IMPROVED MODELS OF INDIVIDUAL ENERGY TECHNOLOGY CHOICE: THEIR IMPLICATIONS FOR ENERGY TECHNOLOGY MARKET PARTICIPANTS AND POLICY-MAKERS

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Abstract

In order to effectively influence individual end-use energy technology choices, energy technology vendors, service providers and policy-makers must understand the decision process of technology adopters. This requires that the technology characteristics which consumers consider to be important be identified, along with the consumer's level of awareness of available technology alternatives, and the costs and benefits they believe to be associated with refinement of their technology choice. At present, this decision process is most commonly represented by a simple net present value criteria which assumes that the decision maker has full, costless information and seeks only to minimize expected life cycle cost, regardless of technology service quality differences or relative levels of uncertainty about technology cost and performance. The unreasonableness of these assumptions, together with the widely noted descriptive failings of such models, motivates the more careful analysis of the characteristics of energy technology decisions and the development of alternative decision models found in this paper. In particular, seven principle characteristics of energy technology choices are identified, and are used to motivate four different types of models. The appropriate model for a given energy technology decision can then be determined by identifying the subset of the seven characteristics pertinent to the technology in question, and then choosing the model type most capable of addressing those characteristics. An sample calculation for each of the model types presented is provided in the appendices.

Both the seven decision characteristics identified and the improved modelling methods presented provide new insight into consumer energy technology choices. The "paradox" of the apparent inefficiency of many individual energy technology decisions is found to result primarily from the small scale and infrequent nature of the energy technology decisions of individuals, rather than from market failures. However, the conclusions of economic theory regarding the efficiency of market outcomes are not found to hold for most energy technology markets, since energy technology investment opportunities are for the most part proprietary (because they lie in private homes and buildings) rather than freely available, as the efficiency theorems of economics require.

If energy technology investment opportunities were freely available, they could be optimally exploited by large firms run by energy technology experts, operating at a scale sufficient to legitimize the assumption that the fixed cost of developing energy technology expertise can be ignored for individual decisions. Instead, given the proprietary nature of most energy technology investment opportunities, the key to improving the quality of energy technology decisions, and to the realization of profits by energy technology experts, exists in the provision of expert advice and services to individual decision makers, whose own energy technology investment opportunities are not of sufficient scale to make their own development of energy technology expertise worthwhile to them. Policy makers can best contribute to this process by seeking ways to facilitate and encourage methods of substituting the energy technology decision making capacity of a third party expert for that of the non-expert possessor of the energy technology investment opportunity.

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Introduction

At present, the decision process of the typical consumer of most energy efficient technologies - from purchasers of light bulbs or refrigerators to designers of new buildings or industrial processes - isn't well understood. This presents a problem for anyone interested in influencing or forecasting future energy technology investment. Policymakers responsible for energy technology decisions over the last two decades have grown acutely aware of this problem, as they have tried to design legislation while the necessary analysis was in a state of development. In recent years utility companies have become equally focused on the difficulties of forecasting energy technology investment patterns, as they commit to billions of dollars of demand-side management programs whose success depends on their ability to efficiently and effectively influence energy technology decisions. In addition, the profits of builders, equipment suppliers and even automobile manufacturers depend on their ability to select the right energy technologies for current market conditions.

More than anything else, the gaps in our understanding of many energy technology decisions reflect the inadequacies of the models used to address them. While modelling of energy technology decisions has progressed substantially since it began in earnest roughly twenty years ago, many weak areas still exist. In particular, "micro" models of individual energy technology decisions have received significantly less attention than have "macro" or aggregate models of overall trends in energy technology investment. Unfortunately, macro models can be no better than the micro models they are driven by. And since it is the individual adopter who must be affected if government policies or utility company programs are to succeed, a detailed understanding of their decision process is clearly a necessary first step toward more general goals.

Perhaps the most visible evidence of the descriptive failings of many current models of individual energy technology decisions is the on-going controversy about the high implied discount rate commonly documented in empirical analyses of energy technology choices. In both residential and industrial settings, under the lens of presently applied models, energy technology consumers appear to be acting as if they were evaluating technologies using a discount rate in the 20-100% range. Needless to say, this appears inconsistent with the standard assumptions of (relatively) rational decision makers and (relatively) efficient markets. After such unusually high implied discount rates for energy technology investments are noted, they are typically attributed to amorphous "hidden costs"or "market barriers". This placement of blame is often accompanied by the admission that the behavior documented is actually likely to be less illogical than the analysis suggests, and instead merely poorly captured by the model used to describe it.

This gap in understanding of observed energy technology choices leaves plenty of room for long running debates, particularly among policy makers, about the efficiency of energy technology markets. On one side of the argument, high implied discount rates are attributed to various energy market failures. Policy action to encourage energy efficiency improvement is therefore appropriate. On the other side of the argument, observed behavior is deemed to reflect actual consumer preferences and beliefs, or to match with typical observations of adoption levels of new technologies during their diffusion periods. Policy action is therefore inappropriate and likely to be ineffective or distortionary. Without improved models of energy technology decisions, it seems likely that this debate will remain unresolved.

The discussion above and the problems raised there suggest two general areas where more research is needed. First, present models of individual energy technology decisions clearly need to be improved. Second, the results and insights gained from such improved individual decision models could then be used to more effectively analyze the broad issues of appropriate energy technology policy, and optimal utility company program design.

The aim of this paper is to follow the research path suggested above. Specifically, section one below analyzes the decision problem faced by an individual considering investment in each of a broad range of possible energy technologies. The goal of this section is to identify, for each major type of energy technology, the important characteristics of the decision of an individual seeking to choose among possible technologies of that type, and then to identify a model capable of accurately weighing these characteristics. The framework for this section is provided by seven characteristics which together are argued to capture the important aspects of the full spectrum of energy technology choices. Once the important decision characteristics for a particular technology type are identified, these characteristics are matched with a model type capable of weighing those characteristics against each other. For this task, four basic model types are identified which together are shown to be capable of addressing the full spectrum of energy technology types, with each represented by a particular subset of the seven decision characteristics.

Section two then considers the implications of the improved models of individual technology decisions developed in section one for the "macro" questions of energy technology market efficiency and the appropriateness of various types of policy intervention. In particular, two key insights from the analysis of section one are used to shed light on the true causes of the high implied discount rate "paradox" mentioned above. The discussion concludes that market failures are not the primary cause of the apparently "sub-optimal" energy technology decisions of individuals. Instead, the inherently small scale and exclusive, or proprietary nature of most energy technology investment opportunities is found to lead to only "individually rational", or "satisficing" solutions, rather than "optimal" choices of the kind an expert in energy technology choice would be likely to make. While market forces can't be relied on to "arbitrage away" all gaps in energy technology investment efficiency, as they might be for freely accessible investment opportunities, market forces still help to ensure a basic level of efficiency in energy technology markets since the proprietary nature of most energy technology investment opportunities still creates "indirect" opportunities for profit, such as advising or partnership roles. Questions about the level of efficiency that can be expected in energy technology markets are therefore most effectively addressed by considering the ways in which market based energy service providers can help individuals improve their energy technology choices in exchange for a fee or for a portion of the benefits of the individual's improved choice. The section therefore ends with a discussion of likely future trends in the type of services offered to energy technology consumers, of government policies which could facilitate the expansion of this range of private services, and of the implications of trends in the level of services offered for the average efficiency of energy technology investment decisions.

Section 1 - Modelling Individual Energy Technology Choices

If we seek to improve the modeling resources now available, it seems natural to first reconsider what we have learned from previous modelling work. In hindsight, past modeling failures often appear to have been caused by the assumption that one simple framework, such as net present value analysis, is capable of describing observed consumer behavior across the full range of energy technologies. It now seems clear that energy technologies are much too diverse for this to be practical, ranging from household lighting decisions to industrial equipment choice and process design. (Appendix A summarizes the classification method of residential, commercial and industrial energy technologies used in the rest of the paper). In addition, empirical evidence appears to suggest that some technology groups are described quite well by models presently in use, while other technology groups are yet to be effectively modeled in practice. A natural first step, then, is to try to identify which models work for which technologies and why. Second, using these insights, we can list the technologies for which we do not currently have satisfactory models, and for each of these, reevaluate our approach.

If the goal is to evaluate the effectiveness of particular models in describing particular energy technologies, how can we best make this judgement? While empirical evidence may be the only categorical way to establish the validity of the models employed, it is a premise of this paper that sufficient empirical evidence now exists about consumer energy technology choices to make a careful reexamination of the characteristics of the energy technology decisions considered (by modelers) to be most important (to consumers) worthwhile. Rather than an exhaustive cataloging of specific modeling successes and failures, therefore, the focus here is on the identification of common core characteristics of energy technology choices, and how particular combinations of these characteristics, as embodied in particular technology groups, match with particular modelling approaches.

Are energy technology choices sufficiently different from other investment decisions that they require us to invent new modelling approaches to address them? In many cases, no. They are diverse, however, and in order to choose the right approach for a particular technology class, we need to consider the particular characteristics of that class. This section presents seven decision characteristics, which are argued (in various combinations) to describe the primary concerns of decision makers across all major energy technology classes. These seven characteristics are used as a conceptual structure for consideration of individual technology types that, it is hoped, will emphasize the common characteristics of energy technology choice problems as well as illuminate particular types of energy technologies. After identifying the seven characteristics, major classes of energy technologies are addressed in tandem with a model type argued to be appropriate for analyzing members of that technology class. In each case, the choice of the model type is based on the subset of the seven criteria argued to be germane to the technology class in question. The first technology classes considered are those for which, based on available empirical evidence, it appears that relatively appropriate models presently exist. Subsequently, technology classes which are not well described by models currently used are identified, and connections are made between the combination of decision characteristics central to these technologies and the failure of existing models to adequately address such combinations of characteristics. Finally, alternative modelling approaches for problems not presently well addressed are presented. For each model type, an example calculation for a representative energy technology is provided in an appendix in order to illustrate the method and the analysis required.

In brief, the task of this section is both to take stock of where energy technology choice modelling is today, and to encourage the addition of several new modelling techniques to the set of models currently used in order to extend the range of energy technologies which can be accurately modeled. The goal is to make clear ways in which presently available models can be used effectively, and to present examples of technology classes for which new modelling capabilities are both necessary and available. A conceptual framework based on the identification of seven characteristics of energy technology choices is developed to guide and provide insight into the technology class - model type connection. Viewed from this perspective, the challenge of effective energy technology choice modeling across the spectrum of energy technology choices appears substantial, but decomposable and manageable. The same perspective suggests that relying solely on more simplified or uniform methods is likely to result in only limited success, and thereby contribute to the continuing frustration of consumers of modelling results, such as policy makers and utility company planners.

Seven Characteristics of Energy Technology Choices

In order to effectively analyze the modeling tools used to describe energy technology choices, it is necessary to have a clear understanding of the important characteristics of energy technology decisions. A natural first step in doing this is to consider what energy technology choices share with "standard" investment decisions, both in physical or "real" assets, and in financial or "paper" assets. We can then consider the important aspects of energy technology decisions (by technology type) which are not included in this list, and thereby get a feeling for how, and in what cases, standard investment analysis models will need to be augmented. This is done briefly below, as a lead in to the seven proposed characteristics of energy technology choices. (For a more in depth treatment, see "Modelling Energy Technology Choices: Which Finance Tools are Appropriate?, EMF working papaer, February, 1993)

The "standard" investment opportunities which the major financial models were developed for break down into two classes: models of financial, or "paper" investments, and models of real or "physical" investments. Financial investments are the focus of the most well known models of modern finance, such as the Capital Asset Pricing Model and the Arbitrage Pricing Theory. Because financial assets are only "promises to pay", they can be completely represented by describing the (possibly uncertain) dollar amounts associated with them. The models assume the financial investments in question are publicly available, in any fractional amount, in liquid, no transaction cost markets. The necessity of these assumptions to the results of the models make the models of only tangential interest for energy technology investment analysis, where access to the investment is often limited, the investment can only be made in certain size amounts, and transaction costs are generally significant. In contrast, standard models of investment in physical assets assume that an all-or-nothing investment of substantial size is to be made, and that there are substantial set-up and sunk costs to consider, assumptions which make these models much more relevant to energy technology decisions. These "real" investment, or project analysis models are principally based on net present value (NPV) methods. The models assume that the decision maker has an accurate understanding of the investment in question, reflected in projected up-front costs, cashflows over the investment's useful life, and salvage value, if any. Difficulties involved in using these models include choosing the appropriate discount rate, and addressing uncertainty and sunk costs when present. As with models of financial assets, these models typically assume that the problem at hand can be completely described by the various dollar amounts to be paid or received over time.

Most energy technology choices do require the decision maker to consider the factors addressed by models of investment in physical assets as described above. Specifically, there are typically up-front and on-going costs (which may be uncertain) to trade-off, and often substantial sunk costs to consider. These factors will naturally take places as three of the characteristics energy technology models must address. For most energy technologies, these three considerations alone, however, fall short of capturing all the important concerns of the decision maker in question. First, many energy technology decisions are not adequately summarized by dollar amounts alone, due to perceived differences in service quality across choices. The effects of personal tastes and preferences therefore enter the decision. Second, specific energy technology applications are rarely investment opportunities available to the general public. A potential investment in lighting or building shell measures is an opportunity available to the owner or occupant of the building in question alone, not to any enterprising and well-informed market participant. This is significant because it means that general market forces do not come to bear on most energy technology investment opportunities. In contrast, in many markets good opportunities only exist until they first come to someone's - anyone's - attention. That lucky someone (and often those who are quick to follow) capitalize on the opportunity and rapidly eliminate it. The importance of this sort of profit seeking behavior to claims of the efficiency of the free-market system can hardly be overemphasized.

In contrast, in energy technology markets, good opportunities are likely to persist until they come to one particular person's attention - that of the potential owner or user of the technology. There is clearly less reason to believe that this will happen in a timely manner, if at all. In fact, it may not happen at all, even if the decision maker in question is aware of the opportunity, because the economics of exploiting only one such opportunity are likely to be significantly worse than those that would result if the entrepreneur in question could operate in scale - by adding a water heater blanket to every water heater lacking one and taking all the savings, for instance, rather than just adding one in their own home. The problem is that when each individual home owner or business owner must become aware of the relatively small opportunities for energy technology investment in their own home or business, the fixed costs associated with gathering enough information to effectively exploit them, or to recruit others to help them do so, may swamp the benefits of the change. In other words, economies of scale - a crucial element of efficiency in most cases - can't normally be brought to bear on most energy technology adoption decisions, even if they can be brought to bear on production of the technology in question. A well known joke about economic efficiency (and economists!) highlights this distinction. Two economists, walking down a busy street, see what appears to be $10 bill lying on the sidewalk. One says to the other "Is that a $10 bill?" The other responds, "It couldn't be. Someone would have picked it up by now." Should the two economists be looking over a fence into someone's backyard, however, even they would likely admit that what looks like a $10 bill laying on the ground may actually be one.

The discussion above has highlighted the characteristics which energy technology choices share with "standard" investments in physical assets - up front costs, on-going costs, and the possibility of sunk cost concerns - and also has pointed out two factors which can make energy technology decision problems significantly more complicated. First, different energy technologies may have different service quality characteristics, creating a role for personal tastes and preferences. Second, the proprietary nature of many energy technology investment opportunities means that market forces may not drive investment behavior in the way economic analysis often assumes. Instead, the characteristics of individual decision makers, such as their familiarity with the technology in question, and the cost associated with their moving up the learning curve far enough to make a reasonable decision, may hold the key to explaining energy technology investment behavior. Characteristics chosen to address these two complicating factors add to the three investment characteristics listed above, and complete the seven characteristics which make up the framework for analysis of energy technology choices used in this paper. The discussion in later sections amplifies the following definitions, and describes models through which they can be addressed.

1. Service Quality
   - Do the energy technology alternatives available have significantly different in-use characteristics?

2. Search/Information Costs
   - Must the user/purchaser commit significant amounts of time and/or money to identify, analyze and acquire the energy equipment in question?

3. Amount of Money Involved
   - Are the up-front and on-going costs of the technology substantial? Are they small enough that the purchase may be thought of as a consumption, rather than an investment item?

4. Uncertainty About Up-front Cost
   - Is the total up-front cost, including equipment, installation and training, well known to the purchaser?

5. Presence of Sunk Costs
   - Is the technology, once purchased and installed, largely a sunk cost, or can the decision be reversed at low cost?

6. Uncertainty About On-going Costs
   - Are the likely on-going costs of the technology, including energy usage (and cost), efficiency take-back, and operation and maintenance, well known to the user?

7. Uncertainty About Equipment Performance
   - Is likely equipment performance, including service quality, operability, reliability and availability of support, well known to the end-user?

Choosing Models for Particular Classes of Energy Technologies

The natural test of the validity and usefulness of the conceptual framework provided by the seven characteristics described above is whether they 1) provide insight into energy technology choices across a wide range of technologies, and 2) help us identify, or create, appropriate models for particular technology classes. This section attempts to establish that the seven characteristics listed above do achieve these goals. The section is organized around model types because, fortunately, there appear to be significantly fewer model types required than energy technology classes in need of analysis. Each subsection presents a model type, describes it briefly (some will undoubtably be familiar), and emphasizes its requisite assumptions and areas of applicability. Energy technology classes which fit with the model type are then identified. For each model type, at least one sample calculation is provided to highlight its characteristics, as well as to illustrate the "fit" claimed between the model type and the technology classes identified with it. The "established" model types considered include behavioral models and deterministic net present value analysis. The more recently developed methods of analysis described include net present value analysis with uncertainty, irreversible investment methods, and incentive-compatible contract design.

A Note on Discount Rates

Most investment analysis models, including most of those which follow, require the modeler to select a discount rate. The "right" choice for this rate is the source of unending controversy. In the particular case of energy technology investment decisions, some have argued that the discount rate should only reflect the current "time value of money", while others argue that a risk premium should also be added, and still others that a "socially optimal" discount rate is appropriate. Clearly, the appropriateness of these suggestions is context dependent.

In what follows, the appropriate choice of discount rate seems less controversial due to the particular context assumed. Since the specific purpose of the models presented below is to accurately reflect the actual decision process of individual decision makers, it seems clear that the discount rate chosen should reflect their individual circumstances and beliefs. In particular, the individual's personal access to capital (or credit), the return available to them on alternative uses of their funds, and their perception of the appropriate adjustment to this opportunity cost of capital given the riskiness and illiquidity of the investment should be accepted as the appropriate determinants of the discount rate used in their analysis.

I. Decisions Where Behavioral Models are Appropriate

Behavioral models, such as hedonic analysis methods, are appropriate when consumer preferences for different technology characteristics are perceived to be of equal or greater importance to the consumer's technology choice than purely economic criteria, such as cost-efficiency. Not surprisingly, behavioral models are the life-blood of marketing agencies who seek to determine what will sell, particularly at the greatest premium to the product's "utilitarian" value. The most common type of behavioral model uses regression analysis to identify the preferences of the "average" consumer for particular product characteristics. This is accomplished by regressing a variable representing "product purchased" on variables representing important product features, and using the resulting weights as indicators of the significance the "average" consumer places on the given product features. An excellent example in the energy technology area is the design and marketing of cars. All new cars are clearly capable of getting their owner from point A to point B, and some, usually not the best sellers, can do so for much smaller up-front and per mile costs than others. Auto purchasers pay large premiums for generally non-utilitarian features, such as styling, acceleration, and status. The CARS model, included in EMF-13, attempts to capture observed auto purchasing behavior using these methods.

From the perspective of the characteristics listed above, number one, service quality, must clearly be important for behavioral models to be appropriate. Number seven, uncertainty about equipment performance, may also be important. In this case, uncertainty about the in-use characteristics of a new or alternative technology may discourage a potential purchaser, even if their (uncertain) expectation is that the alternative technology will be comparable or possibly better than the technology they are familiar with. Finally, characteristic number three, amount of money involved, often suggests that a behavioral model is appropriate. For small purchases, a consumption rather than an investment perspective is likely to be taken by the buyer, and service quality emphasized over economic criteria. As the CARS example illustrates, however, consumption and service quality factors can be dominate, even for substantial purchases.

Energy Technology Classes For Which Behavioral Models Are Appropriate

- Cars
- Residential lighting (e.g. compact florescent vs. incandescent)
- Small appliances

Examples of Behavioral Models for Energy Technology Choices

As mentioned above, the CARS model provides an excellent demonstration of the effectiveness of behavioral models when service quality considerations are important, and readers are referred to that study for further details. In Appendix B a simple example is presented which also highlights the trade-off between service quality differences and monetary costs by comparing the relative benefits of incandescent, halogen, and compact florescent light bulbs.

II. Decisions Where Deterministic Net Present Value Models are Appropriate

The well-known deterministic net present value (NPV) method is appropriate for straightforward, well-defined investment analyses, a category which at least some energy technology choices fall into. Characteristics required of a member of this category, in the framework of the seven characteristics presented above, are: service quality is homogeneous across alternatives (characteristic 1), alternatives are easy to identify (2), amount of money involved justifies an investment analysis (3), and cost and performance parameters are well known (4,6,7). It is generally implicitly assumed that the low level of uncertainty about the cost and performance of the technology in question makes sunk costs (6) of limited concern.

To meet these criteria, energy technologies must be familiar, well understood, and provide a commodity-like service. These qualities are necessary to eliminate a role for search costs, technology performance concerns, and service quality. In addition, use of the technology must be predictable, if on-going cost is to be accurately estimated. This means there must be a minimal behavioral aspect to usage, so that the potential for "take back" or for an impact from inefficient operation is limited. In contrast to small home appliances and lighting, for which behavioral models were argued above to be appropriate, large home appliances, such as refrigerators meet this criteria quite well. Their services, features and designs are relatively standard. Store labels give their purchase price and annual energy usage, and it is expected they will be plugged in and left on. Lighting and heating and cooling in commercial buildings also often meet the required criteria, since they are usually installed according to standardized design criteria, and centrally controlled, with operating periods and levels set to meet utilitarian service standards.

Energy Technology Classes For Which Deterministic NPV Models Are Appropriate

- Large residential appliances (refrigerators, freezers, washers and dryers)
- Standardized applications of commercial lighting and HVAC (heating, air conditioning and ventilation) measures

Examples of Deterministic NPV Models for Energy Technology Choices

Appendix C presents a simple application of deterministic NPV methods to a homeowner's choice among three types of water heaters. The importance of the discount rate and planning horizon assumed are illustrated.

III. Decisions Where NPV With Uncertainty or Irreversible Investment Models are Appropriate

The deterministic NPV analysis described above is no longer appropriate when important cost and performance parameters are uncertain. Consumer uncertainty about actual cost savings and performance characteristics of new energy technologies is common, and often has a significant impact on the decisions they make. Useful models can still be created of consumer decisions under uncertainty as long as an approximate description of the consumer's level of uncertainty, in the form of probability distributions over the relevant variables, is available. However, the presence of uncertainty, especially about more than one variable, greatly complicates the required calculations, and often requires specialized software. One notable exception are decision problems which can be addressed with irreversible investment techniques, which in some cases allow analytical solutions.

In the framework of the seven decision characteristics listed above, problems which are appropriately addressed with irreversible investment models or NPV with uncertainty models share the same general characteristics as those appropriately addressed by deterministic NPV models, with the additional complication of uncertainty about at least one important decision parameter. Therefore, they are appropriate when the amount of money involved justifies an investment analysis (3), and at least one of the following holds:

a) service quality across alternatives is not homogeneous or is not well understood (1)
b) alternatives are not easy to identify (2)
c) cost and performance parameters are not well known (4,6,7)
d) uncertain returns make incurring sunk costs an important concern (5)

Whether irreversible investment methods or NPV with uncertainty methods are more appropriate for problems of this type depends primarily on the nature of information gathering opportunities available. "Passive" information gathering opportunities are assumed by irreversible investment methods and describe situations in which uncertainty is reduced simply by the passage of time. An energy technology example of such an information gathering opportunity (see sample calculation in Appendix D) is the opportunity to wait for one of your neighbors to try a building shell improvement which you have been considering, and to observe their actual experience before making your own decision. In contrast, "active" information gathering refers to a consumer's opportunities to reduce their uncertainty in the present, at some cost, measured in either their time or money. If opportunities of this type are available, NPV with uncertainty methods (which can also incorporate passive opportunities) must be used. Expanding on the example above, the homeowner might also be able to improve their understanding of the building shell measures they are considering by spending a Saturday researching the possibilities themselves, or by spending a small sum to hire an expert to evaluate them for them. Using the active-passive information distinction, the appropriate model for a decision with characteristics included in a) through d) above can be identified. Cases a) and b) suggest active information gathering opportunities are likely, and therefore that NPV with uncertainty methods are appropriate. If only passive information gathering opportunities are available regarding cost and performance parameters, cases c) and d) could be analyzed with irreversible investment methods. If active information gathering opportunities regarding cost and performance parameters are also available, NPV with uncertainty methods are required.

Energy Technology Classes For Which NPV With Uncertainty and Irreversible Investment Models Are Appropriate

- Residential HVAC and building shell measures, due to
  - site specific characteristics
  - likelihood of take-back effects
- Industrial applications
  - motor driven machines, conveyors, fans, etc.
  - industrial process design

Examples of NPV With Uncertainty and Irreversible Investment Models for Energy Technology Choices

Appendix D illustrates the methods of NPV with uncertainty and irreversible investment through an extended analysis of the alternatives facing a home owner considering attic insulation and weather stripping alternatives. The example seeks to illustrate both the nature of the assumptions and of the required calculations of the two methods and the impact that relatively small changes in assumptions and in alternatives considered can have on the conclusions reached.

IV. Decisions Where Incentive Compatible Contracts are Appropriate

"Incentive-compatible" or "principal-agent" contracts are generic terms for solutions to problems where at least two different parties, with different goals and concerns, must jointly make a decision or accomplish a task. While the two terms are often used synonymously, incentive compatible is used here because of the employer-employee connotation often attached to the term principal-agent. Examples of energy technologies to which incentive-compatible contracts are relevant include builder vs. buyer input on new building energy technology features, and landlord vs. tenant choice of energy equipment and utility bill sharing. The "theoretical" solution to problems of this kind is to draw up a contract between the parties that specifies the rights and responsibilities of each. The two most common complications which arise in drawing up such a contract are the difficulty of anticipating and specifying responses to each possible contingency, and of monitoring the actual actions of the two parties over time. Contracts which do not incorporate simple ways to overcome these problems quickly become unwieldly and expensive to write as well as to enforce. Well designed contracts alleviate these difficulties by providing incentives to each party which encourage them to act in reasonable and mutually responsible ways as often as possible; hence the term incentive-compatible. The gap between theory and practice in incentive compatible contracting exists because real world contracts are generally highly situation dependent, and because the real world is usually significantly more complicated than the theoretical models of it for which general solutions have been derived.

The first step taken in the design of an incentive-compatible contract is to model the decision problem of each of the individuals who are to be parties to the contract. In the builder vs. buyer example, presumably the builder seeks to choose the equipment that will maximize their profit on the sale of the home. To do this, they will choose the equipment that maximizes the difference between their equipment costs and the value a buyer will be likely to place on the equipment when valuing the overall house. On the other hand, the buyer presumably hopes the builder will choose the equipment he himself would choose, or perhaps that he will be able to get good quality equipment as part of the house "package" for a cost increment smaller than the equipment's actual value.

The standard solution to the problem described above is to solve the problem of the builder and the buyer separately. Since the actions of each party affects the other's outcome, each party must estimate the likely behavior of the other in order to solve their own problem. For instance, the builder might assume that the equipment the buyer would ideally choose is the equipment that would minimize their total discounted costs over the X years they expect to own the house. The builder might estimate the distribution of X over the population of potential buyers, and then choose the equipment which maximizes their expected profits given this population of buyers.

In contrast, an incentive compatible solution to the builder vs. buyer problem would seek ways to achieve a more generally ideal or "best overall" solution. A natural "ideal" solution is to have the builder install the equipment with the lowest life-cycle cost, and then ensure that the builder, as well as subsequent buyers and seller of the home, are fairly compensated for their investment. As the preceding analysis shows, however, both home builders and buyers will only be willing to pay for this "least life-cycle cost" equipment if they feel sure they will be reimbursed for it accordingly - either by realizing on-going savings, or through a compensating adjustment to the home's resale value. One way to ensure that this is the case would be to create a basic method of evaluating the energy efficiency of a house, and a way of translating this rating into a present value to be added to the sale price of the home. If this could be efficiently operationalized, it would eliminate resale value concern as a deterrent to the installation of more efficient - but more costly - energy technologies.

In effect, the goals of incentive-compatible contract design include all of the following: 1) to reduce the uncertainty faced by the various decision makers involved, 2) to thereby reduce the amount of background research and monitoring required of the parties involved, and 3) to improve the end quality of the decision from an overall perspective. In the example above, the incentive-compatible scheme described should 1) reduce the builder's level of uncertainty, as well as their exposure to non-recoverable (or sunk) costs at time of sale, 2) reduce the buyer's uncertainty and exposure to non-recoverable costs (at time of resale), 3) reduce the amount of effort previously required of buyers and sellers to adequately research and document a home's energy use characteristics, and 4) improve the average quality of energy equipment installed.

In general, since the level of uncertainty about up-front and on-going costs and about equipment quality can change due to the introduction of an incentive compatible contract, energy technology decision characteristics 4, 6 and 7 are relevant. Incentive-compatible contracts can also affect the risk of sunk costs (5), the need to incur search or information costs (2) and the resultant service quality (1). For all this effort to be worthwhile, the amount of money involved would likely have to be significant (3). To estimate the effect of these changes in the characteristics of the decision on the individual choices of each relevant party, a method such as NPV with uncertainty is likely to be required.

Energy Technology Classes For Which Incentive-Compatible Contracts Are Appropriate

- Technologies with different buyers and users, such as
  - Energy technologies built into new homes (HVAC, building shell measures)
  - Energy technologies purchased by landlords and used by tenants
- Technologies installed under "shared savings" plans
  - Energy technologies installed or paid for by energy service companies or utilities, in exchange for a share of on-going savings

Examples of Incentive Compatible Contracts for Energy Technology Choices

Appendix E illustrates the general nature of the calculations required to analyze the potential of an incentive compatible contract in a particular situation by considering in greater detail the hypothetical builder vs. buyer example described above.

Summary of Insights From Individual Energy Technology Choice Models

The goal of this section has been to reconsider methods of modelling individual energy technology decisions in light of what we have learned about actual consumer energy technology choices, and about decision modelling under imperfect information and uncertainty. To guide the discussion, seven basic characteristics of energy technology choice decisions were presented, and together were argued to encompass the important decision parameters of all the major classes of energy technologies. Individual technology types described by various subsets of these characteristics were matched with modelling approaches appropriate for that subset of characteristics. Four classes of models were presented, which together were found to be capable of spanning the range of modelling requirements identified. Both the range of the characteristics and of the models required to effectively analyze the full spectrum of energy technologies were found to extend well beyond those of traditional investment analyses. The two principal reasons that standard investment analysis methods were found to be inadequate are 1) service quality differences play an important role in many energy technology choices, requiring a method of modelling the impact of personal tastes and preferences and 2) due to the proprietary nature of many energy technology investments, decision maker specific levels of awareness, uncertainty and access to capital are crucial determinants of many energy technology choices, and require methods of evaluating opportunities available to decision makers to gather information, reduce their uncertainty, and fund their energy technology purchases. These factors have received little emphasis in previous analyses of energy technology choices, and appear to have significant potential for resolving existing energy technology investment "paradoxes".

In section two below, important "macro" issues concerning energy technology market efficiency are reconsidered using the expanded set of tools for modelling individual energy technology choices developed above. The implications of the proprietary nature of many energy technology decisions are found to be particularly important to the analysis of energy technology market efficiency and behavior.

Section 2: Market Forces and the Decision Environment

The goal of this section is to consider the implications of the insights into individual energy technology choices gained from the analysis of section one. In that section, two "special" characteristics of many energy technology choices were found to play an important - and previously generally overlooked - role in energy technology decisions, and as a result to require extensions to traditional investment modeling approaches. These two characteristics are service quality differences among competing technologies, and the role created for individual levels of energy technology expertise and access to capital by the proprietary nature of many energy technology investment opportunities. In this section, the "macro" implications of these special "micro" characteristics, and in particular their impact on the nature and efficiency of energy technology markets, is addressed. Together, these two factors provide a natural framework for reconsidering previous analyses of energy technology market behavior and of appropriate policy actions, and suggest a somewhat different role for both government and private industry in affecting future energy technology investment behavior. The role of each of these two factors in determining energy technology investment is considered separately below. Discussion of potential market and government based actions, including specific programs and business opportunities, together with their likely impact on the efficiency of future energy technology investment levels, makes up the remainder of the section.

The Role of Service Quality Effects

As described in section one above, service quality differences across competing energy technologies can have an important effect on individual energy technology choices due to differences in personal tastes and preferences. As a result, taking into consideration these personal choice effects can impact standard analyses of energy technology market efficiency in two important ways. First, taking careful stock of consumer preferences for the different levels of service quality provided by competing energy technologies is likely to make many observed energy technology choices look substantially more rational than they appear under traditional simple NPV analysis, where only monetary costs and benefits are considered. The car and compact florescent bulb examples in the behavioral model subsection of section one illustrate this effect, since in those cases consumers clearly weight service quality differences more heavily than purely economic criteria. Second, acknowledging this effect makes it clear that in cases such as these, consumer choice of less economically efficient energy technologies does not reflect a market failure. On the contrary, regardless of how idiosyncratic they may seem, personal preferences must be acknowledged as the appropriate basis for individual choice. To facilitate analysis, in economic theory individual preferences are often assumed to be homogeneous and to reflect "economically rational" criteria, but this is only for convenience. The arguments of section one suggest that this simplification needs to be abandoned in the case of certain energy technologies, and observed choices in these cases accepted as simply "personally preferred" rather than irrational or inefficient. In brief, the subset of the energy technology choices commonly labeled irrational or economically inefficient which are actually determined primarily by service quality differences are not evidence of market inefficiency, but instead of the effects of personal tastes and preferences previously overlooked by simplified modeling approaches.

The Role of Decision Maker Specific Characteristics

In contrast to the modelling challenge presented by technology service quality differences described above, the important effects that individual-specific levels of expertise and access to capital have on individual energy technology choices, and which result from the proprietary nature of many energy technology decisions, do have significant implications for the workings of energy technology markets. These implications effect both the types of goods and services that are likely to be traded in energy technology markets, and the efficiency of the allocation the markets are likely to produce. The reason for these effects, as discussed briefly in section one, is that for a rational investor to choose to invest in such a proprietary opportunity, the benefit of the investment must more than off-set the costs, in time and money, of the particular decision maker moving far enough up the learning curve to effectively exploit it. In contrast, in the "standard" markets which theories of economic efficiency assume, opportunities are freely accessible. This allows entrepreneurs to leverage their investments in education and training through economies of scale in their application. Under these conditions, investors can be fairly idealized as having extensive investment experience, and marginal learning costs of zero. Idealized, large scale investors of this kind will naturally choose to learn as much as possible about the investment under consideration. This means that they will eliminate the uncertainty that stems from their own lack of information, and be left to face only the inherent risk of the project. Clearly, this idealized expert will 1) make better decisions (in fact, they can generally be relied on to make optimal decisions) 2) on average, invest more in efficient new technologies, because: a) the benefits of the new technology need only balance out its purchase cost for this investor, while they must also outweigh the "learning" cost of the "one-off" investor, and b) the idealized investor will have a lower (or at most equal) level of uncertainty than the "one-off" investor. In summary, the proprietary nature of many energy technology decisions means 1) individual decisions are much more difficult to model because to do so effectively requires that individual idiosyncrasies be analyzed, and 2) energy technology decisions on average are likely to be made less effectively, since they are made by "one-off" rather than idealized, high volume investors.

In light of the above, it appears that the improved "micro" models of section one can add significantly to our understanding of observed levels of efficiency in energy technology investment, and of energy technology markets. In particular, micro models which appropriately reflect the impact of the proprietary nature of many energy technology investments on the individual choice process suggest that the average quality of energy technology decisions will reflect the average level of energy technology expertise of individual decision makers. Because few people have substantial expertise in energy technologies, this implies that majority of energy technology choices are unlikely to be made in an optimal way.

This conclusion in itself is hardly revolutionary. It matches the results of most empirical studies, and people on all sides of the debate are likely to accept it. It is significant here, however, because in this case it follows as a basic conclusion of an improved model of individual energy technology choice, rather than existing as a poorly explained empirical fact. The net result is that we now have an appropriate analytical framework to use to address this commonly accepted but problematic fact. This framework provides a basis for designing and analyzing policies and programs, and for more accurately forecasting future trends. Relying on this framework, these questions are addressed in broad terms below.

<u>The Policy Design Question Revisited</u>

To address policy questions using the insights gained from the improved models of individual energy technology decisions presented above, it is most helpful to work forward from the basic problem, relying on the insights gained into its causes, and to consider how specific policy alternatives might mitigate those causes. In particular, if we know that many energy technology choices are likely to be made in a sub-optimal way from an expert's perspective - because they are likely to be made by non-experts - can we develop ways to improve them? Are market failures the cause of this poor decision quality, or does an expanded range of market based products and services hold the key to their improvement?

The market failure question is especially easy to answer if we believe in the analysis presented immediately above and in section one. Market failures are generally accepted to be the result of externalities, public goods, or increasing returns to scale. (For a more complete discussion of market failures and barriers, see "Back to Basics: Searching for Principles to Guide the Energy Conservation Debate, EMF working paper, November, 1992) Clearly, none of the factors is the driving force of the poor decision quality identified above, which instead results primarily from the "one-off" nature of individual's proprietary energy technology investment opportunities. For instance, while the failure to adequately correct for pollution externalities in energy prices may be a market failure, correcting it would not resolve the decision making challenges faced by individuals. As a result, higher energy prices might shift the aggregate amount of energy technology investment up, but the lack of energy technology expertise among individual decision makers would continue to lead to generally sub-optimal technology choices. It could be argued that information about new energy technologies is a public good, and if more fully disseminated would mitigate the individual's decision making challenge. It is interesting to note that existing information provision programs, such as appliance labelling and new car fuel efficiency posting are among the most widely supported energy technology policies. In most cases, however, (as discussed more fully below) the main challenge to decision makers as identified in section one is not the availability of general information, but of decision specific information and methods of analysis. In summary, market failures occur when the decisions that individual's make in their own best interest do not appropriately take into consideration the effects of those decisions on those around them. In contrast, the problem identified here is that the limited resources available to individual decision makers lead to "satisficing", or individually "cost-benefit balanced", rather than truly optimal decisions. In other words, the problem is not that individual decisions need to be better coordinated, as is the case when market failures are present. Instead, the problem is that the quality of the decisions individuals make in their own best interest could stand to be improved.

Unfortunately, economic theory doesn't provide much help in addressing this problem. In fact, most of economic theory assumes individuals have full information at all times, and unlimited capacity for analysis. As described above, this assumption is much more likely to be (approximately) valid when economies of scale can be achieved by the decision maker, allowing their marginal costs of analysis to approach zero, and their decisions to approach the idealized optimum. Assuming economies of scale are available, and that there are not important market failures at work, we can feel comfortable "leaving well enough alone". However, the analysis above of the effects of the "one-off" nature of most energy technology decisions suggests that decision makers will naturally face a trade-off between the value and the cost of additional analysis, and that the standard "economies of scale effect" argument is not valid in this case. Instead, since the benefits of a careful analysis will only be realized once, its associated costs are likely to discourage individual decision makers from undertaking an in-depth analysis. Decision costs are therefore are quite likely to have a substantial impact on the quality of a consumer's choice.

If we accept that individual decision maker "resource constraints" have significant effects on their energy technology decisions, and accept that the average efficiency of energy technology decisions will be limited as a result, it is natural to consider possible ways to off-set the effect of these constraints. To do so, it seems clear that individual decision makers will need to receive some kind of help from expert third parties. Simple common sense suggests three basic ways this could be provided: 1) individual's decisions could be made for them, presumably by government, using mandates and standards, 2) a large enough positive incentive - such as a discount or rebate - could be established to make the right choice "glaringly obvious", 3) individual decision makers could hire energy technology experts to help them make their technology choices, thereby achieving a better outcome, in exchange for a fee equal to a portion of their savings. Clearly the first alternative violates freedom of choice, and seems likely to be appropriate only in special circumstances, such as for technologies for which unconstrained individual choices are likely to be highly predictable and uniform. The second alternative also in effect makes individual's choices for them, since they are "lead" to the "right" choice. It is also certainly possible that for "positive" incentives to work effectively, they would need to be so large that they would offset any savings gained, even without consideration of the equity issue of who would fund these incentives. In contrast, the last choice is a market based alternative, which relies on the development of benefit sharing arrangements between individuals with energy technology investment opportunities and energy technology investment experts. The potential of these arrangements of this kind is explored more fully in what follows.

The basic goal of the third, market based, "expert advice" alternative is to design mutually beneficial arrangements between individual decision makers and energy technology experts that would allow responsibility for particular energy technology decisions to be partially or completely shifted to the energy technology expert. This translates to a search for potentially operational and profitable markets for energy technology advice and services. The profit potential for these services lies in the money that non-expert individual decision makers would normally leave on the table when making energy technology decisions based only on their own expertise. Expert third parties can profit by offering products or services capable of helping the actual energy technology consumer improve on this "unaided" decision, in exchange for a share of the benefits of the improved decision.

That some profit potential is available for such expert services seems clear. Whether enough savings can be achieved at low enough cost for such a service business to be truly feasible is less clear. As a start, to make markets for their advice and services work, experts will need to convince individual decision makers of their competence and integrity. To do this effectively, experts may need to enter into some sort of partnership with the decision maker, or at least operate in a way likely to gain their trust. While this makes the task of the entrepreneurial expert more difficult, it is no different than the type of challenge commonly faced by other service businesses. Many businesses which provide decision advice to other types of decision makers currently exist, ranging from business consulting firms which help their clients make the most of the businesses they own or run, to investment advisors who manage the money of others, and even to marriage counselors and wardrobe consultants, who help people improve their relationships or the image that they present. While few third party service providers in the energy technology markets are as established and experienced as comparable providers in these industries, entities such as energy service companies, utilities, equipment suppliers and contractors currently do provide valuable services to energy technology decision makers, and make a profit by doing so. The generally self-interested, profit-seeking efforts of these entities do significantly affect the decision environment of individual decision makers by making relevant energy technology information, services and equipment available to them. If in the future new services and improved delivery methods are developed by these and related energy technology businesses, it seems reasonable to expect that the average quality of energy technology decisions will improve as a result of the enriched set of resources that will be made available to individual decision makers. The prospects for trends of this kind in energy technology services are considered below, including discussion of 1) the sorts of services currently provided, 2) reasons why the range of services offered is likely to expand in the future, 3) what new services are likely to be offered, and 4) how, in some cases, the offering of new services could be facilitated by policy initiatives.

Business Opportunities in Providing Energy Technology Services and Advice

The above discussion has argued that expanding the range of (for-profit) energy technology services and advice is a worthwhile goal - both of policy makers and entrepreneurs - since it is likely to provide profitable business opportunities as well as improve the average efficiency of energy technology decisions. In what follows, the basic nature of energy technology service opportunities is addressed, relying on a framework provided by the identification of three general categories of energy technology service opportunities. The categories help place current energy technology services, and also suggest several prospective new services, most of which depend on recent developments in consumer lending and information technology, or facilitation by future targeted policy initiatives. The three categories, each a subsection below, are: 1) Information vendors and performance guarantors, which describes opportunities to provide information to or reduce the uncertainty of energy technology decision makers, 2) Asset-based lending, which describes lending opportunities for energy technologies, and 3) Cost-benefit sharing, which describes opportunities for partnership-like arrangements between technology end-users and third parties.

It should quickly become clear from the following discussion that the link between the analysis of individual decision problems presented in section one and the analysis of market opportunities for energy technology services provided in this section is the way in which the likely inadequacies of unaided individual decisions are likely to attract market forces seeking to profit by facilitating and improving those decisions. Because entrepreneurial energy technology experts cannot directly invest in and profit from proprietary individual energy technology investment opportunities, their next best alternative is to seek to profit by providing individual decision makers with services capable of improving the quality of their decisions. Since services of this kind comprise the primary external resources available to resource constrained decision makers, by considering the perspective of their providers, we can both better understand the environment in which individual decisions occur, and perhaps learn how to facilitate the provision of new services which could improve that environment.

I. Information Vendors and Performance Guarantors

Since most consumers only face a particular type of energy technology choice once, or at most very infrequently, their analysis of those choices is likely to be limited by their lack of familiarity with available alternatives. In addition, the cost, in time and money, of developing the necessary background to make the relevant decision wisely is likely to overwhelm the associated benefits. This dilemma of the individual makes it natural to consider the ways in which a consumer's energy technology information gathering and evaluation task can be facilitated by or delegated to a "for-hire" advisor. The challenge is to determine how, credibly, and for a fee, to make the knowledge and abilities of third party experts available to individual decision makers. Meeting one of two general criteria seem necessary for this to occur. First, information or advice is likely to be considered reliable by its potential purchaser if its provider is viewed as established and credible. Second, advice can be further substantiated if its provider "puts their money where their mouth is" and offers some sort of performance guarantee for the alternatives they suggest. Each of these alternatives are discussed briefly below, where it is assumed that the field of potential energy technology experts is made up of utilities, energy service companies, equipment suppliers, and contractors.

• Information Vendors

Energy technology experts seeking to sell only information face perhaps the greatest challenge in establishing their credibility since they are putting nothing beside their reputation at risk when offering their advice. Still, substantial numbers of people succeed in offering their advice for a fee in other areas, and their methods and experience can serve as a guide for those in the energy technology field.

Nor surprisingly, expert advice is most often considered credible if its is given in an area in which the expert has a strong track record, and when they have the incentive to be fair, or at least conservative in their assessments. A natural example of this is the advice of an experienced financial advisor who seeks to establish or maintain on-going advising relationships. Due to their specialized nature, energy service companies are most likely to be considered truly expert in energy technology choices, but most lack a significant history and scale, a problem also likely to be faced by most specialized energy technology contractors. In addition, because both energy service companies and energy technology contractors profit from the sale of energy technology equipment, they are likely to generate suspicion regarding their intentions, as of course would equipment suppliers. In contrast, while utilities may not naturally be thought of as end-use energy technology experts, because of their status as large, well established corporations, their service record with consumers, and their history of trying to sell, rather than save electricity, their motives and reliability are likely to be trusted. This suggests, as a second best condition, that an expert may be perceived as credible if they have a strong general reputation - and therefore something significant to lose if their advice is wrong or misleading. According to this criteria, in addition to utilities, large building supply chains may also be able to succeed in the energy technology information and advice business, due to their scale and reputation. While they also clearly have the incentive to make a sale, the general nature of their business provides them with more of an incentive to keep their customers happy on an on-going basis than a business which specializes in energy technologies is likely to have.

• Performance Guarantors

In contrast to advice alone, advice certainly has more credibility when it is backed up by the advisor's own money. However, this benefit to the consumer has a cost to the provider.

Clearly, for an expert to accept financial risk associated with their advice, the claim they are guarantying must be concrete, easily verifiable, and not subject to the customer's discretion. For energy technologies, a natural such target is the complete installed costs of a new technology, or a specific reduction in monthly energy usage from the adoption of a technology not subject to unmonitorable usage, such as a centrally controlled office building lighting system (and not a home heating system which might often be set to a higher temperature). Because installation, and not hardware costs, are most likely to be the uncertain element of up-front costs, contractors or energy service companies seem the natural party to provide up-front cost guarantees. Guarantees of on-going savings may be more difficult to successfully arrange, since as noted above, most contractors are not large, well-established organizations, and therefore are not likely to appear to consumers as credible long-term counterparties. Similar questions about future accountability may also limit consumer confidence in investments with on-going guarantees provided by energy service companies. The complications which on-going obligations pose to parties to energy technology agreements are considered more fully in the discussion of cost-benefit sharing arrangements below.

II. Asset Based Lending

As discussed above under "A Note on Discount Rates", some decision makers may not invest in an energy technology which they believe offers a substantial rate of return because their access to capital may be so limited that they are forced to forego even more promising opportunities or pressing needs. Economic theory often overlooks this potential problem by assuming that capital will search out investments with above average rates of return, and any credit concerns about the end-user will some how be worked out. In contrast, the real world reality for most consumers is that borrowing money for all but a limited range of investments, such as homes and cars, can be difficult, especially for those in low income brackets. The two most important reasons for this are: 1) lending in small amounts (as is the case for nearly all individual needs other than home buying) is only profitable if the loan type offered can be standardized and essentially automated (as are credit cards and auto loans), and 2) lending to those who already have claims on a significant portion of their income is inherently risky. Energy technology loans are unfortunately likely to fail the first, or "high volume" test above for all conventional lenders except perhaps the largest banks. This problem is compounded by the fact that a significant fraction of the consumers likely to seek an energy technology loan will choose to do so because their eligibility for conventional sources of credit is already stretched thin, making them likely to fail the second, or credit quality test.

While the factors described above may have made energy technology lending an unlikely business in the past, there is reason to believe that in the future both factors may be alleviated, and that the situation may therefore change. In particular, loan volume requirements can now be more easily met due to recent developments in the consumer loan delivery methods. Also, consumer credit quality concerns can now be at least partially offset using new methods for structuring asset-secured loans and leases, methods in part derived using the improved models of consumer energy technology choice developed in section one.

Each of these factors is discussed separately below.

• Advances in Consumer Lending Methods

Recent advances in information technology have lead to significant advances in consumer lending services in the last several years. Computerization of nearly all of the consumer lending process, including credit analysis and underwriting, loan monitoring, servicing, and collections have drastically reduced associated costs. In addition, the new automated and essentially anonymous nature of modern consumer lending has made it possible for large, specialized institutions to spring-up, providing niche-targeted services on a nationwide basis. Numerous institutions now offer credit cards, personal loans, lines of credit and home equity loans on a nationwide basis, without providing any other banking or lending services to their customers, and generally without more knowledge of their customers credit characteristics than that contained in on-line credit bureau reports. In addition, quasi-governmental organizations similar to those that have long provided packaging and guarantees of home mortgages now do so for student loans and small business loans, thereby providing a ready secondary market and almost total liquidity to lenders originating such loans. In light of these trends, it seems possible that similar lending services can be developed for at least the most common and standard energy technologies, such as large appliances, heating and cooling equipment, and under a home equity type hybrid loan, building shell measures.

• Advances in Asset Based Lending Methods

Advances in loan delivery technologies, however, do not alter the credit quality of already over extended consumers, which, as noted, are those most likely to desire energy technology loans. The already "tapped out" credit status of some potential energy technology borrowers therefore creates a second challenge to potential energy technology lenders. Over the years, potential lenders and borrowers have found two principal ways to at least partially overcome consumer credit quality problems, however, and it appears that these methods, or a possible hybrid of the two, may facilitate energy technology lending. First, loans under dubious credit conditions can be secured by specific assets, such as a home deed, car title, etc. (or in the underworld, someone's as yet unbroken legs!). Second, new loans or new creditors can replace old ones, such as a mortgage which replaces a rental obligation, or a new mortgage which replaces a refinanced one (in the underworld, double or nothing, someone else's legs for your own, etc.). In the case of energy technology loans, the energy technology asset purchased could naturally be used to secure the loan. For "movable" energy technologies, such as large appliances, this method alone should suffice. For the many energy technologies which aren't movable, such as installed heating and cooling equipment, and insulation and building shell measures, the essentially non-transferable nature of the technology is likely to significantly reduce its collateral value to most lenders. For these technologies, however, a hybrid form of securing lending which also makes use of method two above - substitution of a new obligation for an old one - may work, if the loan is made by someone who already has an exposure to the consumer's credit, such as their mortgage holder or local utility. In particular, a loan from either of these two lenders may be justified, or even prudent, if the annualized total cost of the new technology, including loan payments and energy costs, is less than the energy cost alone of the borrower's current technology. If this is the case, as it certainly may be for a consumer replacing, for instance, an old electric space heater with a new gas model, the lender would be able to improve the borrower's overall debt service to cashflow ratio while at the same time booking a new loan on (presumably) profitable terms. This suggests that the mortgage lender or utility in question may even reasonably choose to make an energy technology loan to *improve* the credit quality of one of their existing obligors. It is important to emphasize, however, the special circumstances that make this arrangement work; in addition to their current exposure to the potential borrowers credit, both mortgage lenders and the local utility have an on-going interest in the non-movable equipment in question, and special leverage to use to collect what they are owed. In particular, if the borrower defaults on their obligation to the mortgage lender, their home, including the improved energy technology equipment installed in it, reverts to the lender. If the utility isn't paid, they can cut-off utility service, and also can presumably continue the technology loan/lease arrangement with the future occupant of the home.

It is interesting to note that the analysis of the profit potential of the programs described above rests to a large extent on the improved understanding of individual decisions provided by the analysis of section one, and shows how well-designed energy technology services can break down the "proprietary opportunity" barrier and improve many individual technology choices. The analysis of section one, for instance, suggests why some (credit constrained) consumers might forego energy technology investments with high rates of return, and also why investors with substantial uncertainty about the performance of alternative energy technologies might be willing to accept larger on-going costs in order to avoid making up-front investments with potential sunk costs. The second example above also shows both how new energy technology lending services can increase the average efficiency of in-use technologies, and how certain expert third parties with access to capital (utilities in this case) can, to a reasonable degree, substitute their investment criteria for that of the actual technology end-user.

III. Cost-Benefit Sharing

Cost-benefit sharing describes arrangements which include more than one party as both contributor and beneficiary. Opportunities for cost-benefit sharing of energy technology investments arise when a third party perceives opportunity in providing more than just a loan, or information, or installation cost guarantees to the technology adopter. Natural examples include activities such as those often undertaken by energy service companies and utilities, where some combination of technology choice advice, installation and retrofit services, on-going operation and maintenance, and capital cost funding are provided, usually in exchange for a combination of fees and a share in realized energy cost savings. In a sense, then, cost-benefit sharing includes information provision, performance guarantees, and asset-based lending as special cases in which the benefit to the third party is a one-time fee for service, rather than an on-going interest in the resultant savings or performance. By considering the differences between these special cases and more general cost-benefit sharing arrangements which require the on-going involvement of the parties to the arrangement, the difficulties, as well as the potential, of the more general arrangements can be highlighted. The difficulties stem from the challenge of designing agreements which protect as well as benefit both parties, particularly over the course of an uncertain future. In particular, because the rationale for the agreement derives from the difference in energy technology expertise of the two parties, the consumer is likely to feel at a significant disadvantage in negotiating the terms of the agreement, while the expert, in turn, may feel compelled to accept more responsibility for the final outcome than they would like. At the same time, the primary benefit of on-going arrangements, not surprisingly, is that when well designed, they allow the expert third party to credibly and convincingly mitigate the concerns of individual decision makers about actual on-going technology savings and performance, and in exchange capture more of the benefits of the technology than they would be able to through any other type of service. In the framework developed earlier, well designed cost-benefit sharing agreements allow third party experts to most completely substitute their energy technology decision making skills for those of non-expert individuals, and at the same time gain most complete access to proprietary energy technology investment opportunities.

As was true for the discussion of incentive-compatible contracts above, of which cost-benefit sharing agreements are a special case, it is difficult to provide illustrative general examples because successful agreements are highly situation dependent. The utility lending program described under asset-based lending above is one simple, standardized example. The best current "real world" examples are the more comprehensive energy service company offerings. These usually target companies with large, relatively simply and homogenous energy technology retrofit or upgrade opportunities, and offer to pay a significant portion of the up-front costs in exchange for a share of on-going savings, which are usually quite easy to measure due to the simple and standard nature of the technology in question. These programs become almost "free money" for their clients, since they require little analysis, little capital, and entail little downside risk. In other words, they effectively open the "proprietary investment door" to the energy service company, for a share of the benefits realized. It is up to clients to learn enough about their energy technology investment opportunities to ensure they get a fair share of the benefits, and up to both parties to design future agreements that will allow these types of programs to expand to include a greater range of technologies.

Summary of Factors Affecting the Consumer's Decision Environment

The goal of the above discussion has been to illustrate the ways in which an individual's energy technology decision environment is, and is becoming ever more so, a function of market forces which seek to profit by helping such individual decision makers effectively exploit their proprietary energy technology investment opportunities. Individuals without sufficient information, risk tolerance, or capital to proceed with a promising energy technology investment on their own provide entities like utilities, energy service companies, equipment suppliers and contractors with potentially profitable advising, risk-sharing and lending opportunities. As the technologies of providing these types of services advance, as they have recently due to advances in information technology and contract design, the nature and cost of the services provided to individual decision makers will also advance. In some cases it may be possible for small regulatory changes to facilitate new utility company activities of this kind, or for simple policy initiatives to serve as catalysts for new services by energy service companies or contractors. Whatever their genesis, it seems clear that if the range of cost effective services can be expanded, the average level of decision quality, and therefore of energy efficiency, will improve proportionately.

Conclusions

In the first section of this paper, models of individual energy technology choices were discussed. It was argued there that several factors distinguished energy technology choices from the types of investments standard financial modeling tools were developed to address. Most important among these distinguishing factors are service quality considerations, and decision-maker specific levels of information, uncertainty, and access to capital. Models capable of addressing these considerations were then presented, and were used to illustrate their implications for the likely quality of the energy technology decisions of individual consumers. The most important conclusion of this section was that due to the proprietary nature of most energy technology investment opportunities and the "one-off" nature of the decision for the consumer, most energy technology decisions are likely to appear sub-optimal from the perspective of an expert in energy technology investment.

In the second section of the paper, the causes and implications of the likely sub-optimal nature of individual consumer energy technology decisions for the efficiency of energy technology markets and for government policy design were addressed. Because the "satisficing" nature of individual energy technology choices was found to result naturally from the limited amount of resources that a rational decision maker would choose to employ to make a single, specialized decision, market failures were ruled out as the primary cause of inefficient energy technology investment decisions. Rather, the key problem identified was the need to develop ways to make more expert services accessible to consumers, thereby enabling them to make decisions in their own self interest more effectively without having to become energy technology experts themselves.

Three basic ways to transfer responsibility for energy technology decisions from their non-expert individual possessors to energy technology experts were then presented. These included expert mandating of individual technology choices, expert selection of positive incentives for consumers to make the "right" decision, and finally, the development of markets for expert advice and services for individual decision makers. As a general approach, market based advice and services have the clear benefit of allowing individual decision makers to retain their decision making autonomy, and ensuring that the cost of expert services and advice employed in a particular decision will always be balanced against their benefits to that decision. The drawback of the market based approach is that broad and efficient markets for expert advice and services, as well as for energy technology loans, appear somewhat difficult to develop.

As is true for any type of expert offering services or advice, the challenge to energy technology experts is to develop services which end consumers of energy technologies will choose to purchase to help them capitalize on their energy technology investment opportunities. Clearly, to be successful energy technology experts will need to establish confidence in their advice and services among potential clients. This is likely to be easiest to achieve if they "put their money where their mouth is", either by guarantying their results, or entering into some sort of partnership with the technology user. Some entities, such as utilities, may gain the confidence of their clients through their long service history, "reputation capital", and in some cases quasi-governmental status. In any case, it appears likely that by coordinating their efforts, and by leveraging off recent developments in service business methods, government and private businesses can cooperate to expand the range of energy technology services offered to the consumer.

In brief, the goal of section two is to demonstrate that rather than accepting the inherently limited quality of "one-off" individual technology decisions, or attempting to design ways to encourage individual decision makers to improve their own decision analysis capacities, it is preferable to encourage market based firms to expand the range of services they offer to individuals to facilitate their decision making process. Because the bulk of the inefficiency of energy technology investment results from the difficulties individuals have in making the few and diverse energy technology choices they are faced with, expanding the range of services available to help them overcome these difficulties is the best way to improve the aggregate efficiency of energy technology investment. Due to the proprietary nature of most energy technology investment opportunities, this is the only way to expand the reach of market forces in the area of energy technology investment. Relying on market based services to aid individuals in their energy technology decisions makes it possible for individuals to relieve themselves of the details of their energy technology choices, while still maintaining control over their broad objectives. This is similar to what individual investors have become accustomed to doing when they allocate their savings among mutual fund managers, to whom they delegate specific investment decisions, subject to agreed on general objectives. In contrast, other alternatives like mandates, standards and incentives in essence take away an individual decision maker's control over their energy technology choices.

In combination, the results of sections one and two suggest that the primary aim of both private and governmental organizations which seek to understand and influence energy technology investment behavior should be to better understand 1) the sorts of resources which individual decision makers require to make well-informed energy technology choices, and 2) the extent to which they can rely on expert third parties to supply those resources. The improved models of individual technology choice of section one attempt to provide a framework for answering the first question. The analysis of the general sorts of market opportunities available to energy technology experts in section two attempt to provide a similar framework for the second question. Translating these frameworks into working solutions, however, is likely to require plenty of data gathering, creativity, and trial and error.

Appendix A: Energy End-Use Technology Classes

Residential

- Lighting
- Small Appliances
- Large Appliances (refrigerators, freezers, washers, dryers)
- Hot Water - Heating and delivery
- Heating, Ventilation and Air Conditioning (HVAC)
- Building Shell Measures - Insulation, weatherstripping, windows, etc.

Commercial and Industrial

- Lighting
- HVAC
- Building Shell
- Electric Motors
- Process technologies

Transportation

- Automobiles

Appendix B: A Behavioral Model Example

A "real" behavioral model example requires the analysis of data on real consumer behavior, and plenty of statistics. The simple example which follows attempts to illustrate the impact of service quality differences on a consumer energy technology choice without real data and analysis by considering a simple and familiar technology choice that is often noted as particularly anomalous when considered on purely "economic" terms - the choice between incandescent, compact florescent, and halogen light bulbs.

When consumers choose light bulbs, several factors matter. First, there are basic economics. These can be estimated, for the three bulb types, as:

	Up-Front Cost	Energy Usage	Monthly Energy Cost*	Average Life	Life Cycle Cost*
Incandescent	$0.75	75 watts	$1.00	1000 hours	$1.13
Halogen	$8.0	45 watts	$0.60	3000 hours	$1.08
Compact Florescent	$15.0	15 watts	$0.20	9000 hours	$0.60

* Per month. Assumes light is on 2,000 hours a year, or about 5.5 hours a day, an electricity price of 8¢/Kwh, and a 10% annual, or 0.83% monthly discount rate

If only life-cycle cost mattered, the conclusion would be simple - buy compact florescents. However, other factors are at work. First, few consumers consider light bulbs an investment item. Instead, the "sticker shock" of a $15 light bulb may be significant to those used to the 75¢ light bulb as a consumption item. Other factors, such as light quality and color, lighting fixture styling and appearance, bulb-fixture compatibility, and the likelihood of bulb breakage or limited bulb use each have the potential to more than off-set the 50¢ per month economic savings calculated for compact florescents. Not surprisingly, compact florescents stack up poorly in all of these areas. The contrast between compact florescents and halogen bulbs across these other factors is particularly interesting, given halogen's strong sales growth relative to that of compact florescents. Florescent light is often considered "flickery, blue and sterile", in contrast to the desirable intensity, color, and "directability" of halogen lights. Compact florescents often don't fit in lighting fixtures, and certainly ruin the appearance of many recent, "shade-less" fixtures, while halogen bulbs are small and versatile, making them perfect for many new fixtures, if ill-suited for many traditional ones. Finally, the impact of a broken bulb is less catastrophic, and given their structure, less likely, for a halogen than a compact florescent bulb. This short tally of features suggests that many halogen bulbs will come home in new light fixtures - and be assured of a place in them in the future (by necessity) - while compact florescents will only be purchased if dollar cost concerns dominate, and assuming they fit, the fixture is on a lot, and it isn't likely to get knocked over. Incandescent bulbs still are clearly the right choice for the many situations when "standard" light, general compatibility, or "disposability" matter most.

Appendix C: A Deterministic NPV Example

The following simple example illustrates how net present value analysis (NPV) can effectively resolve questions about the appropriate trade-off between up-front and on-going costs when these costs are well known. It also shows how the results of NPV analysis can be effected by changes in the parameters assumed.

The example considered is that of a home-owner choosing a new water heating system. For simplicity, it is assumed that only three choices are available: a standard gas heater, an efficient gas system, and an indirect gas system which is integrated with the homeowner's space heating boiler (presumed to exist) to improve efficiency further. The up-front cost, annual energy cost, and average life of the three alternative technologies are:

	Up-Front Cost	Annual Energy Cost*	Average Life
Standard Gas	$425	$190	13 years
Efficient Gas	$500	$174	13 years
Indirect Heater	$700	$148	30 years

* Assumes gas price of 60¢/therm. The data for this example are taken from "Consumer Guide to Home Energy Savings" by the American Council for an Energy-Efficient Economy.

Since the standard and efficient gas heaters have the same useful life, their NPVs, including up-front equipment cost and the discount value of future energy costs, can be compared directly to determine the most economical technology. Assuming a 10% discount rate,

$$\text{NPV of Standard Heater} = -\$425 + \sum_{i=1}^{13} (1/1.1)^i \times -\$190 = -\$1{,}775 = \text{net present cost of } \$1{,}775$$

$$\text{NPV of Efficient Heater} = -\$500 + \sum_{i=1}^{13} (1/1.1)^i \times -\$174 = -\$1{,}735 = \text{net present cost of } \$1{,}735$$

The larger on-going costs associated with the standard heater therefore more than off-set its lower up-front cost over its useful life, making the efficient heater the better choice. For a discount rate of 20%, however, these results reverse, since the future energy cost savings provided by the efficient heater are then more heavily discounted. The net present cost of the standard heater in this case is $1,286, compared to a net present cost of $1,289 for the efficient heater.

The NPV of the indirect heater over its 30 year useful life cannot be directly compared to the net present value of the standard and efficient gas heaters over their 13 year useful lives, since the NPV of the indirect heater includes the discounted value of all associated costs to the homeowner of hot water over 30, rather than the 13 years. Instead, to compare the three technologies, the NPV of each can be transformed into an equivalent annual payment which includes both the annual energy cost and an annual equipment "amortization" payment equal to the amount the homeowner would pay if they borrowed the money for the equipment at the 10% discount rate assumed, and repaid the loan in equal annual payments over the equipment's useful life. This equivalent annual total payment is often called the annualized life-cycle cost. The results of these calculations are:

	Annual Energy Cost	Equipment Amortization Payment	Annualized Life Cycle Cost
Standard Gas	$190	$59	$249
Efficient Gas	$174	$70	$244
Indirect Heater	$148	$74	$222

If the homeowner actually planned to sell the house in 10 years, and did not expect a future buyer would pay either more or less for the home based on its water heating system, he may wish instead to compare the three alternatives again, this time using a 10 year horizon for each. Since after making this assumption all three alternatives have the same horizon, their NPV's can be compared directly:

$$\text{NPV of Standard Heater} = -\$425 + \sum_{i=1}^{10} (1/1.1)^i \times -\$190 = -\$1{,}592$$

$$\text{NPV of Efficient Heater} = -\$500 + \sum_{i=1}^{10} (1/1.1)^i \times -\$174 = -\$1{,}569$$

$$\text{NPV of Indirect Heater} = -\$700 + \sum_{i=1}^{10} (1/1.1)^i \times -\$148 = -\$1{,}609$$

In this case, the ranking of the three alternatives is quite different than the ranking based on annualized life-cycle cost calculated above, with the indirect heater coming in last, the standard heater second, and the efficient heater first. Clearly, the decision maker's planning horizon must be considered carefully in order for the results of NPV analysis to be reliable.

Appendix D: An Irreversible Investment/NPV With Uncertainty Model Example

This appendix illustrates the methods of the theory of irreversible investment and NPV with uncertainty through their application to a simple problem. The problem is that of a homeowner deciding whether or not (and when) to add attic insulation to their home. The several decision alternatives considered were constructed to be as simple as possible while still capable of demonstrating the important features of both approaches.

Imagine a homeowner (Jim) who just received a promotional mailing from a supplier of attic insulation. Jim's home, constructed in the 1950's, currently has single-paned windows, limited weather-proofing, and no attic insulation. The mailer advertises that their attic insulation program leads to a 30% reduction in heating costs "for the average home", at a cost of approximately one dollar per square foot. An asterisk references a footnote that cautions that actual savings depend on the design of the house, as well as on its weather-proofing and heating system. Jim's home is a single storey, 2,000 square foot house, with an old gas heating system.

Jim knows that the attic insulation mailer came from a local company, and therefore that the mailer's savings estimates are probably appropriate for local weather conditions. The company appears reputable, but he doesn't know much about it, and he knows even less about how his heating and insulation systems compare to local averages. All in all, he decides that the actual reduction in his heating bill could just as likely be 10% as 25 or 35%. Also, he typically only uses the heating system six months of the year, and doesn't have an air conditioner. His average heating bill during these months is $150. Finally, he knows all his neighbors received the same mailing, and he's fairly sure that at least one of them will have the insulation added this year.

A. Summary of Initial Information:

Expected Cost of Insulation = $1 per square foot × 2,000 square feet = $2,000
Annual heating bill = Monthly heating bill × 6 heating months
= $150 × 6 = $900
Annual heating bill savings:
At 10%: = $900 × 10% = $90
At 25%: = $900 × 25% = $225
At 35%: = $900 × 35% = $315
Assumed discount rate: 10%

B. Irreversibility Theory Approach

Fortunately, Jim knows more about investment analysis than insulation. A simple calculation lets him compare the possibility of insulating his attic now or waiting until after a neighbor has tried it. The problem fits the irreversibility theory framework because Jim has the exclusive right to invest in attic insulation for his home (since no one else could undertake and profit from the project) and because installing the insulation is an irreversible investment (since the insulation can't subsequently be removed and returned or resold). Further, there is the possibility of learning costlessly from a neighbor's experience. Jim expects that if a neighbor installs the insulation and says after their first year's experience that "its working out well", he can revise his beliefs and expect either a 25 and 35% savings with equal likelihood. If the neighbor reports after a year that the insulation isn't working out all that well, then Jim will expect either 10 or 25% savings with equal likelihood. For the one year delay not to detract from the investment opportunity, the horizon for the savings is assumed to be arbitrarily long.

Graphically, Jim's alternatives are:

Time:	0	1	2	...	...	...	∞
Insulate Now:							
		\$90	\$90	...	...	...	∞
	-\$2,000	\$225	\$225	...	...	...	∞
		\$310	\$310	...	...	...	∞

$$NPV = -\$2{,}000 + 1/3 \times [\sum_{i=1}^{\infty} (1/1.1)^i \times (\$90 + \$225 + \$315)] = \$310$$

Wait for Neighbor:

	0	1	2	3	...	...	∞
			\$225	\$225	...	...	∞
Good News		-\$2,000					
			\$315	\$315	...	...	∞

$$NPV = - \$2{,}000 + 1/2 \times [\sum_{i=1}^{\infty} (1/1.1)^i \times (\$225 + \$315)] = \$970$$

	0	1	2	3	...	...	∞
			\$90	\$90	...	...	∞
Bad News		-\$2,000					
			\$225	\$225	...	...	∞

$$NPV = - \$2{,}000 + 1/2 \times [\sum_{i=1}^{\infty} (1/1.1)^i \times (\$90 + \$225)] = -\$267.50$$

If Jim goes ahead now, he can expect a \$310 positive NPV. However, if he waits until next year and learns from the experience of his neighbor, he can avoid the possible downside he faces now (a meager 10% heating bill reduction), and invest only if the neighbor has "good news". Assuming the neighbor is as likely to have good news as bad, Jim's expected NPV if he waits is 1/2 × \$970 = \$485, greater than the NPV of going ahead today. It therefore pays to wait, even though the investment's NPV is significantly positive now.

C. NPV Analysis with Uncertainty

The analysis above can be extended and made more realistic by incorporating additional information gathering opportunities, and by considering the impact of the finite number of years Jim is actually likely to own the house. This requires the methods of NPV with uncertainty, as illustrated below.

First, Jim knows he won't remain in his house forever, as he was forced to assume above so that the investment opportunity would remain unchanged despite its one year postponement. Instead, he would like to consider the insulation investment's payoff if he stays in the house for only 10 more years, as well as if he stays 20 more years. He estimates that a future buyer is likely to compensate him for only one-half the cost of the insulation, or \$1,000.

Jim would also like to address two other complications. First, when he called the insulation company to ask about the offer, he was told that for \$100 one of the company's representatives would carefully examine his home in order to provide a more accurate assessment of the benefits that attic insulation would provide him. If he later went ahead with the insulation, the \$100 would be credited against the \$2,000 cost. Second, at a cost of a weekend and about \$500 in materials, Jim believes he can do a lot of the other basic weatherproofing that his house needs, and at the same time get a better idea of the benefit the attic insulation might provide. He estimates that the weatherproofing would reduce his heating bill by 5%, independent of the benefit of the attic insulation. His own lost weekend would be offset by any positive NPV of this alternative, and by the knowledge that he had "done the right thing". In addition, weatherstripping the front door would allow him to finally resolve whether the living room was always cold in the winter because of the gaps around the front door or because the kids left the door open so often.

First, Jim reconsiders the basic alternatives considered above, but now takes into consideration the alternative 10 or 20 year term, and the \$1,000 "salvage value":

<u>Insulate Now</u>:

Time:	0	1	2	...	...	...	10 or 20	11 or 21
		\$90	\$90	...	...	...	\$90	\$1,000
	-\$2,000	\$225	\$225	...	...	...	\$225	\$1,000
		\$310	\$310	...	...	...	\$315	\$1,000

Given a 10 year horizon,

$$\text{NPV} = -\$2{,}000 + 1/3 \times [\sum_{i=1}^{10} (1/1.1)^i \times (\$90 + \$225 + \$315)] + (1/1.1)^{11} \times \$1{,}000 = -\$359.15$$

Given a 20 year horizon,

$$NPV = -\$2,000 + 1/3 \times [\sum_{i=1}^{20} (1/1.1)^i \times (\$90 + \$225 + \$315)] + (1/1.1)^{21} \times \$1,000 = -\$77.02$$

Therefore, Jim won't go ahead without further information under either the 10 or 20 year planning horizon. Note that this result conflicts with the $310 *positive* NPV for the "insulate now" alternative when an infinite horizon was assumed.

Wait for Neighbor:

• Case 1: Neighbor has Good News

Time:	0	1	2	...	...	...	10 or 20	11 or 21
			$225	$225	...	...	$225	$1,000
Cashflows:		-$2,000						
			$315	$315	...	...	$315	$1,000

Given a 9 year remaining horizon,

$$NPV = -\$2,000 + 1/2 \times [\sum_{i=1}^{9} (1/1.1)^i \times (\$225 + \$315)] + (1/1.1)^{10} \times \$1,000 = -\$59.52$$

Given a 19 year remaining horizon,

$$NPV = -\$2,000 + 1/2 \times [\sum_{i=1}^{19} (1/1.1)^i \times (\$225 + \$315)] + (1/1.1)^{20} \times \$1,000 = \$407.17$$

• Case 2: Neighbor has Bad News

Time:	0	1	2	...	...	...	10 or 20	11 or 21
			$90	$90	...	...	$90	$1,000
Cashflows:		-$2,000						
			$225	$225	...	...	$225	$1,000

Given a 9 year remaining horizon,

$$NPV = -\$2,000 + 1/2 \times [\sum_{i=1}^{9} (1/1.1)^i \times (\$90 + \$225)] + (1/1.1)^{10} \times \$1,000 = -\$707.41$$

Given a 19 year remaining horizon,

$$NPV = -\$2{,}000 + 1/2 \times [\sum_{i=1}^{19} (1/1.1)^i \times (\$90 + \$225)] + (1/1.1)^{20} \times \$1{,}000 = -\$533.88$$

The analysis reveals that waiting to learn from the neighbor's experience creates a positive NPV for Jim's project if he assumes a 20 year horizon (which leaves 19 years after the one year wait). In that case, he will go ahead with the project if the news is good, which occurs with probability .5, and do nothing if the news is bad. The NPV *today* in this case is $(.5 \times \$407.17)/1.1 = \$185.08$. If he assumes a 10 year horizon, he won't insulate regardless of what his neighbor says, since the investment has a negative NPV over the remaining 9 years of his residency even if the news is good.

$100 Inspection by Insulation Company Representative

Jim believes the insulation company's inspection will be helpful. In particular, he wants to know whether the relatively poor quality of his home's weatherproofing and wall insulation will increase or decrease the impact of the attic insulation. If the inspector suggests a decrease will result and sounds discouraging, Jim will assume his savings will be 10% for sure. If the inspector suggests an increase will result and sounds encouraging, Jim will assume that 25% or 35% savings will result, with equal likelihood. This inspection alternative can be represented as follows:

- Get Inspection:

Time:	0	1	2	...	...	...	10 or 20	11 or 21
Bad News:	1/3 × -$100	0	0				0	0
		$225	$225	...	...	...	$225	$1,000
Good News:	2/3 × -$2000							
		$315	$315	...	...	...	$315	$1,000

Given a 10 year horizon,

$$NPV = 1/3 \times -\$100 + 2/3 \times [-\$2{,}000 + 1/2 \times [\sum_{i=1}^{10} (1/1.1)^i \times (\$225 + \$315)] + (1/1.1)^{11} \times \$1{,}000] = -\$73.01$$

Given a 20 year horizon,

$$NPV = 1/3 \times -\$100 + 2/3 \times [-\$2{,}000 + 1/2 \times [\sum_{i=1}^{20} (1/1.1)^i \times (\$225 + \$315)] + (1/1.1)^{21} \times \$1{,}000] = \$238.12$$

As was true for the "wait for the neighbor" alternative, it makes sense to proceed with the inspection if the planning horizon is 20 years, but not 10. Also, the NPV in this case, $238.12, is larger than the expected NPV for waiting given a 20 year horizon, which was $185.08. Jim would be wiser to spend $100 for this active information gathering alternative than to wait a year for the free, but less reliable, information from his neighbor.

$500 Weekend Weatherizing Project

By investing $500 and a weekend Jim believes he can learn as much as he would from the insulation company inspection, as well as reduce his future heating bill by 5% regardless of whether he ends up adding the attic insulation. Jim expects that a future buyer of his home would compensate him for one-half the cost of the weatherproofing, as was assumed for the cost of the attic insulation. This weekend "do it yourself" alternative can be represented as follows:

Do Weather-proofing:

Time:	0	1	2	...	...	...	10 or 20	11 or 21
Looks Bad	1/3 × -\$500	\$45	\$45	...	...	...	\$45	\$250
		\$270	\$270	...	...	...	\$270	\$1,250
Looks Good	2/3 × -\$2500							
		\$360	\$360	...	...	...	\$360	\$1,250

Given a 10 year horizon,

$$NPV = 1/3 \times \left[-\$500 + \left[\sum_{i=1}^{10} (1/1.1)^i \times \$45 \right] + (1/1.1)^{11} \times \$250 \right]$$

$$+ 2/3 \times \left[-\$2,500 + 1/2 \times \left[\sum_{i=1}^{10} (1/1.1)^i \times (\$270 + \$360) \right] + (1/1.1)^{11} \times \$1,250 \right] = -\$129.52$$

Given a 20 year horizon,

$$NPV = 1/3 \times \left[-\$500 + \left[\sum_{i=1}^{20} (1/1.1)^i \times \$45 \right] + (1/1.1)^{21} \times \$250 \right]$$

$$+ 2/3 \times \left[-\$2,500 + 1/2 \times \left[\sum_{i=1}^{20} (1/1.1)^i \times (\$270 + \$360) \right] + (1/1.1)^{21} \times \$1,250 \right] = \$206.08$$

As was true for Jim's alternatives to wait and to have the insulation company inspection, this alternative only has a positive NPV over a 20 year horizon. For the 20 year horizon, Jim is better off doing the weatherstripping than simply waiting for his neighbor's results (NPV of $206.08 vs. $185.08), but would be even better off if he chose the insulation company's $100 inspection, yielding a $238.12 NPV.

Appendix E: An Incentive Compatible Contract Example

This example "does the numbers" for the builder vs. buyer example described in the text, looking only at the type of water heater selected, and using the same choices considered in the deterministic NPV example of Appendix C. The impact of the incentive-compatible contract is measured by considering its effect on the type of energy equipment likely to be installed, on the annual energy cost of an average home owner, and on the equipment resale value risk faced both by the builder and by subsequent owners of the home.

Assume, as in the Appendix C, that the water heating equipment choices being considered by the builder include a standard gas water heater, a high efficiency gas heater, and an indirect heater with an efficient gas boiler. The costs and useful life for these choices (from Appendix C) are :

	Up-Front Cost	Annual Energy Cost*	Average Life	Life Cycle Cost*
Standard Gas	$425	$190	13 years	$249
Efficient Gas	$500	$174	13 years	$244
Indirect Heater	$700	$148	30 years	$222

* Assumes gas price of 60¢/therm and a 10% discount rate. Life-cycle cost is annual equivalent cost, including both equipment and energy costs.

Before implementation of an incentive-compatible energy equipment valuation scheme, the builder estimated that most buyers were unlikely to compensate him for his up-front investment if he chose to install indirect heaters, both because they are unlikely to be familiar with their benefits and long life, and also because they are unlikely to plan to stay in the home long enough to realize enough on-going savings to off-set the larger up-front cost required. Instead, the builder chooses to pay the additional $75 and install the efficient gas heater, allowing him to present the house as equipped with "energy efficient technologies".

New regulations are then passed which require that the value of a home's major energy-using equipment over the equipment's remaining useful life be added to the home's purchase price. Specifically, the purchase cost of the equipment is spread over its expected average life, and this figure is used as the "annual equipment value" for each year of the equipment's expected life. The purchaser of a home pays the discounted value of the home's energy equipment over its remaining expected life, based on the equipment's annual equipment value, calculated using their mortgage rate. This system essentially fixes the homeowner's energy equipment cost at its annualized equivalent value for each of the years they own the home. Any capital investments they make, should they sell their home, will be "purchased" by the subsequent buyer using the same method.

Under the new regulations, homeowners will naturally demand energy technologies with the lowest life-cycle cost, since this is what they will be paying, regardless of how long they own the home. Builders will respond by installing this equipment, both because they can be sure it is the equipment that buyers will demand, and because they now know they will be fairly compensated for it.

The net result of the new system for our water heater example is that indirect water heaters will always installed, buyers will minimize their utility bills while funding their investment in efficient energy technologies at their mortgage rate, as part of their mortgage loan, and the energy technology "resale value" risk of both builders and buyers will have been eliminated.