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DESIGNING UTILITY - TAILORED INCENTIVE PROGRAMS FOR ENERGY EFFICIENCY AND CONSERVATION

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I. INTRODUCTION

Recently, a number of states, including New York, New Hampshire, Rhode Island, Maine, Wisconsin, Massachusetts and California, have instituted innovative shared-savings programs for utility conservation. These programs offer significant monetary incentives for utilities to develop and sponsor conservation measures for their customers. To date, the utilities have been quite receptive to these plans, and companies like PG&E and the New England Electric System are committing large expenditures to fund energy efficiency over the next decade.

Critics of these programs argue that customers can invest in energy conservation themselves, and that utility sponsored programs may serve only to displace and possibly exceed the efficient private level of expenditures on energy efficiency.[1] Advocates of the utility programs argue that utilities are ideally suited to administer conservation programs because they possess first hand knowledge of conservation options and of their customers' needs and habits. Thus, advocates claim, utilities can overcome information and contracting problems, which allegedly create market barriers to efficient investment in energy efficiency, by offering conservation programs directly to their customers.

Most shared-savings programs are still in the experimental phase, and therefore it is too soon to know whether the utility sponsored conservation approach will work. However, the programs have a number of attractive features from an incentive regulation viewpoint. While each program is slightly different, most of them have two provisions in common. First, utilities are compensated *based on performance*, which is usually measured by the net benefits created (*i.e.* value of kW's saved) as a result of their conservation investments. This is in contrast to the usual cost-based compensation which regulators use for supply-side programs. Second, decisions regarding the level of funding and the types of conservation measures to be undertaken are *delegated* to the utilities. A third attribute possessed by some of the shared-savings plans, especially the Collaborative arrangement in California,[2] is that utilities are allowed to pick different compensation schemes to suit their special circumstances. I refer to these as "Utility-Tailored Incentive Programs" (U-TIPS).

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1 For example see Ruff (1988).

2 For details see Schultz and Eto (1990).

In theory these three provisions, (1) performance based compensation, (2) delegation of decision making, and (3) U-TIPS, should have a number of desirable properties. Assuming utilities really are ideally suited to deliver conservation programs, they should be given authority to develop their own programs, provided they are rewarded based on how well their programs perform. U-TIPS are important because utilities differ with respect to their customer mix, their supply and demand circumstances, and their contractual and financial situations. Together these factors determine the costs and effectiveness of different conservation measures for each utility. A policy such as U-TIPS, which allows the utility to choose a plan most appropriate for its demand and supply circumstances, will generate a larger surplus to be split between rate payers and shareholders.

The purpose of this paper is to examine and characterize the incentive properties of U-TIPS and to develop a methodology for incentive regulation of demand-side programs. The next section reviews some principles of incentive regulation and lists desirable features of a utility conservation program. Section III provides a model to analyze shared-savings programs and U-TIPS. Section IV discusses the properties of these programs and compares them with the shared-savings plans which have already been implemented in California and elsewhere. Section V covers extensions to the analysis and policy recommendations for shared-savings programs.

II. PRINCIPLES OF PERFORMANCE BASED INCENTIVES PROGRAMS

During the 1980's economists developed a theory of incentive contracting for application to the regulation of utilities and government procurement.[3] To date, the adoption of incentive regulation in practice has been limited, although alternatives to standard rate of return regulation, such as price caps, indexation, and performance based compensation are being utilized with greater frequency.[4] This section reviews the principles of incentive programs and lists some criteria that must be satisfied for performance regulation to work in demand-side management.

Program decisions should be delegated to the utility.

The shared-savings programs are based on the premise that utilities are well informed about energy efficiency alternatives, about the characteristics of their customers, and about the costs and benefits of conservation. Consequently, they are in the best position to design and implement conservation measures.

Programs should be tailored to the utilities' needs.

U-TIPS generate a larger surplus to be split between rate payers and shareholders.

Utility incentives should be aligned with desirable behavior.

Utilities should be rewarded based on their performance in generating net savings from energy efficiency investments. The net savings from a particular conservation measure are defined as the value of total energy savings minus total program costs (including customer costs).

Utility profits should be limited.

Political realities require that utility shareholders should not profit unreasonably from the incentive program.

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3 See Sappington (1991) and the references cited therein for a review of these developments.

4 See Joskow and Schmalensee (1986) and the NERA report entitled "Incentive Regulation in the Electric Utility Industry" for a discussion of incentive regulation in the electric utility industry. Landon and St. Marie (1990) point out some practical and legal limitations to replacing rate of return regulation with incentive regulation.

Voluntary utility participation should be insured.

Utility participation in shared-savings plans requires that energy efficiency investments be made as profitable as other utility activities.

Shared-savings programs must be administratively feasible.

Rules for calculating shared-savings must be agreed upon in advance, and calculations must be based on observable quantities to avoid regulatory dispute and litigation over utility performance and compensation.[5]

Regulatory review of shared-savings plans should be consistent and even-handed.

Regulators must resist the pressure and temptation to "ratchet up" performance requirements for shared-savings programs. Anticipating such future adjustments may induce utilities to reduce their current level of performance.

III. A MODEL OF SHARED-SAVINGS

In this section we present an informal description of our shared-savings model for energy efficiency.[6] A formal characterization and analysis of this model is contained in the appendix.

Customers

Customers receive utility from the electricity services they consume, which depends on the quantity of electricity consumed as well as the stock of energy efficient investment they have purchased. For example, an energy efficient appliance allows customers to achieve the same level of service with lower electricity use. We denote by $U(Q,e)$[7] the utility enjoyed by a customer as a function of Q, the electricity consumed, and e, the level of energy efficient investment. For simplicity in the discussion to follow, we assume all customers are identical.

There are costs to the customer associated with the purchase of e. Studies of energy efficient investment[8] suggest that these costs may be high, as they include the cost of gathering information about the investment, overseeing the installation of the appliance or insulation, and possibly arranging and paying for financing. The utility can reduce the customer's cost of acquiring e by providing assistance in the form of information about the investment, by overseeing installation and by subsidizing the financing of the investment. We denote by $C(e,a)$ the customer's cost as a function of the level of investment, e, and the amount of assistance, a, offered to the customer by the utility.

The consumer surplus customers derive from electricity service is given by $CS = U(Q,e) - pQ - C(e,a) - P$ where p is the unit price of electricity and P is a fixed charge (hook-up fee) that is paid to the utility. Demand for electricity and energy efficiency are determined by the customer who maximizes consumer surplus with respect to Q and e respectively for a given level of utility assistance, a.

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5 Schultz and Eto (1990) contain a nice discussion of criteria necessary for the successful administration of shared savings plans.

6 The model is due to Lewis and Sappington (1991).

7 Here, we adopt the services approach to representing energy efficiency advocated by Cicchetti and Hogan (1990).

8 See Dubin and McFadden (1984) and Hausman (1979) for estimates of implicit discount rates used by customers in the purchase of energy efficient investment.

The Utility

The utility provides both electricity and demand-side assistance to its customers. We assume that the long-run cost of generating and distributing electricity is given by $G(Q) = gQ$ where g is the constant long-run average cost.

The costs of providing conservation assistance are a bit more complicated and require some explanation. We assume that total costs consist of two components, direct resource costs, denoted by $R(a)$, and managerial costs given by $M(a,q)$. Direct costs include utility expenditures on subsidies and rebates, on installation, and on providing information to customers. We assume direct expenses can be accurately observed by the regulator. In contrast, managerial costs, which include the opportunity costs of devoting managerial effort to supporting conservation, cannot accurately be monitored. For the utility this opportunity cost depends on its customer base, on its knowledge and expertise with conservation programs, and on the opportunities it has to engage in other potentially profitable activities. For some utilities the opportunity cost is high, while for others it is low. We assume that the utility is privately informed about these costs, which are indexed by the variable θ. We assume that θ is a continuous variable and that it can take on values in some range $[\underline{\theta},\overline{\theta}]$ Higher values for θ correspond to higher total and marginal costs of managerial effort.

In what follows we will refer to a utility's "type" by its θ. Only the utility knows its type as parameterized by θ, and thus whether it is a high or low-cost provider of conservation services.

Regulatory Scheme

Regulations governing the utility's conservation programs should satisfy the criteria listed in Section II. For administrative feasibility, utility compensation can only depend on observable variables. Most of the shared-savings programs currently implemented assume that the value of the net savings from each conservation measure can be calculated. For purposes of general discussion we also adopt this strong assumption, although we subsequently relax it in our discussion of extensions in Section V.

For concreteness in computing net savings we assume that Q and e are substitutes, so that each unit of energy efficient investment allows the customer to reduce consumption of electricity by $k > 0$ units. The resulting net savings, denoted by NS, becomes $NS = ekg - [C(e,a) + R(a)]$. The first term on the right hand side of the equation is the value of energy saved and the second term is the measured costs of the investment. Measured investment costs include the customer's costs $C(e,a)$ and the direct resource cost $R(a)$ to the utility. (Recall that managerial costs, $M(a,\theta)$, cannot be observed by the regulator.)

We restrict attention to simple incentive schemes which offer the utility a fixed payment plus reimbursement of direct costs and a share of the net savings generated from each conservation measure. It turns out that these simple compensation arrangements, when correctly calibrated, are optimal and that they resemble (but are not identical to) actual shared-savings formulas that are used in practice.

Denoting by P the payment to the utility we have $P = T + R(a) + b\,[NS]$, where T is the fixed payment or transfer, $R(a)$ is the reimbursement for direct costs, and b is the share of net savings earned by the utility.

Given the payment formula, the profit for a utility of type θ is given by $\pi(\theta) = P - R(a) - M(a,\theta) + pQ - G(Q)$. The first three terms above represent the net profit (including opportunity costs of management) from conservation, and the last two terms are the profits from electricity sales.

Aside from designing incentive programs that are easy to implement, the regulator would also like to compel the utility to use its superior knowledge of conservation costs and opportunities to offer the most cost effective energy efficient assistance to its customers. Recall, however, that the regulator cannot dictate how the utility should behave because it does not know the utility's type and whether it is a high or low cost provider of conservation assistance. Instead, the regulator can offer U-TIPS. These are implemented by allowing the utility to select from a menu of different incentive plans. If the menu is constructed correctly, the regulator can cause the lower cost utility to select an incentive scheme which induces it to provide relatively large levels of conservation assistance, whereas the higher cost supplier will select another scheme which induces it to deliver lower levels of conservation.

This self-selection process is accomplished by varying the fixed transfer, T, and sharing a percentage, b, of the compensation formula. Consider two utility types, denoted by θ and θ' with $\theta > \theta'$, so that the θ-type is the high-cost supplier and the θ'-type is the low-cost producer. Suppose the regulator intends for a high-cost type (resp., low-cost type) to select the incentive plan characterized by $\{T(\theta),b(\theta)\}$, (resp., $\{T(\theta',b(\theta')\}$). Then it must be most profitable for the high-cost utility to select $\{T(\theta),b(\theta)\}$ rather than $\{T(\theta'),b(\theta')\}$. These are self-selection constraints which the regulator must satisfy when designing the menu of programs from which the utility can choose.

In addition to the self-selection constraint, the incentive programs offered must also satisfy a participation constraint meaning that the utility must earn some minimal level of profits to insure its participation.

Finally, we assume that while the regulator does not know the type of utility it is dealing with (whether it be a higher-cost or lower-cost type), it does have some subjective beliefs about the utility's type as summarized in a probability function $f(\theta)$ which indicates the relative likelihood that the regulator places on the possibility that the utility is of type θ. Presumably the regulator forms these beliefs based on past experience and interaction with the utility.

Given these considerations, the object for the regulator is to choose a menu of incentive plans characterized by $\{T(\theta),b(\theta)\}$ to maximize expected consumer surplus subject to the self-selection and participation constraints.[9] The solution to this exercise is discussed in the next section.

IV. CHARACTERIZATION OF U-TIPS

Properties of U-TIPS

U-TIPS should be designed for efficient utilization of the utility's conservation capabilities consistent with its cost of providing assistance. In addition, U-TIPS should provide the utility with sufficient but not excessive profit to participate in these programs. This is accomplished by offering different programs, each tailored to a particular cost-type of utility.

The U-TIPS are depicted in Figure 1 where payments, P, received by the utility are plotted as a function of measured net savings, NS. Each schedule offers the utility a fixed payment and a positive share of the net savings. Notice that the steeper schedule, the one which provides for a larger shared-savings, is designed to attract the θ-type utility which is a lower-cost provider of conservation services. This type of utility should be able to generate large net savings from conservation. Thus it is induced to accept a lower fixed payment for expenses in order to earn a higher share of net savings which are anticipated to be large. The high-cost θ'-type utility would prefer the flatter schedule. This utility prefers to trade some shared-savings, which are anticipated to be relatively small, in return for a larger fixed fee to cover its expenses.

The principle for constructing U-TIPS is clear: utilities which are the most effective conservation suppliers are encouraged to provide more service by allowing for greater sharing in the net savings generated.[10]

[9] For simplicity, we have assumed that consumer demand for electricity and energy efficient investment is deterministic. The analysis could easily be extended to account for the possibility that random shocks affect the demand for such products and services.

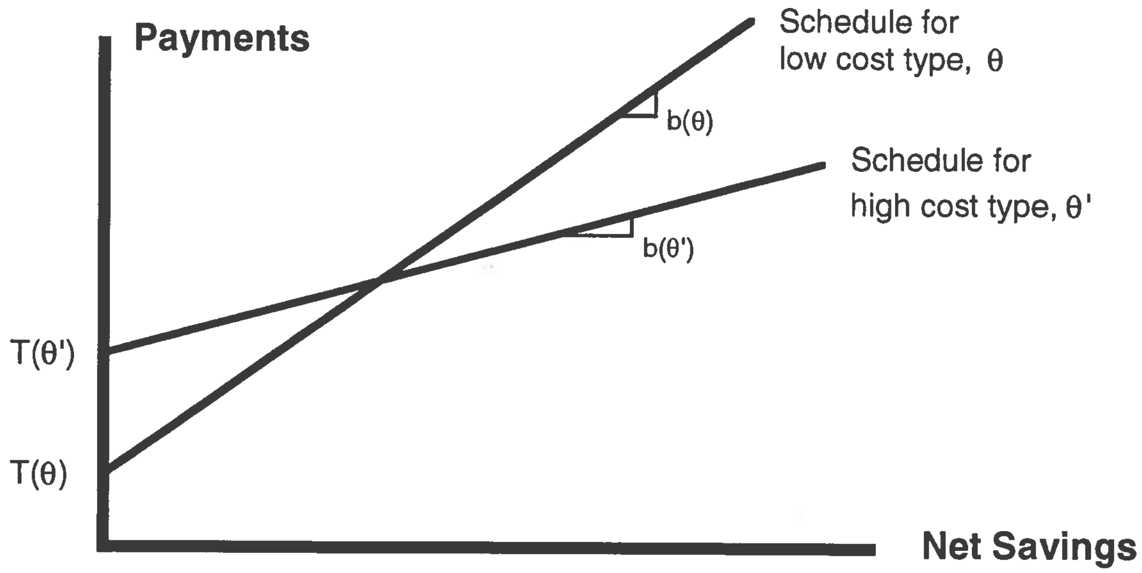

Figure 1. Compensation Formulas

Listed below is a summary and explanation of the properties of U-TIPS starting with the first property which we have just discussed. These properties are formally derived in the appendix.

Low-cost utilities choose more performance-sensitive payment schedules.[11]

Low-cost utilities are induced to provide more assistance and they generate larger net savings.[12]

This is expected since low-cost utilities can efficiently support more conservation programs.

The lower-cost utility earns greater profit than the higher-cost utility.

This is an undesirable, but unavoidable, feature of U-TIPS. It is undesirable since we want to limit any excess profit for the utility. To see why it is unavoidable, suppose the regulator offers a schedule $\{T(\theta'), b(\theta')\}$ which would yield the high-cost utility type, θ', its break-even expected level of profit. Since the regulator does not know the utility's type, a low-cost type, θ, could also accept the $\{T(\theta'), b(\theta')\}$ incentive plan and provide the same assistance, $a(\theta')$, as would the high-cost utility. However, since the low-cost utility can supply $a(\theta')$ at a lower cost, it would earn excess profits equal to its cost advantage which is $M(a(\theta'),\theta') - M(a(\theta'),\theta) > 0$. Consequently, it is impossible to prevent the more efficient utility from earning some excess profit. It is the fact that the regulator is uninformed about the utility's cost which leads to this result.

10 This is analogous to the different insurance contracts that one observes. Individuals who can self-insure at a low cost usually opt for contracts with a low premium and a high deductible and coinsurance provisions. Those who are unable to self-insure elect to purchase contracts with lower deductibles and higher premiums.

11 In particular, we find that $T(\theta)$ is increasing in θ, and that $b(\theta)$ is decreasing in θ. Thus lower cost-types choose a lower fixed fee and higher shared savings program.

12 In particular $e(\theta)$ is decreasing in θ, and $Q(\theta)$ is increasing.

Utility supply of conservation assistance is below the efficient level.

For all utility types, $\theta > \underline{\theta}$, $b(\theta) < 1$. This means that the utility only receives a fraction of the net savings created from conservation assistance, but it must pay the full cost of providing service. Consequently the utility provides too little service from an efficiency point of view. But why shouldn't the sharing percentage, $b(\theta)$, be increased to encourage greater service? Recall that the lower-cost types command excess profits since they can provide a given level of assistance at lower cost. In order to limit these excess profits, the regulator induces the utility to supply less assistance by setting the sharing fraction below 1. This reduces the number of units over which the low-cost types can exercise their cost advantage, and thus it reduces their excess profits. This property illustrates the important principle that limiting utility profits and providing efficient levels of conservation are incompatible goals. There must be a partial sacrifice in efficiency in order to constrain utility profitability.

U-TIPS increase total net savings from conservation.

U-TIPS, which allow utilities to select incentive programs tailored to their particular cost situation, produce greater net savings than a single or uniform shared-savings plan would. The advantage of offering a menu of incentive plans rather than just one is that it allows the regulator to tailor the shared-savings incentives to the utility's privately observed cost information.[13] Simulations comparing total net savings under U-TIPS and under single incentive programs reveal that total net savings may be significantly higher with U-TIPS.

Comparing U-TIPS with Actual Shared-savings Plans

Like many of the shared-savings plans which have already been implemented, U-TIPS compensate the utility by providing a fixed fee, reimbursement of direct expenses, and a share of the net savings. This procedure for compensation has the advantage that it is easy to implement provided utility costs and net savings can be measured readily. Problems of measurement are discussed in the next section.

Despite their apparent similarities there are some important differences between U-TIPS and the shared-savings plans used in practice. For example, some shared-savings plans in California and other states involve a change in compensation formula if utility performance falls outside a designated band. With U-TIPS the compensation formula is the same at all levels of utility performance. We find, at least for a large class of situations, that the incentives needed to motivate the utility to perform are amply provided with a simple linear sharing rule.[14]

Some sharing rules, like the one adopted by PG&E, calculate net savings as the difference between the value of electricity saved and the costs to the utility of implementing the program. Notice that customer cost is excluded from the calculation. This practice has two potentially undesirable features. First, it biases upward the measure of shared-savings, and second it may influence the utility to undertake conservation investments which are only cost effective from the utility perspective. It is possible that the utility may choose investments which are not efficient and pass up investments that are cost effective when it ignores the customer cost of participating in the program.[15]

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[13] The advantage of offering menus of incentive programs over a single one has been analyzed in the accounting literature by Baiman and Evans (1983) and Melumad and Reichelstein (1989).

[14] For some applications it may be necessary to use quadratic or piecewise linear sharing rule to implement UTIPS. For example, see Picard (1987).

[15] However, see Schultz and Eto (1990) for a defense of this approach.

Of course the distinguishing feature of U-TIPS is that utilities are encouraged to adopt investment programs tailored to their particular cost situations. This differs from most shared-savings plans in that the regulator relies on the utility, which is better informed to select the environment in which it is most effective in delivering conservation service. This principle of delegating some decision making authority to the utility is the cornerstone of incentive regulation.

V. EXTENSIONS AND RECOMMENDATIONS

Thus far, our discussion of U-TIPS has been based on two important assumptions which are also used (with some exceptions) by regulators in the design of shared-savings programs. The two assumptions are (a) investment in energy efficiency reduces energy demand, and (b) it is possible to measure the net savings from conservation investment.[16] In this section we consider relaxing these assumptions, and we examine other extensions of the analysis.

Utility Assistance May Increases Electricity Use

It is possible that some worthwhile investment in end-use efficiency may cause customers to consume more electricity, rather than less. In principle U-TIPS can accommodate this by rewarding the utility based on some measure of the net benefits generated from the investment. In this case, net benefits are calculated as the difference between the increase in consumer satisfaction and total utility and the customer investment cost. Of course it may not be straightforward to measure increases in consumer satisfaction, and therefore, constructing a valid measure of net benefits may be difficult. This brings us to our second extension.

Inability to Measure Net Savings

Shared-savings incentive plans presume that an accurate measure of the net savings can be calculated. Certainly for some applications this may be true, but for others like energy audits, and customer education, it may be impossible to accurately measure the energy saved or the cost to the customer of the program. This precludes basing utility compensation on net savings. However, as long as it is possible to measure the total amount of electricity consumed, it is possible to construct U-TIPS where the utility is compensated based on the reduction in electricity demand beyond some target level.[17] In this instance, the utility sets a target level of electricity demand., and it is then rewarded for reducing electricity consumption below the target level. Different incentive schemes are offered, and low-cost conservation utilities are induced to select plans which require greater reductions in electricity, but which compensate the utility more generously for reductions that are achieved.

Using Rates to Provide Incentives for Conservation

One alternative which has not been considered in the design of demand-side management programs is restructuring rates to induce conservation investment from the utility. This possibility is considered in Lewis and Sappington (1991). There it is shown that, in some instances where it is not possible to measure net savings, rate restructuring is useful because it allows the regulator to make more accurate inferences about the utility's effectiveness in delivering conservation programs.

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[16] See Lewis and Sappington (1991).

[17] See Lewis and Sappington (1991).

Opportunity Packages

At the start of a shared-savings plan, the utility may wish to implement several conservation measures to learn which of them is most effective. Landon and St. Marie (1990) provide an interesting analysis of how utilities could be allowed to pick a subset of conservation programs which turn out to be the most effective. Their performance would be judged based on the aggregate net savings generated from all of the programs. This would extend the latitude given to utilities to tailor their own conservation programs.

Dynamic Adjustments in Shared-Savings Programs

The advantage of U-TIPS is that the utility itself selects the program which is most attractive given its costs. Knowing this, regulators may be tempted to employ more stringent performance standards for utilities which reveal themselves to be low-cost providers. However, utilities may act strategically from the outset to hide their true costs from the regulator unless they have some assurance against this ratcheting of performance criteria. This is an important problem which needs to be addressed in the design of any type of incentive program.

Yardstick Comparisons

To a limited degree, utilities face similar costs and obstacles in implementing conservation investments. To the extent that circumstances are comparable, shared-savings plans might be structured so that each utility is partially compensated based on its performance relative to some comparable group of utilities. One must exercise caution in advocating this form of regulation, however, since it is difficult to discern to what degree and in which dimension different utilities can validly be compared for purposes of compensation.

Correcting Market Failure

One argument for utility sponsored conservation programs is that they can overcome market barriers to private investment in energy efficiency. To the extent that this is true, utility programs should be aimed at directly correcting the perceived market failure, whether it be a lack of information, metering problems, capital market imperfections or contracting difficulties with energy service companies. Market imperfections are most easily overcome if the source of the problem is clearly identified and dealt with directly.

Appendix

Assumptions

In the formal analysis of U-TIPS we make the following technical assumptions. Subscripted variables refer to partial derivatives unless otherwise noted.

(A1) $U = U(Q,e);$ $U_1 > 0,\ U_{11} < 0,$ $U_2 > 0,\ U_{22} < 0$

(A2) $C = C(e,a)$ $C_1 > 0,\ C_{11} > 0,\ C_2 > 0,\ C_{22} \geq 0$

(A3) $G = G(Q);$ $G' > 0,\ G'' \geq 0$

(A4) $R = R(a);$ $R' > 0,\ R'' \geq 0$

(A5) $M = M(a,\theta);$ $M_1 > 0,\ M_{11} \geq 0,\ M_2,\ M_{12} > 0,$

(A6) $d/d\theta[F(\theta)/f(\theta)] \geq 0$

Assumptions (A1) to (A4) are fairly standard. Assumption (A5) indicates that the total and marginal cost of managerial effort is increasing in θ. In (A6), $F(\theta)$ is the cumulative distribution function for θ. (A6) is a standard regularity condition which is invoked to simplify the analysis, and it is satisfied by a large class of distributions including the uniform, normal, logistic, chi squared, exponential, and Laplace.

Analysis

We assume that the regulator sets price equal to marginal cost of electricity generation[18] and offers the utility a menu of incentive plans denoted by $\{a(\theta),P(\theta)\}$, where a( ) represents the level of conservation assistance provided and P( ) is a payment which the utility receives. The variables a( ) and P( ) are written as a function of θ meaning that the plan consisting of $a(\theta)$ and $P(\theta)$ is intended for the utility type θ. However, the utility may choose any plan from the menu. So in order to induce the utility to choose $\{a(\theta),P(\theta)\}$ the profit the utility expects to earn must be maximized by choosing this plan. Formally this requires:

(a1) $\pi(a(\theta),P(\theta),\theta) \geq \pi(a(\theta'),P(\theta'),\theta)$, for all θ,θ'

where $\pi(a(\theta'),P(\theta'),\theta) = P(\theta') + pQ - G(Q) - R(a(\theta') - M(a(\theta'),\theta)$ is the profit earned by a utility of type θ which selects plan $a(\theta'),P(\theta')$. (a1) is referred to as the self-selection constraint, meaning that the utility will self select the plan which it finds most profitable.

Denote by $\pi(\theta) = \pi(a(\theta),p(\theta),\theta)$ the profit of a type-θ utility which selects the program intended for it, $a(\theta),p(\theta)$. Assuming that the schedules $\{a(\theta),P(\theta)\}$ are differentiable we have that

(a2) $$d/d\theta[\pi(\theta)] = \pi_1(a,p,\theta)a'(\theta) + \pi_2(a,p,\theta)P'(\theta) + \pi_3(a,p,\theta)$$
$$= -M_2(a,\theta) < 0$$

since the first two terms are zero due to self selection. According to (a2), self selection requires that the profits of the utility be decreasing at the rate of $-M_2(a,\theta)$ with higher realizations of θ. This means that higher-cost utilities will earn less than lower-cost utilities. In order to satisfy the second order condition for

18 Lewis and Sappington (1991) show that marginal cost pricing is optimal for this type of problem, although there are environments in which it is optimal to set prices above or below marginal cost.

profit maximization (self selection) it is easy to show that $a'(\theta) \leq 0$. This implies that higher-cost utilities provide less conservation assistance.

Recall that the utility must expect to earn some minimal profit, $\bar{\pi}$, in order to participate in the program. This simply requires that

$$\text{(a3)} \qquad \pi(\bar{\theta}) = \bar{\pi}$$

since all other types with $\theta < \bar{\theta}$ earn strictly higher profits from (a2).

The formal statement of the regulator's problem is to choose a menu $\{a(\theta),P(\theta)\}$ to maximize expected consumer surplus, given by

$$\text{(a4)} \qquad {}_{\theta}\!\int CS(\theta)\, f(\theta)d\theta$$

subject to (a2), (a3), and $a'(\theta) \leq 0$, where

$$\text{(a5)} \qquad CS(\theta) = U(Q(e(a(\theta),p),p),\, e(a(\theta),p)) - pQ(e(a(\theta),p),p) - P(\theta) - C(e(a(\theta),p),a(\theta))$$

Notice that Q and e are chosen by consumers to maximize consumer surplus for a given price p, and a given level of utility assistance $a(\theta)$. By incorporating the constraints (a2) and (a3) into the problem, and manipulating some of the terms, one can show that the regulator's problem now becomes one of choosing $\{a(\theta)\}$ to

$$\text{(a6)} \qquad \text{maximize } {}_{\theta}\!\int [CS(\theta) \;-(F(\theta)/f(\theta)\, M_2(a(\theta),\theta)]f(\theta)d\theta$$

The first order conditions characterizing the solution to (a6) are given by

$$\text{(a7)} \qquad -C_2 - R' - M_1 - (F/f)M_{12} = 0 \text{ for all } \theta \in [\underline{\theta},\bar{\theta}]$$

At this stage it is instructive to consider an example to see how the solution to the regulator's problem can be implemented using simple linear incentive schemes. (The analysis changes somewhat under different specifications, but the qualitative results remain the same.) Assume that Q and e are perfect substitutes and that

$$C(e,a) = C(e - a),\; C',C'' > 0$$
$$G(Q) = gQ$$
$$M(a,\theta) = M(a + \theta),\; M',\, M'' > 0,\; M''' = 0$$

According to this specification, utility assistance, a, acts as a perfect substitute for e, as might be expected if the utility provides financial subsidies to the customer. Electricity is supplied at constant average and marginal cost. The cost of managerial effort is parameterized by θ in a particularly simple way.

With this specification it is easy to verify that the first order conditions are also sufficient, and that $a'(\theta) < 0$ as required to satisfy (a2).

It remains for us to demonstrate that the solution to (a6) as characterized by (a7) can in fact be implemented by offering the simple linear incentive programs $(T(\theta),b(\theta))$ presented in the text. From (a2) and the fact that $a(\theta)$ is monotonically decreasing we can write P as a function of a, such that

$$\text{(a8)} \qquad P(a) = \bar{\pi} + {}_{\theta}\!\int^{\bar{\theta}} M'(a + \tilde{\theta})d\tilde{\theta} - [p - g]Q + R(a) + M(a + \theta)$$

Differentiating P with respect to a and recognizing that θ is a function of a we have

$$\text{(a9)} \qquad P'(a) = R'(a) + M'(a + \theta) > 0$$

Differentiating $P(a)$ again with respect to a yields

$$\text{(a10)} \qquad P''(a) = R'' + M''(1 + d\theta/da)$$
$$= R'' + M'' \{1 - (R'' + M'')/(-M'' - d/d\theta[F/f])M''\} > 0$$

where $da/d\theta$ comes from differentiating (a7). (a10) implies that the regulator offers the utility a schedule of choices, $P(a)$, to select where $P(a)$ is strictly convex. But since $P'' > 0$, notice it is possible to support $P(a)$ with a series of hyperplanes of the form $P = \tilde{T}(\theta) + \tilde{b}(\theta)a$. However, it is easy to rewrite these linear equations in terms of net savings. In particular if we let

$$\text{(a8)} \qquad b(\theta) = 1 + (F/f)M''/[- C' + R']$$

$$\text{(a9)} \qquad T(\theta) = \bar{\pi} + \int_{\underline{\theta}}^{\theta} M'd\theta + M - b\theta)NS(\theta)$$

where $NS(\theta) = pke(\theta) - R(a(\theta) - C(e(\theta),a(\theta))$, it is easy to verify that the solution to the regulator's problem may be implemented by offering incentive programs $\{b(\theta),T(\theta)\}$.

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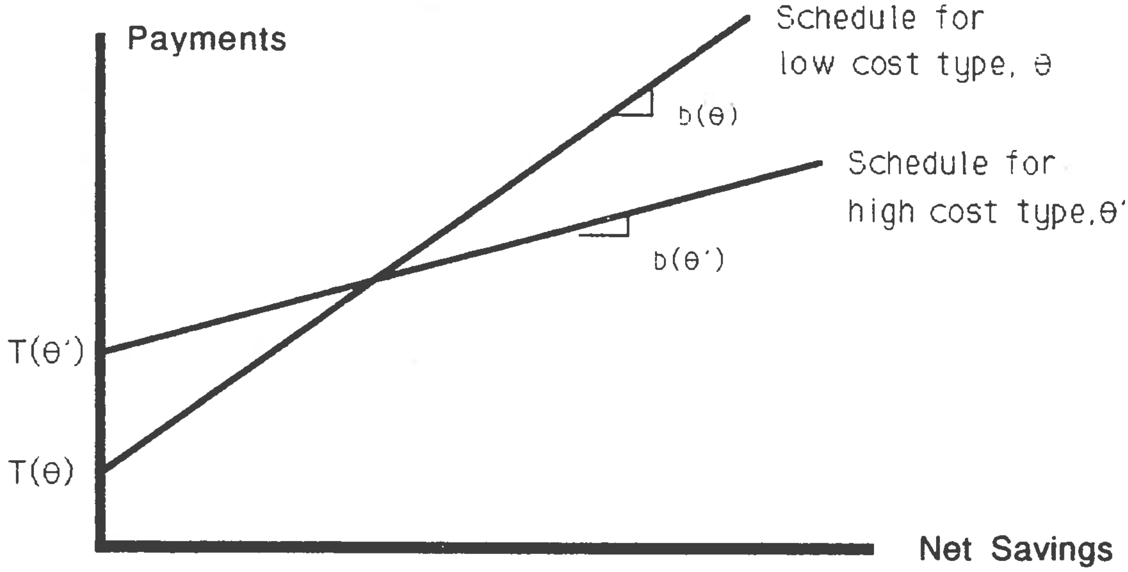

Figure 1 Compensation Formulas

The principle for constructing U-TIPS is clear: utilities which are the most effective conservation suppliers are encouraged to provide more service by allowing for greater sharing in the net savings generated.[10] Listed below is a summary and explanation of the properties of U-TIPS starting with the first property which we have just discussed. These properties are formally derived in the appendix.

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[10]This is analogus to the different insurance constracts that one observes. Individiuals who can self insure at a low cost usually opt for contracts with a low premium and a high deductible and coinsurance provisions. Those who are unable to self insure elect to purchase contracts with lower deductibles and higher premiums.