ECONOMIC INCENTIVES IN THE PURCHASE AND USE OF ENERGY-USING
PRODUCTS: PAST PRACTICES AND NEW DEVELOPMENTS

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PREFACE AND ACKNOWLEDGEMENTS

This paper reviews the set of analytical tools commonly used to describe the purchase and use of energy-saving technologies and compares them with recent advances in applied microeconomics. Its goal is to determine if supplementing or replacing parts of the traditional tool kit will better equip the Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) to design and promote the superior energy-using technologies of the future. The paper was prepared at the request of EERE's Jerry Dion, and is part of a larger set of white paper's intended to inform EERE's senior managers and program officers about the state of the art on a number of topics of special relevance to the EERE program.

The advances in applied microeconomics discussed herein can be generally described as the theory of investment under uncertainty, behavioral economics, and the economics of asymmetrical information. While these concepts are quite familiar to economic methodologists and well entrenched in many applied topics, they are only now beginning to be applied to the field of energy technology analysis. If this work proves accurate, the new concepts would appear to hold substantial interest for those designing energy-saving technologies and promoting their penetration into markets.

Two principal lessons arise from this exercise: First, because consumer demands for energy technologies are usually derived from their demands for products that make use of energy services, energy technologies are rarely evaluated in isolation. Hence, the analysis would benefit from much greater attention to the context and circumstances in which the technologies would be used. Second, in considering products that contain advanced energy technologies, consumers bring with them constrained budgets and competing demands for budget resources, face uncertain information, and are wary about advice on how to spend their money. Thus, decision-making is less mechanical and much more complex than that implied by traditional approaches. These lessons lead to the conclusion that technological change is far less automatic than that implied by simpler models, which presume fully informed and "rational" purchasers who are hypersensitive to marginal opportunities to save energy. The lessons also imply a set of policy guidelines with the potential to improve the attractiveness of energy-saving technologies to the marketplace.

EXECUTIVE SUMMARY

This paper introduces the behavioral foundations of investment decision-making from the eyes of an economist, and relates these foundations to the purchase and use of energy saving technologies. It first examines the characteristics of energy technology choices and presents the conventional explanations of market failure in their consumption. It then presents a simple exposition of economic cost-effectiveness. Following this, new developments in the economics literature are related to this simple exposition, and changes or enhancements to the conventional conclusions that these theories offer are summarized.

Three new developments are singled out for consideration. The first, the theory of investment under uncertainty, is a theory of both choice and timing. It suggests that when an investor can wait before making a decision to invest, the investor may rationally delay even a cost-effective investment until uncertainty abates. This behavior is reinforced if the sunk costs of investment cannot be fully recovered and if the investor is risk averse. This theory is closely akin to what we have described as the simple model of cost-effectiveness, but it also provides an alternative set of policy options. In particular, the theory focuses attention on the mechanisms generating uncertainty and predicts that investors will be especially sensitive to potential losses, the so-called "bad news principle," and less sensitive to potential gains. Thus, policies that compensate investors who experience bad news, i.e., for whom the investment turns out to be a bad choice, may be more effective than policies that provide smaller levels of compensation for both winners and losers. In other words, warranties may be more effective than subsidies. The theory also implies an optimal sense of inertia, by reminding us that cost-effectiveness may not translate quickly into market penetration.

The second development of interest is the increasing attention paid to psychological influences on economic theory and on the techniques of experimental economics that have permitted economists to test the predictions of theory and examine more closely the institutions through which transactions of goods and services actually take place. Examples of these developments include the tendency of decision makers to:
- Judge changes in benefits (utility) from points of reference rather than absolutely,
- Apply declining interest rates to events in the future relative to events in the present, and
- Formulate an optimal vision of future behavior (such as saving a tax refund) only to execute the plan in a sub-optimal manner (to spend the refund on current consumption).

There are several implications from these developments, which include the following:
- Reinforcement for the proposal that consumers and decision-making agents (hereafter agents) weigh prospective losses more heavily than prospective gains,
- That agents consume more energy in current periods than could be justified through an analysis of conventional discount rates, and
- That policies which enable agents to make decisions corresponding more closely to their optimal, but frequently unrealized plans, may improve welfare (and save energy).

The third development of interest is the explicit modeling of information in the decision process and particularly in circumstances when parties to the decision are unequally informed as to the facts surrounding the decision. In its simplest form this theory deals with two parties, the more informed and the less informed, and two circumstances, when the more informed party offers the deal and when the less informed party offers the deal. These situations are referred to as signaling theory, and moral hazard and adverse selection theory, respectively.

The principal message from this work is that asymmetrical information leads to strategic behavior and the need to take into account the impact that choices by one party have on choices by other parties. It suggests that more informed parties have incentives to reveal their superior information strategically, and that less informed parties have strong reasons to be suspicious about gratuitous offers of information. By taking the lessons this theory teaches into account, government agencies could improve their information provision programs. One example is to develop reputations for collecting and disseminating information tailored to individual and realistic situations. Another is to require government to take its own advice regarding energy conservation, thus demonstrating its commitment and belief in the practices it encourages others to take, much as is now done in the Federal Energy Management Program (FEMP). It also suggests that in dealings with the private sector, the government should assume that this sector would use its superior knowledge of market conditions and consumer tastes to its best advantage. By considering these lessons and using them to its advantage, government can improve its public/private partnerships and its relationships with its contractors. The principal example is developing contractual relationships that allow private sector partners to collect appropriate profits from their activities, while providing incentives to behave efficiently.

In summary, the paper concludes that applying a simple model of engineering costs and benefits can lead to the conclusion that cost-effectiveness is an attribute of a technology itself. Relaxing the assumptions of the simple model leads to the alternative conclusion that cost-effectiveness is closely related to the context of use, as well as to the attributes of the technology. Thus, understanding cost-effectiveness requires understanding the context of agent behavior. Insights from behavioral economics suggest that there is often a discrepancy between theoretical behavior and observed behavior. Agent behavior toward risk and toward discounting often departs from theoretical predictions. Indeed, actual behavior may depart from the behavior the agent herself would describe as optimal. Lessons from information theory suggest that when information is unequally distributed, agents always behave strategically and assume that others also behave strategically.

Based on this work a number of policy implications arise. DOE should receive significant payoffs from gaining greater insight into the market place and the manner in which agents value new technologies. Doing this requires an understanding of how technologies are used and how attributes of new technologies, apart from energy savings, contribute to value. There are a number of reasons to believe that consumers would place significant value on programs—such as warranty programs, lease programs, or buyback programs—that compensate them when technologies do not work out as planned. These policies are termed *ex post* because they take place after consumers have developed experience with energy

savings products. *Ex post* policies could offer cost savings over *ex ante* policies that lower the purchase price of energy saving technologies, such as tax credit or price rebates. Finally, strategic interactions due to information differences require government to take care in developing methods to provide agents with information and in developing relations with product suppliers. In particular, government may reassure agents that it has their best interests at heart if it takes special care to understand their contexts and to require its own activities to follow the advice it gives the general public regarding the purchase of energy efficient technologies.

1.   INTRODUCTION

This paper examines how recent advances in economic analysis might be incorporated into decision making at the U. S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE). EERE carries out two kinds of activities. First, it conducts research and development (R&D) to supply households and businesses with a stream of new products that reduce energy consumption and utilize or produce alternative sources of energy. Second, it carries out programs to promote the penetration of these technologies into markets, sometimes called market transformation programs. The better the quality of the decisions made concerning these activities the more success EERE is likely to enjoy.

Success at EERE is largely measured by the ability to meet two targets. Initially, there is a before the fact, or *ex ante*, set of criteria to guide R&D activities and determine when an energy-saving technology is ready for the marketplace. Meeting this first target produces technologies that are sometimes described as "cost-effective." Cost-effectiveness is discussed in more detail below, but in rough terms, it is intended to measure the ability of a technology to deliver a series of net benefits that, over time, offset its opportunity costs. Second, there are after-the-fact, or *ex post*, criterion measured by consumer purchases. If consumers find a technology desirable and buy it, the second target is met. These two measures of success should demonstrate considerable overlap.[1] If cost-effectiveness criteria are properly constructed, and new technologies meet the criteria, consumers should recognize this and purchase them. As it turns out, there are often significant differences between the *ex ante* and *ex post* scorecards, with the result that greater cost-effectiveness is achieved than market penetration. So pervasive are the differences that a literature has developed to explain what has come to be called the "energy paradox."[2]

The basic message of the energy paradox literature is that cost-effective technologies often fail to penetrate markets. By implication, it should be possible to identify why market penetration fails to take place and to undertake government actions to promote market penetration. The conventional wisdom holds that technologies that fail to meet the market test are generally hampered by market failures or market barriers. Market failures derive from circumstances that lead to an inability of markets to provide sufficient information and/or incentives to achieve economic efficiency. Market barriers are closely related, and generally extend the concepts underlying market failure to the specific institutional circumstances of energy markets. An example of a market failure is the inability of utility systems to offer time-of-day pricing. An example of a market barrier is the inability of consumers to consider alternative energy efficiency features apart from other features in products such as automobiles.[3]

Tests for the existence of market failures and market barriers can be applied in a number of different ways. At one extreme, market outcomes are treated as sacrosanct and indicative of

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[1] One reason for lack of overlap is that EERE develops technologies as "backups" in the event that "business as usual" conditions do not continue. In this case, the benefit from the technology might be credited to EERE as a "real option," a topic discussed below.

[2] A review of the energy paradox can be found in Jaffee and Stavins (1994).

[3] For an extensive discussion of market failures and barriers see Brown (2001).

economic efficiency. At the other, the failure of cost-effective technologies to penetrate markets may be taken as sufficient justification for market intervention by government. Intermediate positions argue that special circumstances associated with energy—environmental externalities, dependence on foreign oil, or economic instability from oil price shocks—make promotion of energy-saving technologies a valid role for government. However, despite the rationale for government development and promotion, one fact remains clear. The better EERE understands the economic behavior leading to the purchase of energy-saving technologies, the better it will be able to design its technology development and market transformation programs.[4]

This paper explores one set of opportunities to gain an improved understanding of the economic behavior underlying the purchase of energy-saving technologies—a set that stems from the fact that a number of recent advances in economic thinking have not been incorporated into cost-effectiveness calculations. This includes new ways to view consumer evaluation of investment alternatives, new insights into purchasing behavior, and new insights into the role of information.

In the past, rigid applications of the assumptions of perfect competition tended to make the test of cost-effectiveness into what Joseph Stiglitz (2002) has termed an engineering calculation. This calculation tends to view cost-effectiveness as an attribute of the technology, rather than an attribute of the context within which the technology is applied. Inherent in the engineering calculation is a rigid set of market assumptions that rest heavily on the existence (or the ability to supply) perfect information, the ability of manufacturers to produce equipment that incorporates the new technologies, and the willingness of consumers to accept new, energy efficient equipment as an acceptable substitute for less efficient and often more familiar technologies. These assumptions are often embedded into technology design targets and into programs to promote purchase of the equipment into which they are embedded.

The difficulty with this approach is that it ignores many of the real world problems that consumers face. Information is not perfect; it is uncertain and presents risks that cannot be easily hedged. Gathering information is costly, especially since many energy-saving technologies are new and little market experience can be observed. Consumers may view information supplied by "market players" with suspicion. Often technologies are embedded in larger systems with multiple attributes. Non-energy attributes, sometimes linked to energy efficiency, can significantly influence purchase decisions. Capital markets are imperfect, and made worse by consumer tendencies to observe different discount rates than financial houses. In the real world, households haggle over how to spend marginal dollars and firms struggle over how best to identify and capitalize on market trends. In the simple world of perfect competition, there is no disagreement, because consumer and producer behavior is deterministic, and social and private optima diverge only due to market failure and barriers.

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[4] Stated differently, if a model of cost-effectiveness fails to predict consumer behavior, i.e., "cost-effective" technologies fail to penetrate markets, it makes little sense to use that same model to design policies to promote market penetration.

Many of the advances that have taken place in economics during recent years have sought to relax the rigid and often inappropriate assumptions embedded in what, for lack of a better term, we will call perfect competition. These advances have come through purely economic research and from interdisciplinary efforts that draw from other behavioral sciences, such as psychology, sociology, and anthropology. Based on this progress, there may be opportunities to improve *ex ante* tests of cost-effectiveness in ways that capture the greater state of understanding, and perhaps also to take advantage of new insight into policy development. The goal of this paper is to review the notion of cost-effectiveness with respect to a relatively circumscribed set of advances in economic science. In particular, we focus on three aspects of what might broadly be termed "information economics."

The first advance, the theory of investment under uncertainty, deals with why consumers might delay purchases to reduce uncertainty and how policies might overcome this. The second considers advances in "behavioral economics," the body of thought arising from experimental and other empirical tests of conventional economic theory that have focused attention of psychological aspects of consumer decision making. For example, consumers often behave as if they have implied discount rates that differ from predictions of conventional theory. The third is information economics, the body of analysis that argues that the assumption of perfect information embedded in competitive analysis is rarely met, that often information is distributed among decision makers unequally, and that information use is commonly strategic.

The paper is organized as follows: First, we review the "conventional approach" to cost-effectiveness analysis, a traditional way for framing investment choices. We then examine the key differences between each of the topic areas and the conventional theory. For each topic, we discuss how the conclusion reached from applying the new theory would differ from applying the old, and then we identify the policy implications of the differences. A principal message is that whatever metric one uses to guide policy—the basic, cost-effectiveness model, the investment under uncertainty model, or whatever—one is employing a view of the world that embodies assumptions and simplifies actual behavior. Consequently, there is significant advantage to applying alternative approaches to the same problem and in comparing the policy advice from each.

As always, there are caveats. In most instances, the new theories have not yet been systematically applied to energy issues. However, there is a large body of non-energy research, and no attempt has been made to summarize it all. Instead, the present goal is to provide an easily accessible discussion that raises topics, provides examples, and speculates on opportunities to gain new understanding into investment behavior. Consequently, the review avoids technical detail and strives for explication. Finally, it is recognized that households and businesses can pursue multiple goals so that, in addition to economic incentives, many other forces can influence the decision to invest. Likewise, government has multiple goals. This means that the new literature is more likely to produce insight into choices rather than to provide a new deterministic framework. It also suggests that much of the policy advice provided by current thinking contains value; it simply omits information that may add value.

2.   AN INTRODUCTION TO ENERGY TECHNOLOGY INVESTMENT DECISION MAKING

When potential buyers consider the purchase of an energy efficient technology they are contemplating an investment, that is, a decision to commit to a current purchase in exchange for a stream of benefits (and costs) that will extend into the future. Frequently, the actual decision is embedded within the context of a larger investment decision because most purchases of energy technologies are purchases of larger systems within which the energy component is only one part. Thus, a prospective automobile purchaser evaluates a broad variety of attributes—size, style, performance, and price—in addition to fuel economy. However, the purchaser is usually limited to a relatively small set of attribute combinations. Typically, there are varieties of competing products from which to choose. Hence, focusing solely on the energy component results in an incomplete understanding of investment behavior.

Because energy-using products permeate virtually every aspect of life, the decision to purchase can take a wide range of forms. A residential customer, for example, may consider which technologies to incorporate into a new house, which technologies to use as replacements when existing equipment fails, or which technologies might replace dated, but still serviceable, extant equipment. This customer is constrained by income available to support house payments, the timing of the decision (for example, the lead-time before a choice must be made), the nature of the local housing market, and the set of available technologies. In general, the choice is comparative. Technologies are compared against alternatives, and choices are based on differences in benefits and costs among alternatives.

Commercial building purchasers or owners make similar decisions, but face additional complexities. Whereas a residential customer is seeking to serve his or her own preferences, the commercial owner must anticipate the needs and preferences of building users, such as renters, students, shoppers, or others. Typically, a lending or financing organization must be convinced the decision is correct. Generally, decision-making is more "business-like" in the commercial sector, but it may also be "politically" influenced, as with schools or Federal buildings (Jones, Bjornstad, and Greer 2002).

To set the foundation for the discussion below, we now raise several issues that permeate the consideration of energy technology choices.

First, it is almost essential that some sort of framework be employed to organize our thinking as to the forces influencing energy technology choices. These technologies enter into a broad set of decisions, and such a framework relieves us of the need to consider every single aspect of energy technology purchases as a special case. However, adopting any framework without care also raises the danger of overgeneralization, i.e., inadvertently ascribing behavior to potential purchasers that is not valid. If we do adopt a common basis for a broad range of decisions, we run the risk of mis-specifying the framework for individual applications, leaving out important considerations, or failing to incorporate new information. It is therefore important to subject the basis for generalization to constant scrutiny, use real world data to

estimate parameters, and take care not to draw conclusions beyond the bounds of the analysis.

Second, we approach the study of the purchase of these products from the perspective of the buyer. This approach presumes that it is the *willingness to pay* of buyers that determines which specific product attributes will succeed in the marketplace and which will fail. This is not to deny the distinctive role of the "supply" chain in the production of energy-using products, but rather to assert that suppliers cannot force buyers to makes purchases they do not want. For buildings, the supply chain is made up of a diverse group of players, including original equipment manufacturers, designers, architect-engineers, construction firms, rental agencies, and others. Related groups include elements of the energy sector, such as utilities and other members of the evolving electric power sector. Owing to the diversity of energy technologies, the relationship between the buyer and the seller of these technologies can take a number of forms. The seller may simply tender goods for sale, offer advice, supply information, or take on the role of decision-making agent on behalf of the buyer. Suppliers are constantly evaluating buyer preferences, and they seek to produce products that meet preferences, but they cannot unilaterally force products into the market.

Third, buyers make decisions based on their own evaluations about the variety of influences we discuss below. The process of consumer evaluation may include studying different products, considering the advice of sales personnel, soliciting suggestions by acquaintances, or accessing any number of other information sources. One source of consumer information is government programs. We will refer to this overall body of data as the consumer's information set. It is noteworthy that this information set is generally not purely factual, and that the evaluations reached will differ from consumer to consumer. For example, one buyer may discount product claims from manufacturers and instead may rely heavily on personal experience, while another may study manufacturers' handouts. Personal values also figure heavily in product evaluation.

To the extent that the energy technology is fixed in a larger product, buyers may form their evaluation of the overall product within which an energy technology is embedded without having specific preferences for the energy technology itself. Alternatively, buyers may have preferences for the energy technology without realizing it. A buyer, for example, may prefer windows "that don't fog up" without realizing they are energy efficient. A buyer may appreciate the convenience of an automatic setback thermostat in addition to its energy savings. Any number of attributes of new advanced technologies may elicit willingness to pay.

Fourth, given preferences, information, and constraints such as income or budget, consumers are optimizers. In other words, they try to do the best they can, and even if they cannot fully meet the assumptions of perfect competition, they may do quite well (Akerlof and Yellen 1985). In making a purchase, the consumer considers all alternatives and makes a decision. Having made the purchase, the consumer considers the purchase price "sunk" and separately makes a decision (over time, a series of decisions) on how to operate the product. As an example, a consumer may choose an optimal auto with increased efficiency, but then drive

more due to lower operating costs. We say that consumers make investment decisions in the "long run" and operating decisions in the "short run."

Fifth, purchases are made in markets, wherein the term market makes up the set of institutions within which exchange takes place. Thus, a consumer may purchase gasoline in a market that is constantly adjusting in response to consumer demand, supplier expectations, and the like. However, that same consumer may purchase electricity in a market where an average price is charged, despite the significant variations in the resource cost of meeting electrical loads at different points in the day, month, or year. Many descriptions of market barriers arise from the institutions through which exchange takes place.

Sixth, economists have characterized markets according to a number of different attributes, including their "efficiency." Efficient markets, also termed perfectly competitive markets, provide consumers with the information and incentives to make optimal purchases. The productive inputs are organized to provide products at least cost, and consumers arrange purchases to maximize their personal utility. Large numbers of buyers and sellers, the absence of large individual buyers or sellers who can manipulate prices, and the absence of any "externalities" (such as public goods or decreasing cost industries), characterize such markets. They are also characterized by perfect information. Thus, in efficient markets, prices provide all of the information needed for consumers to make optimal decisions.

Most analysts view perfectly competitive markets as a benchmark that does not exist in the real world, but one that can assist in decision-making. Under conditions of perfect competition, unfettered by government interference, private decision-making leads to an outcome that is both *privately and socially optimal*. Justification for government intervention in energy markets is typically based on departures from the conditions of perfect competition, which we referred to above as market failures or barriers. In these cases private and social optimality depart, in the sense that private agents, left to their own devices, may still make privately optimal, but socially sub-optimal, decisions.

The traditional literature has identified a large number of market failures, i.e., circumstances when private and social optima differ. One set of failures is due to an inability of markets to pass along to consumers the full (external) costs of burning large amounts of fossil fuels. These external costs include costs of pollution, costs due to importing large quantities of oil, and susceptibility of the business cycle to energy price spikes. To the extent that these external costs are not included in energy prices, consumers face prices that are too low and, from society's perspective, over-consume energy and under-purchase efficient technologies. Suppliers will then under-invest in R&D and production of energy efficient technologies. A classical remedy for external costs is to levy a "Pigovian" tax to increase the price to a socially optimal level.

One argument for government to invest in energy-related R&D is that consumers (and taxpayers) have consistently rejected the use of taxes in energy markets to correct for the absence of the full inclusion of pollution and other costs that are external to the prices consumers face. This is called a "second-best" remedy, because, even if consumers confront

markets with socially optimal levels of R&D into energy technologies, they still face prices that are less than socially optimal.

A second market failure lies in the inability of markets to present consumers with full information concerning energy efficiency. To correct this market failure, government has developed market transformation programs. Examples include energy branding (such as Energy Star), information provision, advertising, aggregated or bulk purchasing, and cooperative relationships with industries producing energy-using products. Government also promulgates regulations, such as energy efficiency standards. The Department of Energy's Office of Energy Efficiency and Renewable Energy has been assigned the responsibility for dealing with many of the market failures that lead to over-consumption of energy. We discuss other potential instances of market failure below.[5]

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[5] Other rationales for government actions include the existence of "market barriers," for instance, business practices that impede the penetration of specific technologies in specific instances. Other examples include tax codes that allow fuel costs to be expensed, but require energy technology investments to be amortized, imperfect capital markets, and a general public indifference to the relative small incremental dollar savings that result from marginal improvements to energy-using technologies. Brown (2001) provides an overview of a range of market failures and barriers.

3. CONVENTIONAL APPROACH TO COST-EFFECTIVE INVESTMENT DECISION MAKING

The most basic model of investment decision-making calculates a net present value by forecasting a future stream of benefits and costs that accrue over the life of an asset, discounting this stream to arrive at a net present value, and comparing the net present value with the capital outlay required to purchase the asset. Like many other models of investment, it calculates a "trigger point," where on one side the investment is forgone, and on the other, it is undertaken. One instance of a trigger point is when the present value of benefits exceeds the present value of costs. The results of a present value calculation, however, can be employed in a number of ways. For example, present value calculations can be made for a number of different alternatives to identify the alternative with the highest value. Or, the energy technology alternatives can be compared with other investment or consumption alternatives.

Focusing only on a single asset, the following elements go into such a calculation. The prospective buyer can purchase some energy saving asset at a cost of C. The investment will return a stream of net benefits that, when discounted, sum to a present value (PV). Net benefits in any given year are the benefits, *x*, minus the costs, *c*. Over the lifetime of the asset, assumed to be n years, PV can be calculated by using a discount rate r and summing them. This can be represented as follows:

$$PV = \sum_{(t-1)}^{n} \left[\frac{x_t - c_t}{(1+r)^t} \right] \tag{1}$$

All else being equal, if PV is greater than C, the investment is seen to be cost-effective, and the buyer would rationally purchase the investment. If C exceeds PV the buyer would rationally choose not to purchase it. Symbolically, we can represent this as follows:

$$\text{If PV} > \text{C then invest; otherwise do not invest.}^{[6]} \tag{2}$$

Of course, as was noted above, this simplification removes all context and correspondingly embodies a number of assumptions that may not be recognized. Although a buyer almost never considers purchasing an asset in isolation, the calculation of a positive present value is often treated as a trigger point for investment. Instead, the choice is typically over a set of alternative assets, and the calculation must be repeated for each alternative. The fact that present value exceeds net benefits for one asset does not mean that for other assets it might not provide an even higher present value. It may be appropriate to compare energy-saving investments with returns from other investments or even with other consumption goods.

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[6] If PV and C were equal, the prospective buyer would be indifferent between purchasing and not purchasing.

In addition, the net present value calculation can be very sensitive to the choice of a discount rate. [7] The higher the discount rate, the lower will be the present value calculated and the less likely it will be that the present value will exceed the technology's cost. Stated differently, the higher the discount rate the smaller will be the asset cost a buyer would be willing to pay to receive a flow of future benefits. Unfortunately, choice of an appropriate discount rate to use in technology comparisons is fraught with difficulties.

It is well known that individual households and firms hold diverse asset portfolios, and pay and receive diverse interest rates on different portions of their portfolio. For example, an individual may simultaneously hold a home mortgage at a relatively low rate, an auto loan at a higher rate, and a credit card balance at a much higher rate. Which rate should be used for the energy technology calculation? Ultimately, the purchaser makes this decision, although circumstances, such as the ability to plan, may influence the rate applied. For a prospective homebuyer unconstrained by the lender, the discount rate in choosing a water heater might be the mortgage loan rate. For the homeowner whose water heater burst, the rate might be the credit card rate. Alternatively, any additional credit purchase might be valued at a credit card rate if the prospective buyer holds a credit card balance, because the alternative is to pay down the credit card balance. Moreover, the expected life of the water heater might differ from that of the house, so a water heater payment embedded in a mortgage payment could continue long after the initial water heater had been replaced. Finally, the mathematics of discount rates embedded in present value calculations may differ from the way consumers behave in trading off current and future activities. We discuss interest rates further below, in conjunction with behavioral economics.

Comparisons of benefits that accrue to different technologies are often complicated. The simplest comparison is for two products that are perfect substitutes, that is, that deliver an identical service. In this case, benefits would be identical for each year and costs would be the driving factor. As an example, a consumer might view the light produced by different light sources (bulbs) to be identical. This consumer would choose the least expensive bulb, from among bulbs of equal technical efficiency and would choose the most efficient bulb, from among bulbs of equal price, all else being equal. Given interest rates and performance expectations, she would rationally pay somewhat more for a bulb that was more technically efficient. If she did so, over the life cycle of the bulb, the purchase would be cost-effective.

There are a number of pitfalls in applying the results of this simple cost-effectiveness calculation unquestioningly. For example, products may not be perfect substitutes. Not all potential buyers would view an incandescent bulb and a florescent lamp to produce identical products, even though their candlepower might be measured to be equal. For the ordinary household, there is no simple way to monitor light bulb usage relative to light bulb life and no way to factor in contingencies. What if a child were to bump the light? Would it be as resilient to damage as other light bulbs? There is also a concept termed "transactions costs." How much time and effort is a household willing to put into light bulb purchases?

The present value calculation typically ignores uncertainty. Whereas it may treat the variables used in the present value calculation as the mean of some distribution of possible

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[7] For a review of the issues involved in discount rate selections, see Portney and Weyant (1999).

values, unless sensitivity analyses for different values of uncertain variables is conducted, this is much like ignoring uncertainty. Adding uncertainty raises a number of additional important considerations that are dealt with in detail in the following section.

If the present value is used as a trigger point, it is implicitly assumed that the decision must be made immediately. This has significant implications for the information set available to the buyer. For a buyer whose water heater has burst, a relatively short period of time is available. For prospective homebuyers, a longer planning horizon is available.

It was suggested above that households purchase in the long run, which is simply another way of saying that at some point they take into account all relevant costs. However, this is partly definitional. A household could replace an energy-using asset at any time, but to justify discarding a working asset, the PV from the new asset, including capital costs, must exceed the PV from the current asset, excluding capital costs. This is a difficult test. In other words, few would throw away a light bulb that works. The household also makes decisions concerning the operation of the energy-using asset in the short run. Hence, an expensive, long-lived, energy efficient light bulb might be burned more hours of the day than the bulb it replaced, because the marginal cost (energy use) of doing so is less. These effects, sometimes called take-back effects, lead to less energy savings than those calculated using long-run assumptions.

In many cost-effectiveness calculations, product attributes produced in conjunction with energy savings are excluded from the analysis.[8] This fails to take into account consumers' potential willingness to pay for improvements in advanced energy-using technologies that do not save energy. For example, more energy efficient buildings may also be more healthy buildings, leading to reductions in worker absenteeism and greater productivity. Such a practice ignores benefits that might properly accrue to R&D and fails to provide incentives for product designers to incorporate into their technologies non-energy attributes that might promote market penetration. The roadmapping activities conducted by the "industries of the future" activity articulated the role of energy R&D within the fuller portfolio of industry R&D priorities in an attempt to identify such synergies.

Other complications could be added to this simple calculation. For example, a resale value (S) could be attached. This value may be thought of as the value of an energy efficient investment that can be recovered if a property is sold. If a household purchases an energy efficient house at a premium price because the household believes the present value of benefits exceed costs, the salvage value added represents the household's expectations of a prospective buyer's willingness to pay for the added feature, a willingness to pay that may be positive or may be zero.[9] On the other hand, a renter will likely forfeit salvage value upon moving.

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[8] There appears to be a growing recognition of the importance of including the values placed on these attributes in technology studies owing to the increasing number of studies. See, for example, Figueiro *et al*. (2002) and Heschong and Wright (2002).

[9] In a recent literature review, Laquatra *et al*. (2002) found that such investments are capitalized to variable degrees but that studies are characterized by a lack of consistency.

To summarize, the basic model provides a format for organizing technical aspects of energy efficient technologies, but tends to ignore issues of context. Applied in its simple version, it assumes that energy-related cost-effectiveness is the key driver of market penetration. An alternative approach would add in the non-energy characteristics of the decision to purchase that were identified above as having been ignored. This would convert the analysis of cost-effectiveness into an analysis of market values and would recognize that technology choices are dominated by the context of their use. Of course, most energy analysts are fully aware of the limitations of the basic model and usually incorporate additional details that are important to specific decisions to purchase. While providing useful advice, the basic model tends to trade off simplicity for inclusiveness, and may leave out some factors that buyers think are important. Its advantage is that it is commonly used, well understood, and provides relatively straightforward guidance for R&D targets and for information provision. It can also be used as a foundation from which to relax the assumptions described above selectively for specific applications. We now turn to some specific ways to relax these assumptions, drawing on recent advances in economic analysis. Following that, we examine how the advice available to the policy maker changes from the addition of this new information.

4.   THE SIMPLE THEORY OF INVESTMENT UNDER UNCERTAINTY

Adding uncertainty to the analysis means that the prospective buyer does not believe that estimates of future values can be made with accuracy. Current costs are known, but future costs and benefits are uncertain. Future energy costs might be higher than current costs, but they could also be lower. Energy-saving benefits may be larger or smaller than estimated. A new, unfamiliar technology may meet the buyers' needs as well as a more familiar one, but it may not. The question is: How might buyers change their behavior in response to such considerations? One type of response to uncertainty is to reduce the calculated net benefit, that is, to require a higher rate of return for an uncertain process than a certain one. We term this behavior risk aversion. Another response (when waiting is possible) is to delay purchase until more information is available. This is referred to as the bad news principle, the theory of irreversible investment, or the options theory of investment. We examine each in turn.

4.1   Risk Preferences

To illustrate the influence of uncertainty, consider a situation in which net benefits are known with certainty for some period of time and after that period take some different course that can be described probabilistically. We denote the certain net benefits, which occur between time period zero and time period 1, PV_1, and the uncertain net benefits that take place after that, PV_2. For simplicity, we assume that the new course can take one of two directions: it can either be high (H) or low (L), such that H occurs with probability p, and L with probability (1-p). For example, a prospective buyer may have a current contract for energy during which prices will be certain. At the end of this contract a new contract must be written. High benefits may accrue to an energy efficient investment if energy prices increase, and low benefits may occur if prices drop. From this one subtracts investment costs and adds salvage value. Then we have the following:

$$PV_{1+2} = PV_1 + PV_2 - C + S$$

Which is equal to $PV_{1+2} = PV_1 + pH + (1-p) L - C + S$ (3)

Thus, in undertaking this investment, the buyer must take into account a certain rate of return, an uncertain rate of return, the cost of the investment, and the salvage value.

One way to make this calculation is to simply calculate the "expected rate of return." If the probability of high prices and low prices were each 0.5, the prospective buyer could simply average the results. If the buyer did this, we would say that she had "risk-neutral" preferences. A consumer with risk-neutral preferences is indifferent between a sure thing and a fair bet. For example, if the buyer had risk-neutral preferences, she would be indifferent between a flip of a coin for $2,000 or nothing, and a sure payment of $1,000. Observation shows that, on average, people are risk-averse, that is, they require better than equal odds to accept an uncertain event. What this means is that risk-averse buyers will require a higher rate of return to choose to invest in an uncertain technology than a certain one. The higher the uncertainty or the higher the risk aversion, the larger must be the rate of return.

4.2   The Bad News Principle

The modern theory of investment under uncertainty has produced a number of other models that add realism to the investment choice.[10] One of these models, the bad news principle, focuses on the ability of the buyer to wait until more information is available, that is, until uncertainty falls to a more acceptable level.

To see this, we return to equation three (3) and change the decision to be made. Rather than deciding today whether or not to make an investment, we permit the prospective buyer to either (1) choose today to invest, or (2) wait until the next period at which the buyer will once again make the decision whether or not to invest. For simplicity, we set salvage value equal to zero, assume risk neutrality, and assume that if a bad outcome occurs, the investment would not be cost effective.

The prospective buyer must choose whether or not to invest today, and if not today, whether or not to invest tomorrow. To do this, she calculates the expected value of buying today and compares this with the expected value of buying tomorrow, a point in time at which she will know the future value of energy prices. If she buys today, she receives the certain rate of return but runs the risk of a bad draw, i.e., low prices. If she waits, she gives up the benefits she would receive during the current period (PV_1) but avoids the possibility of having made a bad investment.

We present the mathematics of this model in Appendix 1 and summarize the results here. In period 1 the buyer looks to see how much would be lost if the bad outcome occurred. If this loss would not be compensated by the certain gain that occurs during period 1, the investor would not invest and would instead wait to see if prices went up or down. If prices went down, she would not invest. If they went up, she would invest. By waiting, she would not lose the entire stream of benefits from the new technology if prices went up. She would lose only those occurring during the period she waited, i.e., PV_1, essentially the price she paid for the opportunity to wait. This calculation is almost identical to that discussed above with regard to comparing alternatives. In this case, the alternative is to buy the technology today, given today's state of information, or to buy the technology in the future using the (greater) set of information available then. In other words, the buyer decides both *which* technology to buy, and *when* to buy that technology.

However, consider this. For some potential purchasers, the greatest source of uncertainty for a product that uses new or unfamiliar technology is the performance of the technology. In this case, the certain return is the better understood technology. Here, the prospective buyer will defer the new purchase, i.e., use the older technology while gathering information on new technologies as long there is a prospect of loss from the new technology.

Note that this model makes explicit the fact that, when faced with uncertainty, the prospective buyer does not give up the entire stream of benefits from the investment. She only gives up benefits that would have occurred during the waiting period. In exchange for that loss, she avoids the prospect of experiencing bad news and losing the value of the sunk

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[10] A standard reference is Dixit and Pindyck (1994).

cost (offset by any revenues, L, or by a positive salvage value). This gives rise to the term bad news principle. Note also that one may still delay investing today if the expected value of waiting is greater than the expected value of investing today. This is particularly true if the buyer believes that superior generations of technology will follow the current ones, as has been true for computers. There is evidence that investors apply this model of investment in many circumstances.[11]

The ability to avoid the expected loss gives rise to the term "options model," because the value of waiting is akin to the value of a financial call option in the stock market. A financial call option gives its owner the right, but not the obligation, to purchase a specific *financial instrument* at some point in the future. The creation of a new technology gives buyers the opportunity, but not the obligation, to purchase a specific *product* at some point in the future. Unlike the *financial* call option, the ability to purchase some product in the future gives rise to a *real* option. Thus, one way to view EERE's set of technologies is as a portfolio of real options. This in turn implies that one benefit produced by EERE's R&D is the value of the real option, regardless of whether or not that option is exercised.

It is important to stress that the options investment model, like other models, is a metaphor. The options interpretation leads to the interpretation that buyers require a premium to invest, a situation that appears akin to the behavior observed under risk aversion. In fact, these are separate phenomena and can be self-reinforcing. But perhaps more importantly, the focus on option value as a risk premium tends to obscure the fact that early on, when uncertainty is high, buyers are focused on potential losses, rather than on potential gains.[12]

This view of the investment process provides some very strong implications for policy. Whereas the basic investment model stresses the importance of expected technology performance, consideration of uncertainty stresses the importance of reducing the likelihood of bad outcomes. To promote early adoption, R&D that improves the reliability of the new technology, i.e., reduces its uncertainty, may be as important, or more important, than R&D that improves average performance. For risk-averse consumers, reducing uncertainty tends to reduce the "discount" that risk aversion requires.

However, in addition to the risk preferences issue, the bad news principle can imply different policies from the basic model, because the buyer is comparing a certain current investment with a future uncertain one. To the extent that buyers follow the bad news principle and focus on potential losses, policies that reduce potential losses will make uncertain investments more attractive. Examples of these policies are warranties or guarantees that come into effect only if a bad outcome occurred. For an auto, for example, a new, uncertain engine design might be better marketed with an improved warranty, instead of a lower price. For buyers focusing on salvage value, that is, the ability to recover investments in energy efficient

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[11] For example, Pyndyck and Solimano (1993) apply the model and generate significant option values. Bjornstad *et al.* (2002), replicate the theory's predictions using experimental economics. However, Sanstad, Blumstein, and Stoft (1995) find very small option values when energy prices drive uncertainty.

[12] This confusion likely arises from the very successful book by Dixit and Pyndyck (1994) that emphasizes the financial markets analogy. In contrast, Ben Bernanke's earlier work (1983) gave rise to the "bad news principle" emphasized the focus on decision makers on losses.

technologies upon resale, buy-back or leasing programs might be attractive. We refer to these policies as *ex post* policies, because they come into play after purchase is made.

Compare *ex post* policies to *ex ante* policies, such as investment tax credits or subsidies, which have the effect of lowering costs whether good news or bad news is experienced. For individuals that focus on the downside, *ex post* policies would have the dominant influence. In fact, for these individuals, it is the ability of the *ex ante* policy to overcome the prospect of bad news that encourages market penetration. Thus, a larger *ex ante* program outlay would be required than for an *ex post* policy, where outlays would be required only when bad news occurred. In contrast, for risk-averse consumers, the *ex ante* policy that effectively reduced price (thereby raising effective rate of return) might be preferred.

It is also possible to mix policies or to give consumers choices over which policy is preferred. Auto manufacturers do this by offering alternative types of policies. For example, they may offer a choice of discounts or reduced interest rates. They may give the choice of bumper-to-bumper for one year versus drive train for five years. They may offer car buyers the ability to purchase additional warranty insurance. They may also employ limited time price sales, which effectively reduce the ability of the customer to wait

A variety of other policies derives from this sort of analysis. We have already noted that buyers who perceive a low salvage value may prefer a lease or a buy-back provision. There has not been a significant amount of analysis over the precise types of bad new buyers perceive and what kind of warranty they would prefer. Similarly, there has not been significant study into the type of information that would reduce uncertainty. If a buyer prefers experience over bench tests, demonstration projects may be important, such as those that target buyers who display the tendencies to be early adopters. The point is, that using the concept of investment under uncertainty gives EERE a somewhat different type of advice on targeting R&D and information programs, and provides policy makers with an additional set of policy tools to stimulate market penetration of energy efficient technologies.

5.   BEHAVIORAL ECONOMICS

In recent years a movement in economics, referred to as behavioral economics or psychological economics, has had the effect of subjecting many of the rigidly held assumptions embedded in economic decisions and investment models to empirical scrutiny. To understand why this is important, it is necessary to realize that the field of economics has long embraced a version of the scientific method that has led to a foundation of "maintained hypotheses" upon which economic analysis is based. These hypotheses rely on the logic of theory and on attempts to refute the theory empirically. There is a close parallel to the physical sciences, but also an important difference. In the physical sciences, it is generally possible to design experiments that can isolate phenomena of particular interest. Thus, theory is posited, explicated, and tested directly. Theories not refuted become the basis for further testing and refinement. In the process, some explanations are repeatedly replicated, gain validity, and are maintained.

In economics, it has traditionally been difficult to design experiments, owing partly to the closely held, proprietary nature of much information and partly to the inability to (legally) manipulate market parameters. Instead, observation of market transactions—quantities of product bought and sold at various prices— has long served as the norm for non-participatory observation of economic behavior. In this case, abstract market structures for production and consumption behavior become vehicles for organizing data and inferring key behavioral parameters using statistical techniques. Like in the physical sciences, economic studies have built up a body of behavioral regularities—the maintained hypotheses—that have proven useful in this process. As an example, economic analysts expect to find demand curves that slope downward, and to find otherwise is to call into question the validity of the database, rather than the validity of the theory. Likewise, theory asserts that economic agents, motivated by self interest and engaged in optimizing behavior, will conform to certain patterns. If, for example, one holds that producers hire productive factors to the point at which their wage is just compensated by the value of their marginal product, one can substitute an observable variable, wages, for an unobserved one, value of marginal product. Such analyses form a foundation that has long been an integral part of the economist's bag of tools. It is difficult to overstate the value this process has delivered. For any given observed data point, price and quantity, there are a virtually infinite number of possible explanations. The body of maintained hypotheses provides a standardized point of departure for analyzing economic decision-making.

Like physical scientists, economists have sought to refine their theories and apply them to new areas, but not all applications have shown the theory to predict behavior accurately. Richard Thaler (1989), in particular, has been instrumental in identifying instances where theory breaks down and in calling these instances to the attention of the economics profession. At the same time a new field of empirical enquiry, experimental economics, has developed to provide economists with a new tool to observe economic behavior directly. The combination of Thaler's (and others') observations as to circumstances where theory does not predict, and direct tests of that theory using experimental economics, have allowed the identification of circumstances where behavior and theory are not consistent. While not

without controversy, these activities hold forth the opportunity to refine the existing theory without resorting to creating a new story for each observed anomaly.[13]

Mathew Rabin (2002) has described several potential ways that individual choices can differ from the predictions of standard economic theory that may have relevance for EERE. We review three of them here:

- That individuals evaluate the utility, i.e., improvement in well-being, they receive from a good or service relative to some norm, rather than from absolute levels (discussed below under "Reference Dependence").

- That the information set used by an individual to make choices may be biased by applying rules of thumb and perceptions, and may extend beyond pure self-interest (discussed below under "Bias, Heuristics, and Self-Interest").

- That over time individuals may fail to undertake stable utility maximization decisions (discussed below under "Failure to Optimize over Time").

5.1   Reference Dependence

Reference dependence suggests that individuals evaluate new circumstances or potential choices from some reference point, rather than from the standpoint of absolute gain or loss. This contrasts with the standard model, which assumes individuals focus on absolute amounts. We examine three cases to illustrate this: loss aversion, endowment effects, and inability to process absolute magnitudes.

First, there is evidence individuals appear to feel more pain from losses than benefit from equal gains (loss aversion) (Kahneman and Tversky 1979). Here the point of reference is gain versus loss. Using this logic, the loss one would feel from having their uninsured auto stolen would be greater than the gain he would feel from being gifted a similar automobile. In contrast, in both the basic present value model and the options model, individuals are assumed to respond to absolute values symmetrically in the sense that gains and losses can be directly compared and differ only in income effects.

While loss aversion reinforces some of the conclusions from the "bad news principle," it may also contain new insights. For example, individuals who avoid losses may forego large prospective gains if these gains are uncertain. To the extent this effect is at work, *ex post* policies would be much stronger than *ex ante* policies. However, not all individuals are likely to experience this effect equally, if at all. At any point in time, a restaurant contains diners who order their favorites because they hate to be disappointed by a new dish they dislike, and diners who seek out the new specials for the opposite reason. These diners place different

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[13] It is of no small consequence that Vernon Smith recently received the Nobel Prize in economics (2002) for his work on experimental economics. Moreover, Smith shared the Prize with Daniel Kahneman whose work with Amos Tversky (see Kahneman and Tversky 1979) set the foundation for reference-dependent utility analysis, discussed immediately below.

values on gains and losses. Thus, loss aversion may provide a mechanism for segmenting markets.

Second, people seem to value items they already possess at levels higher than their willingness to pay for related items they do not possess (endowment effects) (Knesch 1989). Evidence shows, for example, that individuals who forego purchase of some asset, such as World Series tickets at a given price, might turn down that same price if the situation is reversed and they already possess the tickets. Individuals also tend to place higher values on their own assets than the market might place on them. There may be more than anecdotal truth in the old saying, "I wouldn't give you a hundred dollars for my (whatever), but I wouldn't sell it to you for a thousand dollars" If this is true, predicting behavior using present value analysis may be unreliable.

Third, buyers who use reference points in decision-making may be confused or even upset by certain presentations of information. If a new hot water heater can save fifty dollars a year, how does that compare to my current hot water bill? Am I spending tens of dollars or hundreds of dollars of which I am unaware? Maybe I'd rather not know. To the extent that individuals look to personal points of reference, there may be value in providing information related to energy efficiency in ways that support this. For example, average consumer outlays on different sorts of energy expenditures might be provided based on income, family size, point in life cycle, or other metrics.

The general message from this body of literature is that presenting information in absolute terms to reference-dependent decision makers may be less effective than tailoring it to their personal decision metrics. This reinforces the argument presented above that net benefits from technologies should be approached from the context of use.

These conclusions also present new opportunities to target research on decision making. For example, consumer groups might be segmented by their choice of reference points. The reference point may be the technology that is currently used, another new technology that is a standard, or some societal norm. Information from such studies might prove useful in some current tools of analysis. For example, might market dynamics models be restated as containing groups that use different points of reference in choosing a new technology? Some might place the highest value on the greatest departure from the norm, and others the lowest value on the greatest departure.

5.2   Bias, Heuristics, and Self-Interest

The standard theory tends to assume that decision-making agents follow fully rational decision processes. This implies that they are able to step back, remove personal interests, and perform calculations that imply possession of a significant knowledge base and a high degree of computational sophistication. Making these assumptions permits decision analysts to generate models of individual decision making that are rational and reproducible. However, in many ways, real world decision makers behave in a less mechanistic manner

than those embodied in models. Here we examine two ways that individual behavior departs from fully rational behavior: assessing risk magnitudes and applying personal discount rates.

There seem to be at least two forces at work in choices involving risk. The first is that agents have difficulties with certain sorts of small probability, high cost events, so they appear to substitute some level of risk they can understand for the one they actually face. A second, perhaps interacting, force is that agents have preferences about risk-related experiences. An extensive literature in risk analysis and psychology documents these tendencies.[14]

Regarding the small risk issue, the average person appears to employ a wide range of devices to assist in problem solving. For example, a very small probability may be rounded off to a manageable "probability." Hence, one-in-a-million becomes something tractable, such as one in ten. Some risks, however small, are treated with significance. Despite the low likelihood of a large accident at nuclear powers stations, some individuals treat them as almost certain. Individuals are also sensitive to the framing of questions as to gains or losses, the order in which questions are asked, or their most recent experience. Some biases are combinatorial. It is sometimes said that individuals are risk averse regarding benefits, and loss averse regarding costs. The point to be made here is that any policy program cannot simply assert the fact or assume rationality and ignore the inherent behavioral effects of doing so. A literature referred to as "risk communication" has developed to assist in communicating the implications of stochastic events to the public.

People also tend to have preferences over certain risk experiences that can complicate matters. The standard theory suggests that the principal driving force over accepting financial risk is its impact on expected utility related to fluctuations in lifetime wealth. In other words, over time people should behave consistently by accepting attractive risks (such as buying a house), avoiding unattractive risks (such as buying lottery tickets), and hedging risks through insurance or other real or financial options. Nevertheless, people tend not to follow this. Purchasing a lottery ticket is a poor bet, but an enjoyable experience. What else can one do to create the opportunity, however small, to gain enormous wealth? Hence, the utility from the purchase of a lottery ticket may be more related to the experience of holding an asset that might make one rich than to the ticket's expected value. Conversely, living by a nuclear power station presents an individual with a relatively small probability of a large loss, but this probabilistic loss may drive the decision to relocate. Why live somewhere that makes one uncomfortable when there are other places to live? Here the gain is in peace of mind.

Numerous other related examples can be presented, but the point remains that decision makers may process risk-related information quite differently than we might expect, and this insight can be quite useful in developing and promoting new technologies with inherent risks. As discussed above, warranty programs may provide cost effective ways for individuals to avoid concern over product failures. However, product failure may be more wide ranging than technical failure. What if I buy a new technology, it works, but I don't like it? By gaining a deeper understanding of the impact of uncertain choices on individuals' well being, EERE might better promote its technologies.

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[14] Paul Slovic and various co-authors have examined this topic extensively. See, for example Slovic (1972) and Slovic and Lichtenstein (1968). See also Rabin (2002).

A closely related issue concerns the manner in which individuals evaluate benefits and costs that occur at different points in time, the notion of discounting.[15] As practiced by the financial community, the application of interest and discount rates to transactions that involve time is well understood. A constant discount rate (which over time corresponds to a compound interest rate) is applied, and by using a few simple calculations, an analyst can easily compare benefits and costs that occur at different points in time in a consistent manner. However, the manner in which individuals apply discount rates appears to differ from standard financial practices. Whereas individuals, like banks, prefer payouts earlier rather than later, the strength of the preferences is quite different. Despite the large and often technical literature on discount rates, the issue can be summarized as follows: A financial institution can distinguish perfectly between a payment today and tomorrow and a transaction 90 days from now and 91 days from now. For example (ignoring compounding for simplification), at 10 percent a daily rate is roughly 0.1/365 and the difference in value between $1000 today and $1000 tomorrow is about $.30. This is exactly the same measured 90-days hence, although to compare the two today, one must calculate the present value of 30 cents 90 days hence, or about $.23. In return for this attention to detail, financial institutions earn considerable profits on small point spreads.

Individuals, in contrast, behave in ways that illustrate they have strong feelings differentiating today and tomorrow, but almost no feelings about 90 and 91 days in the future, despite the fact that analytically the two concerns are identical. You have just won a new Porsche. Would you like it today or tomorrow? Would you take $15 dollars to wait? Of course, the strength of these relationships is individual and context dependent. This issue has been discussed by Akerlof (1991) and modeled explicitly by Laibson (1997). The point is that when individuals evaluate a tradeoff between today and tomorrow, they behave as if they use a very high discount rate. This discount rate appears to decrease in size as the period of comparison moves to the future, until in the distant future, individuals are basically indifferent as to choices over small time periods. This tendency is sometimes termed hyperbolic discounting. Relative to a constant discount rate, this means that consumers under-save for tomorrow and over-consume today. This behavior is illustrated by the dozens of different discount rates have been estimated for different individuals and contexts, none of which may be generally useful for predicting behavior. Frederick, Lowenstein, and O'Donoghue (2002) list 39 studies of discount rates, with estimated rates ranging from negative to virtually infinite levels.

The message in this analysis is that, confronted with a need to purchase today, consumers may not view the purchase of energy-saving technologies wherein significant increases in capital costs are offset by significant life-cycle savings as an attractive tradeoff. On the other hand, consumers do recognize long-term relationships, and when confronted with life-cycle choices may respond differently. In the following section, we examine one behavioral interpretation of this result.

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[15] Detailed discussions of discounting can be found in Portney and Weyant (1999); Ramsey (1928); and Frederick, Loewenstein, O'Donoghue (2002).

5.3   Failures to Optimize Over Time

Thaler and Shefrin (1981) have examined intertemporal decisions and have developed a model that restates the issue in a manner that opens the possibility for policy intervention. This model postulates that people play two distinct roles in decision-making.

One role is the "planner" who carries out logical exercises to determine the best decision. For example, how are you going to "spend" your tax refund? Most respondents reply with some combination of saving, paying off debt, and other good works. The second self is the "doer," whose present bias may or may not lead to carrying out the planner's righteous intentions. How is the tax refund actually spent? Often it is spent on goods for current consumption. Individuals often recognize this tendency in their own behavior and employ seemingly irrational devices to correct for it. Why do people get tax refunds, if they are, in effect, interest-free loans to the government? One reason might be that they build up savings that might not otherwise occur. Another might be that otherwise they would be faced with taking out a loan to pay the tax bill. Another might be that some dislike writing checks to the IRS more than they value the lost interest. Recognition of the planner/doer dichotomy is well reflected in many types of institutions that make it easier for people to avoid present-bias, including employer-operated pension plans, and taking steps to remove temptation (close the bar well before the party ends). Such practices also work in other directions. Would a young athlete prefer a $1 million signing bonus or $100,000 per year forever? Athletic teams who understand present-bias may ultimately save salary dollars.

To the extent this two-role model is valid, it provides an option for policy activities to facilitate "rational" decision-making. One example of successful programs of this type was the demand-side management activities of the 1980s and 90s, wherein utilities promoted energy efficient technologies and practices by making it very easy for households and others to participate. Energy audits were provided, along with lists of qualified contractors. In some cases, follow-up inspection took place. In others, outlays for cost-effective purchases could be financed through utility programs and paid off through electrical bills, where they were effectively netted against energy savings. In still others, utilities simply purchased cost-effective technologies, gave them out, and negotiated a rate of return with regulators through placing them under the regulated rate base. One can imagine a variety of similar programs, though the extensive restructuring of the electrical service industry makes some programs more difficult than others.

Finally, we have suggested the possibility above that consumers may have preferences over a variety of "complementary" products that are reflected in market behavior. Living distant from nuclear power stations may purchase peace of mind, and purchasing a lottery ticket may purchase a sense of hope. Behavioral studies have identified a wide range of additional preferences over the impacts of one's own behavior on others. Thus, in a two-player "ultimatum" game in which one player extends the other player an offer and that player can accept or reject, significant departures from strict rationality are often observed (Thaler 1989). In one ultimatum game, player one is required to divide a pile of (say) six dollar bills between himself and the second player and the second player must choose whether or not to accept the division. However, acceptance means each player get to keeps his bills and

rejection means neither keeps his bills. "Rational" play implies that player one keeps five bills and offers one, while player two accepts. Yet, many player twos will reject such allocations and many player ones will offer allocations that are more equitable.[16] Such observations may hold implications for allocations of energy-related goods, such as electricity in restructured markets. A number of studies have also indicated that individuals have preferences over collective goods, such as green power.[17]

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[16] See for example, Berg, Dickhaut, and McCabe (1995).
[17] See for example, Farhar and Coburn (1999).

6.   INFORMATION ECONOMICS

A special application of the ultimatum game (and refinements) deals with the circumstance in which players have unequal distributions of information, a circumstance that characterizes most "non-commodity" markets and has broad applicability in virtually all interactions between individuals or groups. The models that have emerged from these applications are called principal-agent models, contracting models, or simply asymmetrical information models. These models conclude that information differences give rise to specialized strategies on the part of the "informed" player to exploit his information, and strategic responses on the part of the "uninformed" player to combat that strategy.[18]

There are two fundamental types of asymmetrical information circumstances, neither of which (to my knowledge) has been applied to energy problems. One is when the informed player moves first (offers the deal); the second is when the uninformed player offers the deal. The first is called a signaling problem, and the second is called a moral hazard problem if behavior is involved and an adverse selection problem if characteristics are involved.

Consider a signaling problem of the following kind. I have a used car for sale and offer it at an above-average price, because having owned and driven the car, I am informed that it is above average. A potential buyer observes the car and is uninformed. She may therefore assume a number of things, for example, (1) that I am telling the truth, or (2) that if the car were above average, I wouldn't sell it. My problem is to signal to the buyer that it is an above average car. Ways that I could do that include offering to let the buyer take the car to a mechanic, offering a guarantee, becoming a dealer and selling a larger number of cars, thereby developing a reputation for honesty, or offering a trial ownership period. The point is that without successful signaling I will have fewer buyers than if information was symmetrical, and I will likely sell my car at a lower price. Moreover, the existence of unequal distributions of information means that any move I take will be viewed as strategic. Because both the potential buyer and I have self-interest, the situation is not fully reversible. In fact, my car may not be superior. I may have used it to deliver mail to rural households and have driven it ruthlessly through mud and snow at whatever speed necessary to get the mail out. I may have left it out in the weather while I kept my model train in the garage. To signal otherwise, prior to selling, I may have the auto "detailed," the body polished, the mud scraped off the fender wells, and the scratches touched up. I may take down my model train that I keep in the garage and put the car inside so that prospective buyers see the immaculate auto, snug in the garage, when they come to test-drive it. Not all signals reflect superior products, only superior information.

The buyer also is better informed than I about his characteristics and likely actions. He may be serious and have the money in hand to purchase the car. He may be serious, but may require a significant discount to purchase, or he may even require me to provide financing (an adverse selection issue). He may simply enjoy driving a variety of cars in order to test them to their limits (a moral hazard issue). Many dealerships combat these issues by

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[18] A standard reference to these topics is Fudenberg and Tirole (1991). A very interesting set of discussions of these and related topics can be found in the Nobel Prize acceptance speeches of Akerlof (2002), Spence (2002), and Stiglitz (2002).

checking credit before negotiating a price or by placing a deposit on the potential buyer's credit card. They may require a member of the sales staff to accompany the buyer on test-drives. Buyers who return repeatedly may be refused test drives, or even treated curtly. As an individual seller, I may be limited in my choice of signals. If I offer a warranty without knowing the driving habits of the buyer, I risk expensive repair bills. I may have a difficult time requiring a deposit or conducting a credit check before negotiating. The point of this is that the process of selling/buying a used car is a very specialized process that is wrought with specialized information and incentives. In contrast, a new car market is much like a commodity market; a potential buyer can virtually shop the Internet, because every car is identical. It differs from a commodity market in that new and used car buyers exhibit many (but certainly not all) of the same characteristics and new car sellers must each guard against adverse selection and moral hazard.

These lessons have not been systematically applied to most energy issues, but it is possible to speculate on some relevant applications. First, EERE creates partnerships with private sector groups to carry out R&D. One reason for this is to benefit from the superior knowledge these firms presumably have concerning market conditions and consumer tastes and from the superior knowledge EERE presumably has about energy efficiency. If these presumptions are true, an asymmetrical information situation exists. For example, if a firm knows that a potential technology is a winner, should it partner with the government to produce it when doing so might compromise exclusive access to intellectual property rights by informing the public and its rivals about its inside knowledge? More likely, the firm would have the incentive to keep its best technologies to itself and to share its knowledge of inferior technologies with the government and the public. Moreover, a private firm may benefit from association with government programs. Such programs may provide insider information (about other firms) and may provide good public relations. Payoffs to the firm may be related to many aspects of the relationship, in addition to the payoffs from a successful research effort. Thus, the firm may have the incentive to keep its best ideas to itself and to assign its best staff and greatest efforts to its in-house activities. Knowing this, the government may design incentive programs to call forth superior ideas and superior efforts on the part of its private sector partners. A large literature on principle-agent relationships in R&D contracting exists.[19]

In addition to R&D, EERE carries out extensive market transformation activities, a major aspect of which is information provision. Under such a circumstance, the government, presumably armed with superior information, shares that information with potential producers and purchasers of energy-efficient products. In principle, everyone benefits from such information. However, producers and consumers live in a world of asymmetrical information and (at least instinctively) take such information with a grain of salt. After all, producers want to earn profits, and buyers want the best and most desirable product for their money; the government, in contrast, wants to save energy.

So, what might government do to improve the reception given its energy efficiency information? First, it might seek to develop a reputation for providing solid information, for example, by disseminating information from well-documented consumer applications and

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[19] See, for example, Salanie (1997).

demonstration activities in addition to bench test information. It is fairly well understood that bench test data and market experience can differ (Brown and Macy 1990). In addition, government may wish to take into greater account the attributes of potential consumers. It was suggested above that an extreme application of the competitive market (which may be the norm for many government calculations) is to assume that consumers are homogeneous, or at least largely so. This means that one set of tests can be applied to all consumers (for example, one value on the energy saving label). If consumers are not homogeneous (and they are not), specialized tests may be more readily accepted. Government may (and does) signal its confidence in selected products by requiring their use in its activities. For example, in many cases, government requires the purchase and use of Energy Star products; it requires its private sector landlords to employ certain energy saving practices; it requires its own fleets to meet certain fuel efficiency standards. Failing to do so would signal that government is more serious about consumer energy-use practices than its own practices.

7.   SUMMARY AND CONCLUSIONS

The material presented in this paper is intended to add greater behavioral content to the basic cost-effectiveness calculations embodied in what has been characterized as the basic engineering-economics model. This additional content draws upon advances in the literature of economics dealing with investment theory, interdisciplinary behavioral economics and experimental economics, and information economics. Despite the fact that, in its raw form, this literature is quite abstract and often highly mathematical, the set of messages one draws from applying their logic to issues of energy efficiency technology design and market penetration is quite commonsensical. Moreover, they provide a foundation for additional work aimed more closely at issues of interest to DOE.

The types of conclusions one draws from this review are equally commonsensical. The value of technologies to consumers of all types is contextual. The question is, does it meet the required needs? Consumers value not only energy savings, but also other energy-related attributes. Are such attributes considered in product design? Consumers recognize risks as important elements of their decision process. Does the design process and/or the market transformation process recognize this? What policies might assuage uncertainty? Consumers respond to relative levels rather than absolute ones. Can this influence design of market transformation activities? Consumers sometimes do a better job of recognizing their best interests than acting on them. Can programs help them to act in their best interests? Consumers have a bias toward present gratification. This should not be a surprise. How should it influence policy? Consumers recognize horse traders. Should government adopt particular approaches to information programs to overcome any perceptions of strategic behavior? All of these topics spring from this review.

However, the findings are not deterministic. An important message from this paper is that the principles underlying the behavioral process of technological change, as it relates to energy technologies, derive from theory—tested from facts—but still theories. At all levels, from simplest to most exotic, the theories lend insight and provide a basis for prediction and guidance for policy, but none is complete, and none substitutes for reasoned judgment. It is unmistakable, however, that most recent advances in theory deal with risk and information, topics commonly assumed away by traditional analytical practices. The secondary message is that one ignores these theories at one's own risk. The understanding of economic behavior, increasingly buttressed by interdisciplinary collaboration, is growing, and holds the potential for improving policy and by implication, the Nation's economic welfare.

APPENDIX 1

In time-period zero the present value calculation is given by (3) and the criteria for cost-effectiveness is given by

$$PV_{1+2} = PV_1 + pH + (1-p) L - C > 0 \qquad (1.1)$$

For time-period 2 the calculation is

$$PV_2 = p(H - C) + (1-p) (L - C) > 0 \qquad (1.2)$$

But, since by assumption, if L< C, no investment would be made.

$$PV_1 = p(H - C) + (1-p) (0) > 0 \text{ , or} \qquad (1.3)$$
$$p(H - C) > 0.$$

Because the investor can evaluate all of these parameters, he or she can compare the expected value of investing today, PV_{1+2}, with the expected value of investing when uncertainty is resolved, PV_2. For the investor to invest today rather than waiting it must be true that $PV_{1+2} > PV_2$. We can calculate this condition by requiring that expression (1.1) be greater than expression (1.3) and simplifying, i.e.:

$$X + pH + (1-p) L - C > p(H - C) \qquad (1.4)$$

Obtaining

$$X + (1-p) (L-C) > 0 \qquad (1.5)$$

What this means is that the certain gain must exceed the expected worst-case loss or, if there is no certain gain, as is likely the case with a new technology, the expected value of bad news must be greater than zero. This illustrates the "bad news principle," which is that prospective investors look only at the downside. The so-called option value is (1-p) (L-C), the expected loss from a bad draw.

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