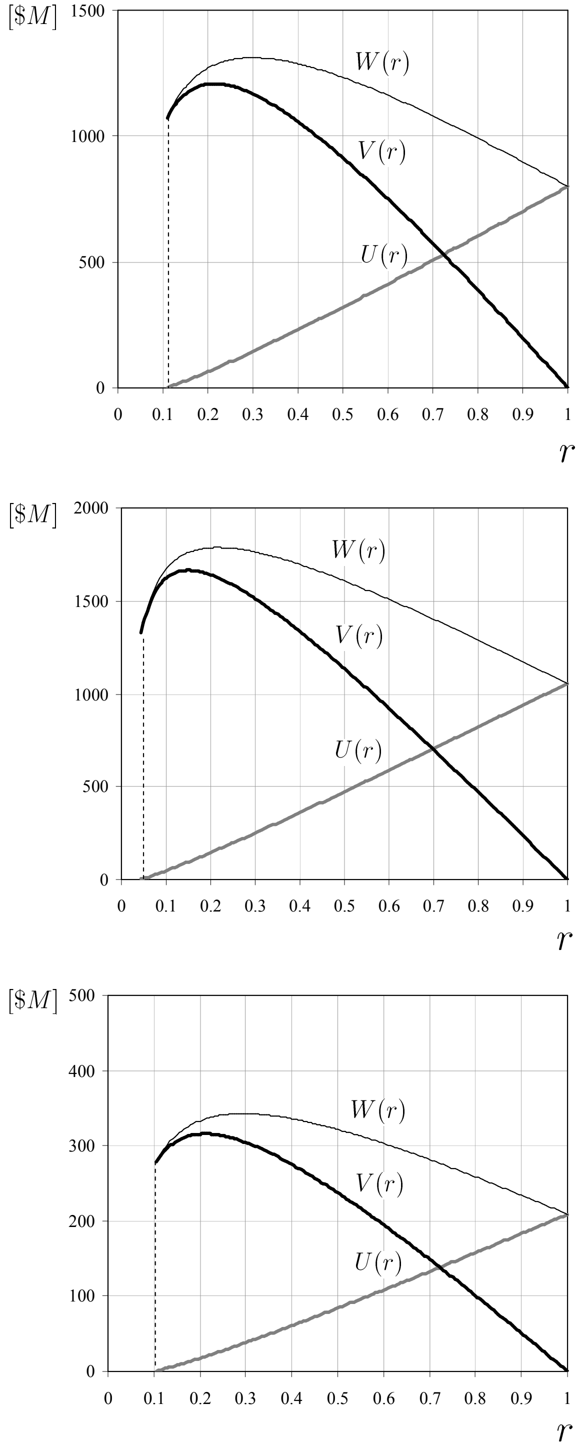

Figure 4 Performance projections for PG&E's 2009-2011 programs (top), SCE's (middle), and SDG&E's (bottom) with respect to an incentive rate

4. 3 Implications of the Economic Model

Alignment of Shareholder and Ratepayer Interests

The alignment of shareholder and ratepayer interests has been the central issue of California's incentive rulemaking. In the rulemaking, the CPUC attempted to establish a so-called "win-win alignment of interests," which will provide shareholders with meaningful earnings that compensate for their foregone supply-side business, while ensuring that ratepayers will receive by far the most of the programs' net benefit (CPUC 2007). Consequently, throughout the rulemaking process, the utilities and their customer coalitions argued with each other about the appropriate determination of the utilities' supply-side comparable earnings. By reconciling their arguments, the CPUC eventually established the supply-side comparable earnings, without taking the shareholders' alternative investment opportunities into account. Then the supply-side comparable earnings were directly divided by a projected earnings basis (i.e., a projected program net benefit) to elicit the adopted incentive rate of 12%.

While it turned out, fortunately, that the CPUC-adopted incentive rate (12%) is about the same as the greatest (11%) of the model-based minimum sufficing rate requirements for the three utilities (see Figure 4),[26] the adopted incentive rate may not suffice to return not only the greatest possible net social benefit, but also the greatest possible bill savings to their customers. The CPUC's incentive-rate decision fails to account for the possibility that a *higher-than-minimum* incentive rate can prompt the utilities to create greater bill savings for the customers as well as a greater net social benefit. The economic model presented in this paper suggests that such a seemingly aggressive incentive rate can be warranted if program parameters – per-customer energy savings targets, marginal energy savings benefits, and program management efficiency – offer a sizeable flexibility in the incentive design, which is likely to be the case in the 2009-2011 energy efficiency programs. The higher any of these program parameters, the greater the design flexibility and the more a higher-than-minimum incentive rate is likely to be justified. With ballpark estimates, PG&E, SCE, and SDG&E will be under the design flexibility of 9, 25, and 10, respectively – all of which are sufficiently greater than the value of 3. With this range of design flexibility, higher-than-minimum incentive rates, namely, positive net earnings for the utilities, are warranted not only for a greater net social benefit, but also for greater ratepayer bill savings.

Table 3 shows the performance projections for the individual utilities' 2009-2011 programs under the three incentive rate scenarios, namely, the CPUC-adopted rate $\tilde{r}$, customers' preferred rate r^{C*}, and socially efficient rate r^{S*}. As shown, the socially efficient rates (22~30%) and even the customers' preferred rates (15~22%) for the three utility programs are obviously higher than the CPUC-adopted incentive rate (12%). It follows that, for all utilities, the CPUC-adopted incentive rate of 12% is projected to involve not only significant net social benefit losses relative to the social optimality scenario (r^{S*}) but also large bill savings losses relative to the customer optimality scenario (r^{C*}). Regarding the PG&E programs, for instance, the CPUC's decision will induce the utility to create \$1.1 billion net social benefit, while incurring \$198 million loss in the net social benefit relative to r^{S*} and \$103 million loss in bill savings relative to r^{C*}. By replacing the CPUC-adopted incentive rate (12%)

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[26] The coincidence seems not to arise because the CPUC reasonably calculated the utilities' minimum earnings requirement (or, equivalently, their opportunity costs associated with energy efficiency). Rather, it may be an artifact of both substantially high supply-side comparable earnings, which does not account for the shareholders' alternative investment opportunities, and missing hidden managerial costs borne by the utilities.

even with the customers' preferred incentive rate (22%), we can reduce the social efficiency loss by $170 million, making both the utility and its customers better off.

Table 3 Performance projections for the utilities' 2009-2011 programs under three incentive rate scenarios : the CPUC-adopted rate $\tilde{r}$, customers' preferred rate r^{C*}, and socially efficient rate r^{S*}

	Utilities								
	PG&E			SCE			SDG&E		
Incentive rate decision	$\tilde{r}$ 12%	r^{C*} 22%	r^{S*} 30%	$\tilde{r}$ 12%	r^{C*} 15%	r^{S*} 22%	$\tilde{r}$ 12%	r^{C*} 21%	r^{S*} 29%
Energy savings §	3,169	3,169	3,169	3,528	3,528	3,528	818	818	818
Justifiable funding †	1,121	838	709	768	687	574	283	214	180
Firm's net earnings†	8	75	144	67	95	161	3	20	37
Shareholder earnings †	151	331	500	225	294	445	37	84	128
Customers' bill savings†	1,105	1,208	1,167	1,652	1,665	1,626	291	316	305
Loss from r^{C*} †	93			13			25		
Net social benefit †	1,113	1,283	1,311	1,719	1,760	1,787	294	335	343
Loss from r^{S*} †	198			68			49		

§ GWh annual savings
† Million dollars

Sensitivity analyses confirm that a *higher-than-adopted incentive rate* can be established to produce not only a greater net social benefit, but also greater bill savings to the customers. To provide more robust insights from the analyses, I focus on PG&E's 2009-2011 programs, whose parameters provide the least flexibility in the incentive design among the three utilities' programs. Figure 5 illustrates the impacts of a marginal energy savings benefit (Panel A) and program management efficiency (Panel B) on socially efficient incentive rate r^{S*}, customers' preferred incentive rate r^{C*}, and minimum sufficing rate r_{min} for PG&E's 2009-2011 programs. The results indicate that, given any not unreasonable misrepresentation of the programs, a higher-than-adopted incentive rate is warranted not only for the greatest possible net social benefit but also for the greatest possible bill savings to the customers; the lower the marginal energy savings benefit or the program management efficiency, the greater the required upward adjustment in the incentive rate. Therefore, as the marginal energy savings benefit declines over time, which is likely, a series of similar-sized energy efficiency programs based on the CPUC-adopted incentive rate (12%) can suffer increasingly greater efficiency losses.

Customization of the Incentive Mechanism

Aside from the proposition that a more aggressive incentive rate can be instigated for all utilities' programs, there is room for even greater improvement. The CPUC may consider deploying *customized* incentive mechanisms for the individual utilities as long as the associated improvement in social efficiency can more than compensate for the political and administrative costs of undertaking utility-specific incentive rulemaking processes. As Table 3 shows, the customized deployment of socially efficient incentive rates for PG&E's programs (30%), SCE's (22%), and SDG&E's (29%) will enhance social efficiency by $315 million compared to the extensive deployment of the CPUC-adopted incentive rate (12%), and it will also improve social efficiency by $34 million even when compared to the extensive deployment of the incentive rate of 22%, which is socially efficient for the SCE programs.

Furthermore, while the CPUC made it clear that the adopted mechanism will be in effect also for subsequent program cycles until further notice,[27] this study suggests that social efficiency can be improved by *updating* the incentive mechanism on a regular basis. This is so because all program parameters – per-customer energy savings targets, marginal energy savings benefits, and utilities' program management efficiency – can change, to some extent, over a series of energy efficiency program cycles. According to the economic analyses, any such changes will affect the stakeholders' earnings/savings opportunities and the associated levels of minimum sufficing rate r_{min} and socially efficient incentive rate r^{S*}: the lower the level of any of those three program parameters, the higher the levels of r_{min} and r^{S*}. In particular, a decline in marginal energy savings benefits or in program management efficiency over subsequent program cycles without updates of the CPUC-adopted incentive rate (12%) being permitted might completely eliminate the utilities' incentive of pursuing energy efficiency activities, which would impede an efficient delivery of the programs. Note that the CPUC-adopted incentive rate falls below minimum sufficing rate r_{min} for the first three data sets in Panel A and the first five data sets in Panel B of Figure 5.

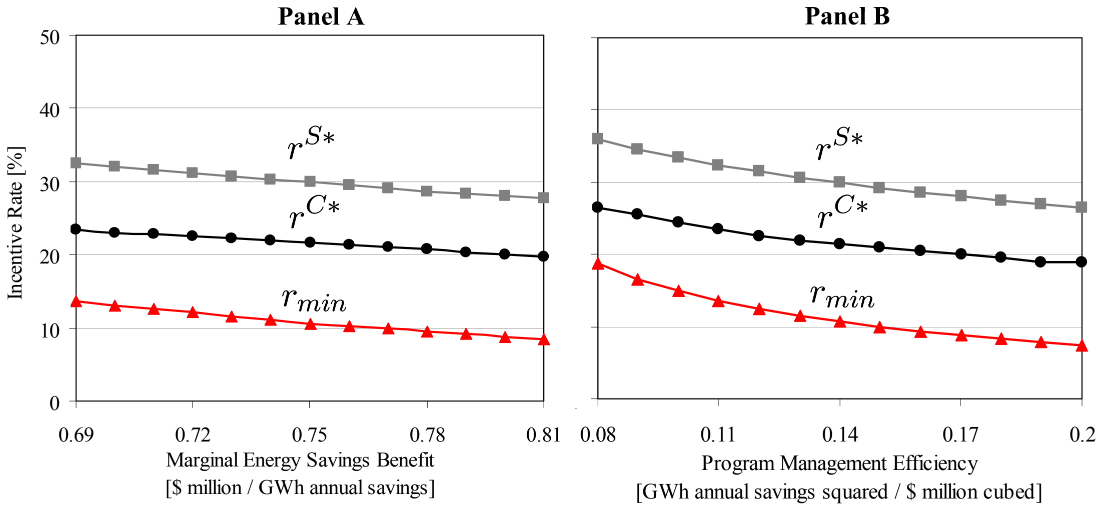

Figure 5 Impacts of the marginal energy savings benefit (Panel A) and the program management efficiency (Panel B) on socially efficient rate r^{S*}, customers' preferred rate r^{C*}, and minimum sufficing rate r_{min} for PG&E's 2009-2011 energy efficiency programs.

5. CONCLUSIONS

In this paper, I have examined the implementation of utility-based energy efficiency programs that employ a shared-savings incentive mechanism. I developed a game theory model that accounts for the conflicting differences between a regulator and an investor-owned utility for the authorization of funding for the programs. Consistent with California energy efficiency programs, the model assume that the regulator adopts an energy

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[27] See CPUC (2007).

savings target before the utility firm proposes program funding, gets the proposal authorized, and begins to manage the programs. With this process, the regulator aims to accomplish dual goals: to produce the greatest possible net social benefit while ensuring the achievement of the target. Three important findings emerged from this work.

First, each utility firm can accomplish the preset energy savings target if the incentive rate for the shared-savings incentive mechanism is appropriate *and* the implementation of the programs is at equilibrium. Namely, with the appropriate incentive rate in place, the utility firm proposes the funding level that the regulator estimates in order for the firm to meet the target, gets the proposal authorized by the regulator, and achieves the target with its optimal level of energy savings productivity.

Second, each utility firm requires a *minimum* level of incentive rate that will encourage the firm to achieve its energy savings target, while producing non-negative bill savings for its customers. This minimum sufficing rate declines with a parameter, which I call the design flexibility, ξ, the level of which is collectively determined by, and increases with, the per-customer energy savings target, the marginal energy savings benefit, and the firm's program management efficiency. That is, the minimum sufficing rate is lower for energy efficiency programs with a higher per-customer energy savings target, for those implemented in utility service areas with a higher marginal energy savings benefit, and for those managed by a utility firm with higher program management efficiency.

Third, a *higher-than-minimum* incentive rate can be needed to achieve not only a greater net social benefit but also greater bill savings for the customers. While the minimum sufficing rate under the low range of design flexibility (i.e., $1 \leq \xi \leq 2$) produces both the greatest possible net social benefit and the greatest possible customer bill savings, the minimum sufficing rate under the mid-to-high range of design flexibility does not. Under the mid range of design flexibility (i.e., $2 < \xi \leq 3$), a higher-than-minimum incentive rate is required to achieve a greater net social benefit. Under the high range of design flexibility (i.e., $\xi > 3$), a higher-than-minimum incentive rate needs to be established to achieve not only a greater net social benefit, but also greater bill savings for the customers. Specifically, if the adopted incentive rate is socially efficient, the energy efficiency programs will accomplish the dual regulatory goals. The socially efficient incentive rate depends again on design flexibility: the higher the level of design flexibility, the lower the socially efficient incentive rate.

Closer examination of California energy efficiency programs in light of the above findings suggests that a *higher-than-adopted* incentive rate can be established to achieve not only a greater net social benefit but also greater bill savings for the customers. The main reason is that current market circumstances yield sizeable design flexibility, under which a more aggressive incentive rate can return an increase in a net program benefit – by allowing the CPUC to authorize lower program funding to utilities – more than offsetting an increase in the utilities' opportunity costs associated with energy efficiency program management. Furthermore, the examination suggests that social efficiency can be improved by customizing incentive mechanisms for individual utilities and updating them on a regular basis. This is because any of the crucial program parameters can vary across the utilities and over a series of energy efficiency program cycles, requiring a different level of the socially-optimal incentive rate to be established for the incentive mechanism.

The work presented in this paper does not address uncertainties associated with energy savings supply and demand. In reality, utility firms face sizeable uncertainties about the penetration of individual energy efficiency measures into the market and their associated energy savings impacts. These supply-side uncertainties may emerge from "path dependence" in energy consumption and other behavioral issues, which make real-world adoption of energy-efficient technologies and measures not as flexible or logical as would be indicated by the model proposed in this work. With regard to the demand for energy savings, particularly over the long term, utility regulators are confronted with uncertainties about future energy demand, future fuel prices, forthcoming carbon emission regulation, and emerging energy technologies of unknown cost and performance. I ignored these uncertainties to focus on the basic implications that the shared-savings incentive mechanism has for the implementation of energy efficiency programs. Future research may incorporate such uncertainties into a more realistic design and implementation of utility-based energy efficiency programs.

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