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Making Energy-Efficiency and Productivity Investments in Commercial Buildings: A Choice of Investment Models

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ABSTRACT

This study examines the decision to invest in buildings and the types of investment decision rules that may be employed to inform the "go -- no go" decision. There is a range of decision making tools available to help in investment choices, which range from simple rules of thumb such as payback periods, to life-cycle analysis, to decision theoretic approaches. Payback period analysis tends to point toward lower first costs, whereas life-cycle analysis tends to minimize uncertainties over future events that can affect profitability. We conclude that investment models that integrate uncertainty offer better explanations for the behavior that is observed, i.e., people tend to delay investments in technologies that life-cycle analysis finds cost-effective, and these models also lead to an alternative set of policies targeted at reducing of managing uncertainty.

EXECUTIVE SUMMARY

The findings that many profitable opportunities for deployment of energy-efficient technologies in commercial buildings are going unexploited are based on calculations with an investment model that assumes investments are "now-or-never" opportunities and does not account properly for uncertainty regarding the outcome of the investment. The irreversible investment, or real options, model allows for the possibility of an investor waiting for uncertainties to be clarified to make a decision. The resulting option to wait is valuable, and investing now requires using that costly option. The availability of deferral as a temporary decision leads to the "bad news principle" by which investors use the worst possible outcome as their decision criterion rather than the expected value. If the worst possible outcome is sufficiently profitable, investment will be undertaken immediately; if not, the investor will wait to see if prospects get better. Unresolved uncertainties can lead to indefinite deferral of investments.

In addition to yielding different assessments of profitability of investments, these alternative views of investment generate different policies to speed up investment. Policies deriving from the traditional view of investment operate on expected values and on investment costs. These policies can reward investors who would have made the investments without the policy assistance while leaving those whose behavior could have been affected by policy with unchanged incentives. The irreversible view of investment produces policies that resolve or reduce uncertainties and use warranties to compensate investors who experience unfavorable outcomes.

Regardless whether investors use expected values or worst possible outcomes to measure the benefit stream of an investment, the different investment criteria require different amounts of information and cost different amounts to calculate. Larger and more critical financial decisions receive closer attention because their potential benefits repay the costs of analysis. A business may find it optimal to relegate smaller investment decisions, and those less central to the principal business line, to more cursory analysis, or even to ignore the investment opportunities.

Market-based information on the financial profitability of alternative technologies is important to investors. The absence of such information, or low confidence in available information represents a market uncertainty to prospective buyers. Similarly, if buyers are uncertain regarding the technical performance of these technologies, the value of the option to wait and see if uncertainties are clarified rises. In both cases, deferral of investments in the new technologies is a likely outcome.

Financial risks are of first-order concern in the commercial buildings industry, security of rental income comprising the largest source of risk affecting owners and investors. As part of the national capital market, commercial building owners hold those buildings as assets in portfolios. They are concerned with the combination of rate of return and risk, for individual buildings and, as importantly, across groups of buildings. Portfolio considerations make simple rate-of-return calculations for energy-efficiency retrofit of an individual building insufficient analysis for

investment. The portfolio in which a new building is to be held will affect cost and technology decisions in new construction and retrofits. Retrofitting to raise the rate of return on a building held in a portfolio may make the building inappropriate for the portfolio in which it is currently held. Retrofits can also be risky since they place additional demands on current cash flows.

DOE could take several actions designed to reduce uncertainties facing investments in advanced building technologies. First, technical performance uncertainties will retain their potency to delay investment despite an extensive program of field testing and demonstrations unless technological developments target the issues perceived by buyers. Survey information on the performance uncertainties perceived by buyers could be used to modify technologies in ways that address buyers' concerns. Second, a hedonic price analysis of commercial buildings could offer productivity information on technologies that both buyers and technology developers would find useful. To date, hedonic studies of commercial buildings have not included technological details, and a prototype study including technologies could encourage further, ongoing studies by various industry groups.

1. INTRODUCTION

The literature on the deployment of advanced building technologies argues that the widespread failure to exploit profitable investments in energy-efficient technology is the result of resistance on the part of individuals and firms to undertake the proper analysis of a technology's costs and benefits—irrationality rather than a market failure. That assessment neglects the benefits and costs of using alternative investment decision criteria and relies on the Neoclassical model of investment, which does not treat uncertainty the way typical investors treat it. In fact, most current policies for accelerating deployment of advanced building technologies are founded in the Neoclassical investment model, which systematically overstates the net benefits investors perceive from an investment and targets policies at variables that investors do not rely on in their decision making. The more recent, irreversible investment, or real options, model allows for the possibility that investors may defer an investment. It accounts the option value of deferring the investment as a cost of the investment, and points to the worst possible outcome, rather than the expected outcome, as the focus of investment evaluations.

The following section examines what goes into and comes out of various investment decision criteria, and how the choice of criteria interacts with the investment problems being solved and processes in the commercial buildings market. The next section introduces the irreversible investment model and sketches the policy implications for the deployment of advanced building technologies deriving from it. Section 4 discusses risks in the commercial buildings industry and the place of advanced building technologies among those risks. The fifth section reports the findings of the energy-efficiency literature on investments in advanced buildings technologies. The final section discusses the policy implications of the irreversible investment model.

2. THE DECISION-MAKING OPTIONS AND THE ISSUES IN USING THEM

The energy-efficiency literature has discussed at some length the criteria that agents use when evaluating the profitability of deploying advanced buildings technologies, both in new construction and for retrofits. Those studies have linked these criteria to questions about the rationality of individual and business investors, the appropriateness of various disciplinary perspectives on the deployment of energy-efficiency technologies in buildings, and to policies for promoting advanced buildings technologies. The choices of investment criteria involve what people are willing to count among the benefits of using these new technologies and how long they are willing to wait to "get their investment back." Many studies have found that people and firms are using implicit discount rates considerably above available borrowing rates to evaluate energy-efficiency investments in both residential and commercial applications. Both individuals and firms appear, in that literature, to resist using more sophisticated investment criteria. Both findings, if true, could retard the deployment of useful, advanced buildings technologies. The high proportion of cases in which commercial building investors choose first-cost, in preference to life-cycle, analysis continues to frustrate agencies charged with development and deployment of advanced buildings technologies that trade off a higher first cost for a lower life-cycle cost. A major purpose of this report is to understand the basis for this preference in a manner that will be relevant to facilitating the deployment of advanced building technologies.

Investors have several options for decision criteria, and they choose a criterion on the basis of their own circumstances, characteristics of the investment they are contemplating, and conditions in the market in which they are investing. The first subsection lays out the criteria for making investment decisions, from simple to complicated, showing what information is required as inputs and what information is given back as outputs to aid the decision maker. The Neoclassical investment model is suitable to use for this exposition although it does not predict how investors will deal with uncertainties with data. We return to that issue in section 3. The second subsection addresses why a decision maker would want to use one or another of these criteria in particular circumstances. The third subsection discusses why the market for building technologies is important to the choice of decision criteria and ultimately to the deployment of advanced building technologies. The fourth subsection considers the factors affecting the value of the information generated by a cost-benefit analysis. The final subsection pulls together the combined implications of the decision making and market themes of this section.

2.1 Complicated Criteria vs. Rules of Thumb

The choices of decision criteria that potential investors have can be distinguished along several dimensions. Some writers on energy-efficiency technologies have stressed the differences in theoretical sophistication among the major criteria that underlie their satisfactoriness. Since all of these criteria are in use for various types of investment decisions, we emphasize their degree of simplicity here as a major factor motivating people to use them. The three most commonly used investment decision criteria are, in ascending order of complexity, the payback period, the internal rate of return, and the cost/benefit or net present value (NPV) assessment.

The payback period can be calculated with or without discounting, and without discounting future benefits it is the simplest criterion of all: how many months or years does it take for an investment to repay itself? Earlier payback periods are preferable to later ones: they imply a higher rate of return on the investment (which itself is a more sophisticated concept), and even more practically, the longer it takes to get one's money back, the more things can go wrong so that the money will never be gotten out of the investment. Even investors using more sophisticated criteria such as the internal rate of return or even a cost/benefit analysis may be interested in the payback period implied by their other calculations. Many investments will keep producing their benefits long after they have simply paid for themselves, but how long a potential investment would take to pay for itself nonetheless remains of interest, if for no other reason, because the person making the decision may be called to account for it some time, and it could enhance job security to be able to say that whatever may happen to this investment in the next, say, five years, "it has already paid for itself, so we haven't wasted the company's money."

Payback period tends to be the sole criterion used to evaluate relatively small investments that are not particularly central to the primary mission of a firm. A particular advantage of it is that the training required to calculate it is minimal: at the most basic, the revenue derived per month (say, in lower energy bills) is divided into the initial cost, yielding the number of months required to make those revenues add up to the initial cost. Discounting the future revenues complicates the calculation a bit, but not terribly.[1]

The internal rate of return (i.r.r) calculation yields an interest, or discount, rate as its "answer." The fact that more distant revenues are discounted relative to earlier revenues makes it a more sophisticated concept, and that the "answer" is a number that can be compared directly to alternative investment opportunities increases that level of sophistication. The internal rate of return is the discount rate that would make the sum of discounted revenues from an investment equal to the present value of its costs. If a firm can put its money in some employment (possibly in the stock market, or just the bank) and earn a higher interest rate, it would be better off doing so than investing in the project under review. If the i.r.r. calculated for the project is higher than what the firm can earn elsewhere, it would do well to undertake the project. The calculation is more intricate than that for the payback period because the i.r.r. is the solution to a polynomial expression in (1+r). The i.r.r. is not commonly used as an exclusive decision criterion on large investment projects, probably because large projects can bear the expense of more detailed calculations. The data requirements are the time stream of returns from the investment—either energy cost savings and when they occur or extra revenue from productivity enhancements and their dates of occurrence.

Cost/benefit analysis eliminates or reduces a number of ambiguities of interpretation left by other decision criteria, and it is generally the criterion of preference on large projects, both public and private. It separates different revenue (benefit) streams and different cost streams, and distinguishes investments that can earn more per dollar from those that earn absolutely more dollars. Cost/benefit assessments tend to be more expensive than the other decision criteria, in terms of both information and training for the person doing the calculations, and therefore tend to be reserved for more expensive projects for which more costly analysis can be repaid by larger increments to revenue streams derived from the more detailed evaluation. Information requirements are time streams of costs (investment expenditures, usually concentrated early in the life of a project, plus the dates and amounts of maintenance and repair expenditures) and benefits—revenues or cost savings—with the benefits frequently separated into components of various aspects of the project. Incremental cost/benefit analyses compare the results of different "amounts" of certain components of the proposed investment, such as quality differentials in materials and sizes or life expectancies of equipment.

[1]In a recent survey of chief real estate investment officers at institutions that make equity investments in real estate—REITs, pension funds, insurance companies, and private investment companies—21 percent of the 125 survey respondents used payback criteria. Most of those were private investment companies (Farragher and Kleiman 1996, 125).

The results of a cost/benefit analysis can be presented in two different formats: a benefit-to-cost (b-c) ratio, which should be greater than one if a project is to be undertaken, and a net present value, a total revenue figure expressed in present-day dollars. The b-c ratio is somewhat like an interest rate or an internal rate of return; it gives an estimate of the degree of profitability of an investment but doesn't tell how much money the investment will actually make. The advantage of the net present value over other decision criteria is that it identifies just how much an investor stands to make from an investment. This information becomes particularly important when investors are constrained in their capital budgets. Under such circumstances, undertaking a high-rate-of-return project that is small may divert funds that could be used on a larger project that promises to deliver a lower rate of return but a larger total net present value. If the high-return project is undertaken, the investor may not have sufficient capital budget remaining to undertake the larger project and be forced to either leave the remaining funds in the bank or put them into a smaller, lower-rate-of-return project which, when added to the small, high-return project, yields a smaller investment income (NPV) than the large project would have yielded. When each project incurs a fixed cost for its evaluation, and those costs are included in the project costs, this budgeting problem can be quite serious.

In applications to advanced buildings technologies, investors have several choices to make about how they would use a cost-benefit assessment. In many retrofits, for which energy savings are a prime motivation (but not necessarily the only one), the analysis naturally takes the form of a life-cycle assessment of costs and benefits, since the energy savings occur over an extended period. In many new-construction applications, the investor (generally the owner) has the major option of examining either first costs of a building or what are called its "life-cycle" costs. With the first-cost calculations, the owner specifies the characteristics wanted in the building and finds the mix of equipment, materials, and construction methods that will minimize the construction costs, ignoring the possibility that different choices might affect operating costs over an extended period. In a very real sense, such first-cost analysis might not even be called a variant of cost/benefit analysis, but for the fact that an amortization of the calculated first-cost is compared to a contemplated (discounted) revenue stream from the future rentals of the building. Information on rentals and operating expenses for specific types of buildings in specific cities are widely available commercially to lenders and potential building owners, so the information for this implicit cost/benefit calculation is readily available (e.g., BOMA 2000) . In a true, or "life-cycle" cost/benefit analysis, the revenue and cost choice with the highest net present value (discounted value of revenues, or benefits, minus the discounted value of costs) would be selected.

The results of a cost-benefit analysis of a given investment can depend on characteristics of the firm conducting the analysis. In practice, a cost-benefit analysis of an investment in a commercial building would examine the after-tax NPV. The tax obligations of firms are highly idiosyncratic, depending as they do on overall financial structure of the firm and the debt-equity characteristics of the individual assets under consideration. The problem becomes more intricate with equity investments in buildings because of the tax shelters available and dependent to a great extent on the depreciation write-offs. The calculations that firms would make with a cost-benefit analysis would be investment analyses, what an investment is worth to the particular firm, not a market analysis, what the firm believes the investment would sell for. The fact that so many of the cost-benefit calculations conducted for energy-efficiency investments in the literature abstract from the situational benefits to an individual firm implicitly makes them market, rather than investment, analyses.

2.2. The Calculus of Making Buildings Investment Decisions

Decisions are products. As such, decisions in general are not free, and careful decisions usually cost more than cursory ones. The choice of investment decision criterion has its own cost-benefit assessment. At the very beginning of the evaluation process, the investor will have some expectation of how much clarification can be contributed by more thorough decision calculations, and that expectation will influence his choices in both the criterion chosen and the effort expended on implementing it. The quality of the information available to use in the calculation will have an important influence on how much effort the investor decides to put into it, and possibly even on the criterion to use. Information on some revenue or cost streams may even be entirely missing, e.g., quantitative information on productivity effects of certain lighting or HVAC choices. Thus the quantity and quality of data can influence an investor's choice of decision criteria, particularly that between the life-cycle and first-cost application of cost/benefit analysis. Of course another important criterion in deciding what kind of decision to produce is how much money is believed to be riding on it.

Decisions share some of the same characteristics as goods such as cars, clothes, and legal services: higher-quality varieties cost more than lower-quality ones. Investment decisions encounter fixed and variable costs. The principal fixed cost of an investment decision is the time required to learn how to make the required calculations. In some firms the fixed cost may be more extensive, including the establishment and maintenance of a department that makes such calculations and keeps supporting records and other information. Most of the other costs are variable, in the sense that the higher the quality of each decision, the more it costs to produce it, and the more decisions produced, the higher the total cost. These variable costs are comprised of staff time and the costs of assembling and using information. The payback period calculation can be made by anyone with a hand-held calculator, although the ability to present the results of the calculation attractively to decision authorities may require a higher level of skill. Cost-benefit calculations require a person sufficiently knowledgeable about the investment to know what benefits and costs to include, where to find the information, what kind of discounting to use, how to execute the calculations, and how to present the results to the person or committee with final decision authority.

Whatever the allocation of decision costs between fixed and variable costs, the cost of making the decision is a fixed cost of undertaking the project and must be debited against the net present value of the prospective investment, either implicitly or explicitly. The benefit of a higher-quality calculation is not necessarily a higher benefit from the investment—the actual revenue and cost streams from the investment are unaffected by how well the decision calculations are performed—but greater confidence in the benefit estimate produced. Of course, within the cost-benefit framework, inclusion of additional net revenue streams—say the value of improved worker productivity in addition to the value of energy cost savings—can produce a higher benefit estimate of certain projects. That still does not affect the actual revenue stream of the project, but just represents a more thorough accounting of the project's actual results.

The choice of decision rule and the effort expended to calculate its content may be a function of the quality of available information. More extensive use of low-quality information need not improve the investor's confidence in the projection of payback period, i.r.r, or net benefit derived from it. "Low-quality" may mean several different things. First, it may be a biased or otherwise unreliable representation of the revenue or cost stream (which includes equipment and material performance data). Second, it may be of questionable applicability to the investment in question because of strong regional effects that can be anticipated or because of differences in characteristics of the investments being compared. For instance, data on HVAC equipment performance may not be available for some parts of the country, leaving investors in uncovered areas without a clear reference base. Alternatively, performance data may be available on a certain range of building sizes, but an investor's proposed building may be outside that range, and the extension of the performance results to the size under review may not be well understood. Information on some revenue or cost streams may even be entirely missing, e.g., quantitative information on productivity effects of certain lighting or HVAC choices. Thus data availability and quality can influence an investor's choice of decision criteria, particularly that between the life-cycle and first-cost application of cost/benefit analysis.

Of course, small anticipated increments to net present value warrant cheap decisions. Small percentages, as contrasted to small absolute amounts, are a more ambiguous issue. Small percentages can be large amounts in absolute dollars, but if decision resources are limited and a large number of small percentages need to be considered, some of them will go unexplored. In commercial building revenues, for instance, energy shares of net operating costs stand alongside comparable shares devoted to repairs and maintenance and administrative costs. In some buildings, local property taxes may rival energy costs in magnitude, and contrary to some initial impressions, those costs sometimes can be changed through efforts of the building owner.

2.3. Building Productivity in the Market

Once it has been determined that an investment in energy-efficient technology is worthwhile, the question becomes whether the productivity benefits can be figured into the market value of the building. This is the market test of the investment decision. In practice, many small factors clutter the ability of market agents to see and act on the gains conferred by energy-efficient technology. Does this mean that the commercial buildings market is rife with gross market failures? Probably not, although it may not be one of the more efficient markets in the economy. Ultimately this is an empirical question. We are unaware of detailed, empirical research on the capitalization of energy-efficiency and other productivity features in commercial buildings, but such research may be helpful in jump-starting the market for the technologies that provide those features.[2]

Consider the case of an investor interested in a commercial building. After conducting a sophisticated, life-cycle cost-benefit analysis of the use of advanced technologies and materials, our investor finds a large net present value differential in favor of the advanced technologies. Could the additional productivity value of such technologies be translated into higher rentals? This is the market test of the investment decision calculation. We refer here to the general notion of *capitalization*, which is the process whereby the market evaluates real economic attributes of an asset. When an additional attribute of a capital asset confers upon its user extra value which can then be captured by the asset owner, we say that the extra value of the attribute has been "capitalized." The question for advanced building technologies is whether their productivity (or cost-reducing) effects are capitalized into the prices (rentals) of commercial buildings.

It is instructive to walk through how capitalization works in practice. Buildings differ in how tenants pay for their electricity. Most common is the "electric inclusion" method, in which electricity costs are passed on to tenants as part of the ordinary base-year calculation. When sub-metering of individual tenants is available, the landlord can buy the electricity at wholesale prices and have a specialized firm read the meters and bill the tenant on a retail basis, frequently resulting in a profit to the landlord (Gelbtuch 1993, 565). In ideal circumstances, under either electricity pricing method, higher energy efficiency should raise the net rent going to landlords, and possibly lower the gross rent paid by tenants, much as reduced transportation costs give buyers lower delivered prices and sellers higher received prices. Under the electric inclusion method, reduced energy bills would reduce landlords' operating expenses. If the rental price facing any building owner in a large urban market were fixed, a landlord reducing his rental prices in response to lower operating costs would find an excess demand for his space; only raising the rental back up to its initial level would equilibrate the demand for his building space with the supply. Under the sub-metering method, tenants encountering lower energy bills would be willing to spend an additional amount for rent up to the difference between the energy bill in an otherwise comparable building.

Sheer disbelief in either energy efficiency or productivity data need not be required for incomplete capitalization of differences in them to be capitalized into building values. In practice, many small factors clutter the ability of market agents' ability to see and act on

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[2]Nonetheless, a number of hedonic pricing studies on office buildings and office rents have been conducted, some examining the price impacts of building structural characteristics (e.g., Brennan et al. 1984; Mills 1992; Wheaton and Torto 1994; Sivitanidou 1996), some addressing the capitalization of amenities in the area around the office building (Sivitanidou 1995, 1996). Two hedonic studies have detected price effects of architectural qualities, as defined by architects in surveys: Hough and Kratz (1983) in residential buildings and Vandell and Lane (1989) in commercial buildings.

these differentials. First, the energy cost differentials are likely to be small percentages of overall rents. Second, building rentals for identical quality space will vary around a metropolitan area because of differences in locational desirability, making comparison of the energy cost differential in rentals difficult to observe cleanly. Changing demands for location within a metropolitan area over time affect building prices and rentals, making the identification of the productivity effects of equipment more difficult. Third, the availability of higher energy-efficiency in a building may involve a trade-off with desirability of location, which may have a financially larger attractive power. Fourth, tenants paying their own energy bills directly under a long-term lease, if confronted with a lower energy bill, might choose to sink their energy cost savings into other business expenses such as amenities for employees rather than space rents. Fifth, a significant fraction of leases are relatively long-term (up to five years in length), leaving at least part of the market to operate slowly, to the extent these are not covered by rent escalation clauses in the contracts. Sixth, when existing buildings are sold, their sale prices depend on current interest rates as well as on their current and projected rentals and the composition of their operating expenses; again, this impedes observation of the capitalization of energy efficiency features. Seventh, vacancies in buildings represent inventories carried by owners, and the pricing of rentals is related to vacancy rates in ways similar to the relationship of current oil prices to oil stocks held in inventory, again complicating owners' ability to observe equipment productivity effects in raw market data. Eighth, sales of commercial buildings occur infrequently; the sales are not transacted in a centralized market like the stock exchange, and their prices are not published. Sales may be made under distress. Sale prices may be influenced also by appraisals and choices of comparables and by a myriad of contractual details.

Does this mean that the commercial buildings market is rife with gross market failures? Probably not, although it may not be one of the more efficient markets in the economy. Commercial buildings are large, expensive, complex, physical capital assets, ranging from $3-7 million at the cheap end to $100 million and up at the high end. The price of a capital asset is just what it last sold for; its valuation is a set of projections of what it is expected to produce over an extended period in the future. It is to be expected that the valuation of such an asset would be measured with some error, and equally to be expected that the price any individual building would command at some particular moment in time could depart by a few percentage points from the valuation calculated by one or more parties by one of several alternative methods.[3] Rental contracts are quite flexible, the menu of options containing a variety of net rents, under which tenants pay parts or all of O&M costs, plus the gross rent option under which the owner (or property manager) pays O&M costs and may be able to pocket profits for efficient operation. Price escalation clauses are common in longer-term leases, reducing owners' exposure to O&M cost increases, of which energy prices are one prominent component.

Ultimately the efficiency of the commercial buildings market is an empirical question. Considerable research has been devoted to capitalization of a myriad of structural and equipment features in residential housing, with the general finding that housing markets do an excellent job of valuing individual features of residential dwellings (e.g., Palmquist 1984), and even a number of their environmental and neighborhood amenities (e.g., Smith and Huang 1995).[4] The capitalization of energy efficiency technologies and equipment in residential housing has been studied and been found to be generally quite thorough (e.g., Longstreth et al. 1984).[5] Some research has explored capitalization issues in industrial buildings and found evidence of capitalization of location and major structural features in industrial buildings (Lockwood and Rutherford 1996). We are unaware of detailed, empirical research on the capitalization of energy-efficiency and other productivity features in commercial buildings, but such research may be helpful in jump-starting the market for the technologies that provide those features.[6]

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[3]A variation among appraisals of a given building within a range of 10% is considered concurrence among estimates (Gelbtuch 1993, 555 n. 4).

[4]This decomposition of the total-package price of a complicated, differentiated product into the prices of its separate components is called "hedonic pricing," representing the viewpoint that what people demand in differentiated products is specific characteristics, and that they are willing to pay for those characteristics. The interesting result of this research is that markets, with very little assistance from public policy, have been able to price these characteristics at just about their supply cost, which represents what economists call efficiency. The technique has been applied to automobiles, residential housing, and household appliance choices, among differentiated, durable goods A recent study of hedonic pricing, or capitalization, in the housing market is Mills and Simenauer (1996), who report, among other results, that the average incremental value to a house contributed by air conditioning is "about $5,000 valued at the sample mean dwelling price, about the same as the cost of installing central air-conditioning" (213).

[5]Of course, this capitalization issue is different from the question whether or not all positive-NPV investments have been undertaken. It simply says that when these investments are undertaken, their values are capitalized in building values, but it gives no indication of whether investments that were not undertaken profitably could have been.

[6]Nonetheless, a number of hedonic pricing studies on office buildings and office rents have been conducted, some examining the price impacts of building structural characteristics (e.g., Brennan et al. 1984; Mills 1992; Wheaton and

2.4. The Value of Information From Cost-Benefit Assessments

If an owner cannot assure herself that the use of a particular component will help a tenant either earn higher revenues from the same operations or incur lower costs, she is unlikely to be able to persuade that tenant to pay a higher rent for the use of the building space with the new component. In such a scenario, the added first cost of some new component would be unable to pay for itself; this fact would be obvious before its installation; and it is unlikely to be selected. There appears to be anecdotal evidence that building owners and operators have little confidence that the commercial buildings market is capitalizing the value of many recently available, advanced building technologies that could enhance net productivity of building occupants. If they are correct in their assessment about the market's operation, their choice of first-cost investment criteria is also correct (their profit-maximizing choice of investment criteria), or at least justifiable, even if the new technologies would enhance productivity. In the case of owners who rent out their buildings, any advantages that might occur would accrue to others; for owner-occupants, their best expectation is of no effect on net revenue, so their optimal choice is to minimize first cost.

There is also the issue of the level of technological detail in which new building owners, be they owner/user corporations or private developers, are interested. There are probably several million technology options in the materials and equipment that go into an investment-grade commercial building, ranging from the characteristics of screws and bolts to HVAC components, windows, and lighting equipment. The developer of a $100 million office building has higher value-added in assembling a financing package, negotiating with local officials, and lining up tenants than he can afford to spend sifting through technology options that may involve a five to ten percent construction cost difference or a five percent user cost difference. Some agent in the developer's team will do this sifting, but the developer will devote his attention to choosing among a small number of total-building options, keeping in mind the loans he can float and the equity he can raise on the one hand and what he can get for the finished building in either sale price or rentals, on the other.

2.5. Summary Observations on Decision Criteria

The choice of investment decision criteria is as much a valuation question as is the choice of equipment selected with the use of any particular criterion. Different people and different firms will select criteria that fit their cost needs and the benefits they expect to derive from more sophisticated calculations. The data themselves influence the choice of

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Torto 1994; Sivitanidou 1996), some addressing the capitalization of amenities in the area around the office building (Sivitanidou 1995, 1996). Two hedonic studies have detected price effects of architectural qualities, as defined by architects in surveys: Hough and Kratz (1983) in residential buildings and Vandell and Lane (1989) in commercial buildings.

decision criteria, and events in the commercial buildings market affect the quality and quantity of data available to support the different criteria. Technology-specific performance data may be a critical link in the marketability of these advanced technologies. If the available data will not support widespread use of investment decision criteria capable of projecting the net benefits of these technologies, the technologies themselves may find circumscribed deployment.

3. DEALING WITH UNCERTAINTY IN INVESTMENTS

Uncertainty is the absence of information. All investments must be made in the face of some uncertainty. Additionally, with most investments, once the investment has been made, you can’t get the full value of your money back if you change your mind. The costs that are irrecoverable if the investment decision is reversed are called sunk costs. If waiting to invest is possible and if it resolves some key uncertainty, existence of the sunk cost gives the investor a benefit from waiting. The value of this benefit amounts to the value of an option. It stands to reason that immediate investment is worthwhile only if the benefit from immediate investment outweighs not only the cost associated with the actual investment but also the cost of the option value associated with waiting.

This idea is the key insight of irreversible investment theory, also known as real options theory. A unique and important feature of this model of investment is that only the down-side risks are taken into account by investors. In order to invest, the worst possible outcome has to be sufficiently good. This feature of irreversible investment theory is known, appropriately, as the “bad news principle.” The policy recommendation emerging from the view of irreversible investment would take the form of a warranty rather than an investment credit.

It is important to recognize that this new model is not a newly concocted set of recommendations about how to invest that investment analysts have been “pushing” for the past few years. On the contrary it represents the efforts of students of investment to understand the data on how investors actually behave. Investors have behaved this way for a long time, but only recently have the tools been developed to understand better the structure and implications of the intertemporal dimensions of those decisions.

3.1 An Overview of Irreversible Investment

When one can delay an irreversible investment, the standard benefit-cost analysis must be augmented by the value of one’s option to delay investment. The standard analysis performed without accounting for such flexibility is no longer valid. Real option values are important when waiting can resolve uncertainties. For instance, waiting to see if the projected market for a new product will emerge or to see if a new technology performs as well in the field as in the laboratory can resolve important uncertainties.

However, some uncertainties simply continue more or less forever: rain in the Corn Belt and the price of energy. Waiting without a specified time to expiration such as appears on an oil and gas lease or a financial option will not clarify uncertainties such as these in any manner meaningful for a real investment. [7] When data indicate that businesses require rates of return on their investments higher than the prevailing interest rates, a plausible explanation is that they are including as a cost of the investment the value of the option of waiting for some key uncertainty to be resolved. Thus the real investment costs that the firm uses in its calculations are higher—they actually have an extra component—than the costs assumed by outside observers. This additional cost has the effect of making the firm look like it is requiring a higher rate of return before it invests.

Greater uncertainty about the return on an investment raises the option value of waiting to invest. The increase in uncertainty raises the value of the possible "good" outcome of the investment but leaves the worst possible outcome unchanged. A project could have a conventionally measured net present value that is positive but it still might be uneconomical to invest presently because the option value of waiting is high. The investment decision may then be cast as the best time to exercise the option by going forward with the investment. The critical question becomes, for what price of the underlying asset in which an investment is being contemplated should the option be exercised? The outcome value that warrants immediate investment is called the *critical value*. The critical value depends on the down-side, not the up-side, risk. After all, one waits to avoid only bad outcomes. Because the investment is deferrable, the up-side possibilities cancel when investing at different times, but the down-side possibility remains, leaving the investor looking at that worst possible outcome instead of the expected value of his investment. This is the "bad news principle" of irreversible investment.[8]

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[7]Financial options, ranging from stock options to commodity options, certainly work on what could be called stationary variances in the underlying asset prices—permanent levels of uncertainty that can make or lose a buyer or seller a lot of money at some moment in time. In real options associated with large physical investments such as a commercial office building, an oil or gas lease exploration and development, or a manufacturing plant, the construction time of the investment is lengthy, frequently measured in years, periods too long to take advantage of short-term, reasonably well anticipated fluctuations in market prices. Additionally, the long economic life of these assets will leave them producing their products long after a temporarily low price has been succeeded by an equally temporary high price. This focus on lengthier periods in large real assets does not imply that investors are uninterested in short-term fluctuations, because evidence from the commercial buildings sector alone reveals that investors are concerned about the timing of their investments so they are not coming on line with their durable asset just as a cyclical downturn is setting in (Sivitanidou and Sivitanides 2000; Bulan et al. 2000; Holland et al. 1995). Sing and Patel (2001) specified three stages of investment in the commercial property market (planning and development appraisal, construction, and institutional investment in the property), each offering different forms of real options to investors. Their empirical study of the U.K. property market from 1979-1997 identified irreversibility effects in all three stages, implying value to real options to defer or suspend the investments. Clearly, the value of energy-efficient technology would be lower during a cyclical downturn in energy prices and higher during a transient period of high energy prices, and such price fluctuations could tip an investment decision in favor of less efficient—and lower first-cost—equipment and materials during a period of low energy prices. These energy price fluctuations would not choke off all choices of higher efficiency during these cycles, but they would reduce the fraction of choices that were of the more efficient varieties. However, a permanent reduction in uncertainty such as conferred by clarification of technology performance should have a larger and more lasting effect on the market penetration of these advanced technologies.

[8]Increases in uncertainty regarding the cost of an investment and of future interest rates have similar effects on option value. Additionally, the greater flexibility provided by packaging investments in smaller possible sizes also makes

The irreversible investment model has entered the literature on energy-efficiency investments in buildings (residential lighting) with the exchange between Hassett and Metcalf (1993) and Sanstad et al. (1995). Hassett and Metcalf used this model in the evaluation of residential energy efficiency investment, with uncertainty located only in the energy price forecast, and reported that the option value could account for the unusually high discount rates consumers appeared to be requiring for these investments. Sanstad et al. (1995) reworked Hassett and Metcalf's problem and concluded that the option value was insufficient to account for the observed discount rates. According to their results, the variance of the uncertain variable (the energy price in their case) perceived by the investor would have to be six times the size of the variance in the energy price to push up the option-inclusive discount rate (called the hurdle rate) to the lower end of discount rates imputed to consumers of energy-efficient appliances. The energy price is not a particularly high-variance series. Technology performance uncertainties, based as they are to a large extent on the absence of reliable, field performance information, conceivably could give variances of that magnitude or larger. Furthermore, Sanstad et al. implicitly use an infinite expiration date on their option specification. Shorter times to expiration yield substantially higher hurdle rates: a one-year strike date on the option, using Sanstad et al.'s numbers, yields hurdle rates from 411 percentage points to 99 percentage points above the base discount rates, rather than 3 to 7 percentage points. Clearly the option cost of making energy-efficiency investments can be large, even when the underlying uncertainties are not extreme. We pursue some implications of this result in the following subsection.

3.2. Policy Implications of the Irreversible Investment Model

The Neoclassical view of investment is that the opportunity to invest is "now or never." The irreversible view is that the timing of investment, as well as the quantity, is a choice variable, and the investor can wait to let the passage of time clarify some matters that are uncertain at present. Energy efficiency policies are significantly influenced by the view of investment they embody—either the irreversible view or the older, "Neoclassical" view on which the irreversible view builds. A simple example will illustrate how different policies follow from these alternative views. Suppose people have the opportunity to invest in some new HVAC system, but they are uncertain how well it will perform. Also suppose that its performance can have two outcomes, "good" and "poor," each with a fifty percent probability. In the Neoclassical model of investment, investors target the expected value of the outcome, which would be half-way between the good and poor outcomes (the average). Agents whose discount rates were low enough for that outcome to meet their financial goals would purchase the new HVAC system. An investment tax credit of, say, twenty-five percent, would raise the expected value to seventy-five percent of the difference between the good and poor outcomes. But suppose the investors actually took the irreversible (deferrable) view of the investment. According to the bad news principle of that model, each investor will use the poor outcome as the outcome against which to base decisions rather than the average of the good and poor outcomes.

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the option value of large-scale investments quite high; the scale-economies of the larger investment must be quite large to outweigh the cost of exercising the option (Dixit and Pindyck 1994, 33-54).

The investment tax credit will raise the decision performance target to twenty-five percent above the low value and will reward people who, by chance, got the high performance out of the investment instead of the poor performance, and need not make whole the people who obtained the poor performance. A warranty would not waste funds compensating people who would have invested in the equipment anyway and got good performance from it, and it would offer protection to investors in the event they lose from the investment. An additional value of the warranty derives from its role as a signal. An equipment manufacturer would not offer a warranty on which he expected to lose money. The terms of a warranty tell the buyer the degree of confidence the seller has in the equipment on which the warranty is offered.

For a given value of an underlying asset, which is the basic source of an option value, a shorter time over which the option can be exercised yields a larger option value. Because the option must be surrendered to make the investment, its value is a cost of the investment. Options with short expiration dates create high investment hurdle rates. What could cause the life of an option to be short or long? Rapid innovation in the technology that is the subject of the investment analysis could shorten the date to expiration on a real option. If vintage A of some technology can be expected to be superseded shortly with vintage B, which has better performance characteristics (say, operation costs), the value of waiting for the new vintage is high as long as purchase of vintage A is not a prerequisite for being able to use vintage B. Too rapid a rate of introducing new technologies that can substitute for one another, or improvements on existing technologies, can make deployment difficult for any of the vintages.

4. RISK IN THE COMMERCIAL BUILDINGS INDUSTRY

Building users, the construction industry, and DOE tend to view commercial buildings as stand-alone structures. They emphasize cost and numerous dimensions of functionality. Agents within the industry—developers, owners, and lenders—tend to view buildings as capital assets and do not look at the rate of return on a building independently of measures of the riskiness of that rate of return.[9] The source of risk to which those agents devote the greatest share of their management attention is the security of rentals, which is of course the major source of income from commercial buildings. This is the case both during the construction phase of a new building, when potential lenders as well as owners examine the extent of advance, long-term rental contracts, and during the working life of a building.

This is not to imply that developers/owners and lenders are indifferent to functionalities or that functionalities are unrelated to risks. Developers and owners

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[9]The survey of chief real estate investment officers cited above, concludes that, overall, these firms use “fairly sophisticated practices” for evaluating risks (Farragher and Kleiman 1996, 125). Of the 125 respondents, 83% quantify their rate-of-return objective, 64% quantify their risk objective, 37% use the capital asset pricing model to adjust the required rate of return, 33% (including half of the insurance companies) require formal quantitative risk analysis with sensitivity analyses, 35% make formal risk adjustments, 68% use discounted cash-flow measures, and 61% do post-auditing of performance of operational projects.

balance building functionality against the rents that a building with those characteristics can command. The functionalities, and the rents tenants must pay for them, influence the extent to which a new building's floor space can be placed under long-term rental contracts. Higher percentages of floor space under long-term contract reduce the principal risk of a building's cash flow. Buyers on the secondary market (Institutional investors such as pension funds, insurance companies, and real estate investment trusts—REITs,[10] closely regulated by federal law) value this low risk and are willing to bid higher prices for buildings so leased out, and the higher resulting price drives down the rate of return, which is roughly the value of annual rentals divided by the sale price.

Whether energy prices are included in rents or are paid separately by tenants, they claim a small share of total user costs (operating costs and either rental or mortgage payment), in the range of 4-5 percent. Applying a given value of managerial resources to stabilizing rental income risk or energy cost risk would be likely to yield a larger return stabilizing the former. Advertising energy-efficient technologies as tools for containing risk will find limited interest in the commercial buildings industry.

The energy-efficiency literature has not particularly associated retrofits with risks. Retrofit construction in commercial buildings generally involves relatively small projects. Consequently the evaluation of investment proposals for retrofits generally can be considerably simpler than the corresponding evaluations of technology choices in new buildings. Financing also will be simpler. Many retrofit projects are internally financed, avoiding the appraisal hoops required for external financing. The evaluation that is done need not focus on the discounted cash-flow characteristics of the entire building, which necessarily slants heavily to tenant occupancy and rental forecasts. Energy-efficiency performance receives greater prominence in the investment decision criteria since other operating costs typically are not expected to be affected.

However, a recent study of commercial mortgage foreclosures has found a positive association between significant capital expenditures for tenant improvements and negative cash flows leading to foreclosure (Ciochetti 1999). This raises a question in energy-efficiency retrofits not yet addressed in the relevant literature: the extent to which the expenditures temporarily depress net operating income, regardless of the long-term effects, and raise the short-term financial risks of a building. Such a risk will be known by the lenders, and surely by sophisticated owners as well, and it will raise the hurdle rate on such investments and possibly constrain the amount owners are willing to devote to remodeling. Both high implicit hurdle rates and constraints on spending limits believed to be related to inefficiencies of information transfer in corporate bureaucracies have been observed and reported in the energy-efficiency literature. This places the variance of rental income into the real option formulation of a retrofit investment, in addition to performance and energy price risks.

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[10]The REIT, in particular, increases the liquidity of commercial real estate assets by permitting investors to purchase a portfolio of buildings through purchase of stock issued by the Trust, avoiding the liquidity risks of purchasing a single building. REITs typically operate and manage income-producing properties as well as own or finance them, and their shares are publicly traded.

5. INVESTMENT DECISION-MAKING IN THE ENERGY-EFFICIENCY LITERATURE

The energy-efficiency literature focusing on commercial buildings has studied retrofits primarily, rather than new construction. That literature has relied on the Neoclassical investment model to judge the extent of profitable investments in advanced buildings technologies and has settled on the bureaucratic structure of corporate decisions as key to understanding why so many profitable opportunities for retrofits go unexploited in commercial buildings. The literature, however, has left the ownership structure of the buildings largely implicit, giving the impression by default that it must be an owner-user. The literature considers the profitability (rate of return) of the retrofit investment but not the risk of making it. It further assumes that the investment in the building components is separable from the rest of the asset, so that the retrofit's profitability is unaffected by the business strategy regarding the entire building. The prevalent portfolio structure of ownership has not been highlighted by that literature.

5.1. The Current Understanding of Energy-Efficiency Decision-Making

With the comparative simplicity of evaluating retrofit energy-efficiency investments, research consistently has found that many opportunities for profitable retrofits go unexploited in commercial buildings (e.g., Koomey and Sanstad 1994; Koomey et al. 1995; Brown 2001). To explain these extra gains left on the table, so to speak, some authors have challenged the conceptualization of human rationality employed in the discipline of economics to predict investment behavior. Others have appealed to the subsidiary concept of bounded rationality, which really just says that otherwise rational individuals have limited capacities to deal with information; after some point just decide they have done the best they are going to be able to do, and make their decision on the information they possess. Yet others have explored the internal organization of corporations and other large organizations such as universities to find barriers to information flows and divergent incentives within their bureaucratic structures.

The idea that large organizations divide up their administrative tasks in ways that incidentally de-emphasize the profits to be gained from energy-efficiency investments has prompted several studies of exactly how these companies make energy retrofit decisions. An early study of two universities found different information bases and different facilities management structures at the two schools (Cebon 1992). The sorts of insights that emerge from Cebon's study are (1) the clash of interests across intra-institutional bureaucratic boundaries that occurs when an energy-efficiency retrofit affects more than one component of the organization; and (2) the internal cash availability in different components of the organization which affects the importance of a given value of investment and the scrutiny it accordingly receives. Cebon offers four policy recommendations to facilitate the deployment of energy-efficiency retrofits: (1) select technologies to fit the decision characteristics of organizations; (2) reconfigure technologies to fit existing organizational structures; (3) identify organizations likely to be receptive to particular technologies of interest; and (4) modify the organizations so they will select the technologies that should be deployed.

DeCanio (1993) provides more detailed, economic analysis of the incentive systems likely to be found in the bureaucracies of large corporations. Individuals' risk-aversion incentives may induce them to avoid investments that would benefit the organization; management may focus its attention on direct, revenue-generating projects within the main business line of a company at the cost of giving lesser attention to cost-cutting opportunities outside the main business line. Personal incentives may emphasize more rapid paybacks than market discount rates would encourage. Benefits may accrue to various departments within a large organization, making monitoring difficult and consequently retarding accumulation of the information needed to make future investment decisions. His policy recommendations are for the federal government to serve as an energy-efficiency information clearinghouse; to encourage internal reorganization of corporations to set up "internal energy management profit centers"; and generally, to serve as a social rallying point to encourage energy efficiency and conservation.

In two subsequent empirical papers based on data from the EPA's Green Lights Program, DeCanio has reported that a number of characteristics of firms, such as the debt-to-equity ratio and the market for its product, appear to influence the desire, if not the propensity, to invest in lighting retrofits (DeCanio and Watkins 1998). Firm characteristics as well as more direct influences on investment cost were associated with the payback period (roughly the inverse of the internal rate of return) predicted for lighting retrofit projects undertaken in the Green Lights Program (DeCanio 1998). Investment theory, as it has been developed in research and as it has been taught to several generations of business men and women, reserves no role for these firm characteristics. An optimal investment choice—which can be a single choice among discrete investments, the amount of investment to make in a particular project, the timing of an investment, or the allocation of one's investments across an array of alternative assets—depends on the timing of the revenue and cost streams, the degree of certainty about both, the interest rate at which future profits are discounted, some interrelations between the earnings of different assets, and the tax structure. The parameters of a good investment are held to be invariant to the characteristics of the firm making the investment: profits and interest rates are profits and interest rates, whether the company processes food or manufactures automobiles and whether it is privately or publicly held, irrespective of the shareholdings of its principal officers. DeCanio's interpretation of these findings is not that investment theory is "wrong" in any useful sense but that corporations could improve their profits by improving their internal investment decision processes.

Kulakowski (1999) studies in detail two large organizations in California, a computer manufacturing company and a large university. As Cebon found, the organizational structure of the decision making for energy-efficiency retrofits differs between organizations and also within organizations, depending on the size of the retrofit. The differing-incentive problem emerges in the form of the university having a department that sold energy internally not wishing to see a lower demand for its product coming from the other departments. Also at the university, small retrofits could be authorized relatively easily, on the basis of a simple payback analysis, but the personnel making those calculations did not perform the payback analysis correctly. The computer company found it administratively more convenient to install lower-quality, generic equipment in a new office building to keep initial costs low, then tear it out and install better facilities out of a different budget drawer, than to install the better equipment in the first place.

5.2. Previous Policy Recommendations About Energy-Efficiency Investment Decisions

The finding some half-century ago that, under fairly restrictive circumstances, profit-maximizing firms would be indifferent to their debt-to-equity ratio contributed to the Nobel Prizes in Economics awarded to Franco Modigliani and Merton Miller in 1985 and 1990, despite the continuing empirical evidence that firms were quite deliberate in their choice of that variable. Considerable research emerged to offer explanations for this discrepancy between theory and fact, but most of the explanations have turned out to be weak. One line of explanation that has been more promising accounts for the fact that different forms of financing involve different types of control over firm operations, which in turn involve different costs to both investing parties (Holmstrom and Tirole 1989, 78-86). The parallel between this case and the energy-efficiency investment case, other than the fact that the debt-equity ratio is a statistically significant variable in DeCanio and Wright's regression model of lighting investments in the Green Lights Program, is that what appears to be an enigmatic discrepancy between optimal and actual behavior is likely to be accounted for by choices firms are making to compensate for costs not noticed by outside observers.

The principal policies currently implemented to foster the deployment of energy-efficient building technologies are information on benefits (generally energy-savings), information intended to reduce search and installation costs, and occasionally assistance with financing. The first is an advertising policy that ignores the potential skepticism deriving from the potential for the sponsoring federal agencies to be publishing self-serving information—i.e., skepticism regarding the magnitude of the benefits advertised. The second two policies are implicit subsidies to reduce investment costs, based implicitly on the Neoclassical investment model's presumption that investors target the expected value of benefits when evaluating a potential investment.

The additional policy recommendations emerging from the energy-efficiency literature have focused on corporate bureaucratic structure on the grounds that information barriers must be the problem inhibiting the adoption of so many profitable investments, many of relatively small cost. DeCanio's recommendation is to encourage corporate reorganizations to maximize profits (minimize costs) from energy management. Cebon turns the tables of DeCanio's suggestion, with the recommendation of tailoring equipment to particular types of organizational structure and targeting adoption of particular types of technology to organizations with particular organizational structures.

DeCanio's suggestion might change who in an organization has information, but need not change the information on the worst possible outcome, while Cebon's is simply Procrustean, cutting the problem to fit a proposed solution as it does.

6. FINDINGS AND POLICY DIRECTIONS

The investment-oriented literature on the market penetration of energy-efficient building technologies has stressed changing the way people think about energy conservation and efficiency investments. From our examination of the activities in the commercial buildings market, it is not clear that most firms, and the agents working within their bureaucratic structures, are misguided in their business pursuits. The commercial buildings industry deals in a type of infrastructure. Accordingly, it is conservative insofar as buyers primarily expect buildings to complement other inputs employed in the production of a particular good or service. The investments in new buildings are enormous, and financial prudence is a mark of excellence among industry decision makers. Data on financial performance of specific building component technologies and materials appear weak, and our policy recommendations focus on strengthening that cornerstone of the market rather than trying to alter preferences.

6.1. Findings

Different investment criteria require different amounts of information and cost different amounts to calculate. Larger and more critical financial decisions receive closer attention because their potential benefits repay the costs of analysis. A business may find it optimal to relegate smaller investment decisions, and those less central to the principal business line, to more cursory analysis, or even to ignore the investment opportunities.

New buildings technologies save energy relative to earlier varieties of equipment and materials and often confer other benefits that can enhance the productivity of firms using them. The extent to which the commercial buildings market is able to identify those values and capitalize them into rentals or building prices is not well known. If the market is not capitalizing them, or if their capitalization is poorly known, investors are without profit-based evidence to use in any investment decision criteria.

Explicitly allowing for uncertainty radically changes the structure of investment decision making. Deferral of an investment, part of which cannot be recovered in the event of a change of plans, becomes a possible decision, and the option to wait for clarification of uncertainties is a cost of making an investment. Investors target the worst possible outcome rather than the expected value of an investment as the decision criterion. Greater uncertainties raise the total cost of investment and may cause deferral of an investment indefinitely.

Financial risks are of first-order concern in the commercial buildings industry. Rental income is the largest source of risk affecting owners and investors. As part of the national capital market, owners of commercial buildings hold those buildings as assets in portfolios. They are concerned with the combination of rate of return and risk, for individual buildings and, as importantly, across groups of buildings. Portfolio considerations make simple rate-of-return calculations for energy-efficiency retrofit of an individual building insufficient analysis for investment. Retrofitting to raise the rate of return on a building held in a portfolio may make the building inappropriate for the portfolio in which it is currently held. Retrofitting at time of sale into a different portfolio is more likely than during an owner's holding period.

6.2. Policy and Research Directions

Current policies to foster deployment of advanced building technologies emphasize implicit subsidies to expected net present value. These policies target cost reduction through information campaigns and financing. The R&D itself could be considered a policy for raising the gross benefit stream, and that is a necessary component of the technology development. Demonstration and testing efforts produce performance information with varying degrees of control, but the market effects of those information policies are unclear.

The irreversible investment model points to the role of uncertainty in creating the option value which can be an important cost of any investment. Raising the expected value of an investment by raising its most favorable outcome does not affect the least favorable outcome, which is the decision variable investors use. Reducing uncertainties reduces the difference between most and least favorable outcomes and thus reduces the value of waiting for further clarification of remaining uncertainty. The option cost of an immediate investment falls, as does the hurdle rate for the investment.

Two major types of uncertainty are amenable to some degree of resolution—technological performance and market capitalization. Whether the aspects of technology performance targeted by field testing and demonstration are the same concerns that owners perceive is an open question. The engineering characterizations of technology performance are in scientific terminology, intended primarily to facilitate communication among technology specialists. Building owners, users, and lenders are concerned with financial variables and factors that influence them—essentially, the profitability of the technologies. The likelihood of a communication gap between developers and buyers should not be underestimated. Assessment of buyers' perceived uncertainties would give technology developers useful information for targeting both continued development as well as testing and demonstration. Whether equipment will work as advertised is likely to be of concern to buyers, but simply raising the probability of successful performance may not alter the worst possible outcomes they perceive. Supplementation of performance information with warranties would limit users' down-side risk.

The market capitalization information is profit-based data on how much the individual technologies contribute to the profits of buildings' users and owners. Current evidence on this dimension of productivity tends to be anecdotal rather than systematic. A difficulty with obtaining systematic information on market-based productivity is that the information is a public good, limiting the incentives private agents have to collect the raw data or analyze it. The statistical nature of this information requires data from a large number of buildings, probably more than even the larger real estate portfolio holders own. To date, the industry trade groups such as the Building Owners and Managers Association (BOMA), the International Facilities Management Association (IFMA), the National Association of Real Estate Investment Managers (NAREIM), or the National Council of Real Estate Investment Fiduciaries (NCRIEF) have not engaged in such an effort. However, the collective research arm of the industry, the Real Estate Research Institute (REEI), has sponsored some limited research on hedonic pricing of commercial office buildings, but no studies targeting the capitalization of building technologies. DOE may be in a position to sponsor a prototype study which would both provide direct profit-based productivity information and provide a template for wider studies conducted by industry groups.

REFERENCES

Hassett, Kevin A., and Gilbert E. Metcalf. 1992. "Energy Conservation Investment; Do Consumers Discount the Future Correctly?" *Energy Policy* 21: 710-716.

Sanstad, Alan H., Carl Blumstein, and Steven E. Stoft. 1995 "How High Are Option Values in Energy-Efficiency Investments," *Energy Policy* 23: 739-743.

BOMA. 2000. *2000 BOMA Experience Exchange Report*. Washington, D.C.: Building Owners and Managers Association International.

Brennan, T., R. Cannaday, and P. Colwel. 1984. "Office Rent in the Chicago CBD," *Journal of the American Real Estate and Urban Economics Association* 12: 243-260.

Brown, Marilyn A. 2001. "Market Failures and Barriers as a Basis for Clean Energy Policies," forthcoming in *Energy Policy*.

Bulan, Laarni, Christopher Mayer, and Tsuriel Somerville. 2000. "Real Options and the Timing of New Investment: Evidence from Real Estate Development." REEI Working Paper; Graduate School of Business, Columbia University, April 7.

Cebon, Peter B. 1992. "'Twixt Cup and Lip; Organizational Behaviour, Technical Prediction and Conservation Practice," *Energy Policy* 20: 802-814.

Ciochetti, Brian A. 1999. "Investment Loss Characteristics Associated with Commercial Mortgage Foreclosures." Real Estate Research Institute Working Paper. Chapel Hill, N.C.: Department of Finance, University of North Carolina.

DeCanio, Stephen J. 1993. " Barriers within Firms to Energy-Efficient Investments," *Energy Policy* 21: 906-914.

DeCanio, Stephen J., and William E. Watkins. 1998. "Investment in Energy Efficiency: Do the Characteristics of Firms Matter?" *Review of Economics and Statistics* 80: 95-107.

Dixit, Avinash K., and Robert S. Pindyck. 1994. *Investment Under Uncertainty*. Princeton; Princeton University Press.

Farragher, Edward J., and Robert T. Kleiman. 1996. "A Re-Examination of Real Estate Investment Decisionmaking Practices," *Journal of Real Estate Portfolio Management* 2: 31-40.

Gelbtuch, Howard C. 1993. "Office Building Valuation Methods," in John Robert White, ed. in chief, *The Office Building; From Concept to Investment Reality*. Chicago: American Society of Real Estate Counselors and the Society of Industrial and Office Realtors, pp. 553-576.

Holland, A. Steven, Steven H. Ott, and Timothy J. Riddiough. 1995. "Uncertainty and the Rate of Commercial Real Estate Development." Real Estate Research Institute Working Paper.

Holmstrom, Bengt R., and Jean Tirole. 1989. "The Theory of the Firm," in Richard Schmalensee and Robert Willig, eds., *Handbook of Industrial Organization*, Vol. 1 (Amsterdam: North-Holland), pp. 61-133.

Hough, D.E., and C.G. Kratz. 1983. "Can 'Good' Architecture Meet the Market Test?" *Journal of Urban Economics* 14" 40-54.

Koomey, Jonathan G. 1990. *Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies*. Ph.D. dissertation, Energy and Resources, University of California at Berkeley.

Kulakowski, Susan L. 1999. *Large Organizations' Investments in Energy-Efficient Building Retrofits*. LBNL-40895. Berkeley, Calif.: Lawrence Berkeley National Laboratory, March.

Lockwood, Larry J., and Ronald C. Rutherford. 1996. "Determinants of Industrial Property Value," *Real Estate Economics* 24: 257-272.

Longstreth, Molly, Anne R. Coveny, and Jean S. Bowers. 1984. "Conservation Characteristics Among Determinants of Residential Property Value," *Journal of Consumer Research* 11: 564-571.

Mills, Edwin S. 1992. "Office Rent Determinants in the Chicago Area," *Journal of the American Real Estate and Urban Economics Association* 20: 273-289.

Mills, Edwin S., and Ronald Simenauer. 1996. "New Hedonic Estimates of Regional Constant Quality House Prices," *Journal of Urban Economics* 39: 209-215.

Palmquist, Raymond B. 1984. "Estimating the Demand for the Characteristics of Housing," *Review of Economics and Statistics* 66: 394-404.

American Society of Real Estate Counselors and the Society of Industrial and Office Realtors, pp. 3-20.

Sing, Tien-Foo, and Kanak Patel. 2001. "Evidence of Irreversibility in the UK Property Market," *Quarterly Review of Economics and Finance* 41: 313-334.

Sivitanidou, Rena. 1995. "Urban Spatial Variations in Office-Commercial Rents: The Role of Spatial Amenities and Commercial Zoning," *Journal of Urban Economics* 38: 23-49.

Sivitanidou, Rena. 1996. "Do Office-Commercial Firms Value Access to Service Employment Centers? A Hedonic Value Analysis within Polycentric Los Angeles," *Journal of Urban Economics* 40: 125-149.

Sivitanidou, Rena, and Petros Sivitanides. 2000. "Does the Theory of Irreversible Investments Help Explain Movements in Office-Commercial Construction?" *Real Estate Economics* 28: 623-661.

Smith, V. Kerry, and Ju Chin Huang. 1995. "Can Markets Value Air Quality? A Meta-analysis of Hedonic Property Value Models," *Journal of Political Economy* 103: 209-227.

Vandell, K.D., and J.S. Lane. 1989. "The Economics of Architectural and Urban Design: Some Preliminary Findings," *Journal of the American Real Estate and Urban Economics Association* 17: 235-260.

Wheaton, William C., and Raymond G. Torto. 1994. "Office Rent Indices and Their Behavior over Time," *Journal of Urban Economics* 35: 121-139.

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