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1994
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Energy Conservation Investments

A rational decision?

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Research Memorandum 1994-33

September 1994





DISCUSSION PAPER



ENERGY CONSERVATION INVESTMENTS ***a rational decision?***

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final version 30-8-1994

Abstract:

Technological analyses show that large potentials for energy conservation exist at the sectoral level. Moreover, a great part of these potentials seems economically attractive, but are not undertaken by industry. This paper provides a theoretical framework in which the energy conservation decision on the firm level plays a central role. It is argued that from an entrepreneurs point of view many theoretical barriers for energy conservation may exist, and that it is therefore rational (from their point of view) not to invest in seemingly profitable energy conservation technologies. Among the theoretical barriers are: high cost of information collection, budget problems, low expected profit due to low energy bill, uncertainty about future energy prices, and being caught in a technological paradigm.

Energy conservation investments: a rational decision?

1. Introduction

Innovation in new technology is essential for firms to stay in business. Not adopting the latest technology can mean that comparative advantages of competitors become large enough to run someone out of business. In practice, many firms that belong to a same sector (e.g. that have more or less the same products or production structure) have very different states (vintages) of technologies. The differences between sectors is probably even larger. The question is: why do some firms succeed in investing much in technological innovation where others fail to do so. Obviously, there can be many reasons for this, which can be divided into economic factors and non-economic reasons. Non-economic reasons must certainly not be regarded as irrational or irrelevant. For example, the fact that some new technological innovation is not part of the core business of the firm and therefore not implemented can be a very rational decision if all the costs entailed with getting the right information and implementation (transaction and adaption costs) outweighs the potential benefits (see section 10).

This paper provides a theoretical framework on investment decisions by firms, in view of technological innovation in general and energy conservation in particular. Many studies have shown that energy efficient innovations that are economically attractive may not all implemented by firms (e.g. Blok *et al.* 1990, 1992, Melman 1990). This behaviour seems, at first sight, somewhat irrational: why are profitable investments not undertaken? The aim of this paper is to provide a theoretical framework in which seemingly irrational behaviour is rationalized by introducing more realistic conditions.

In the next paragraph the possibilities for evaluation of investment projects are given and it is derived that Net Present Value (NPV) method is a theoretically optimal investment criterion. After that, we first begin by providing a very simple investment decision framework by making some strong assumptions (e.g. profit maximization under perfect foresight, unlimited access to capital markets, certain cashflows). The optimal investment decision under these "textbook" conditions is derived in paragraph 3. Next, we relax most of the textbook assumptions in paragraph 4, and conclude in paragraph 5 that even with these highly stylized conditions there may be reasons not to invest in energy conservation technologies. Starting with paragraph 6 we use technological innovation motives (section 6 and 7) and market imperfections (section 8-10) to explain seemingly irrational investment behaviour of firms. We end this paper by listing the main conclusions from each of the different parts of the literature survey.

2. Economic criteria

There are many different ways of evaluating an investment project. Most of them involve evaluating cashflows that are generated by the project. Cashflows can, for example, be the investment costs or generated benefits from the investment.

There are four economic criteria that are widely applied: Cost-Benefit Ratio (CBR) analysis, Pay Back Period (PBP) analysis, Net Present Value (NPV) analysis, and Internal Rate of Return (IRR) analysis (see, for example, Brealey and Myers, 1991; Copeland and Weston, 1988; Bierman and Smidt, 1993). The first two methods do not explicitly take *time preference* into account, whereas the latter two methods do. All of these methods require knowledge on relevant costs and benefits of the investment. For the moment the assumption is made that all relevant cashflows are known to the manager *with certainty*.

Cost-Benefit Ratio analysis calculates the ratio of all relevant costs compared to all relevant benefits. The investment is considered worth implementing if the CB-ratio is less than one, e.g. that all relevant costs are lower than all relevant benefits. This method does not take into account that 1 dollar now is worth more than one dollar in the future (the time-preference motive).

Pay Back Period analysis calculates how long it takes before the initial investment has paid back itself. Assuming that the annual benefit (B) remains constant over time and that no other costs are incurred during the lifetime except for an initial investment (I_0), the formula becomes:

$$PBP = \frac{I_0}{B}.$$

For variable benefits and costs over time, the formula becomes a little more complicated, but the idea remains the same. An investment is considered to be profitable if the PBP of the project is smaller than the *cut-off* period. The cut-off period is defined as the longest period in which a technology is allowed to pay back its investment. All cashflows that are generated after the cut-off period are neglected. The cut-off period is often arbitrarily chosen because there exists no natural theoretical cut-off period. Therefore it remains an *ad hoc* decision rule.

Net Present Value analysis examines all relevant cashflows during the lifetime of a project. Let CF_i be the net cashflow generated in period i , where net cashflow equals relevant benefits minus relevant costs; and let I_0 again be the initial investment required. Then, the Net Present Value is calculated as:

$$NPV = -I_0 + \sum_{i=1}^T \frac{CF_i}{(1+r)^i},$$

where T is the expected lifetime of the technology and r is a discount factor. The

discount factor is used to incorporate *time preference*. It can be interpreted as the reward on investment that investors demand for accepting delayed payment.¹ An investment project is considered to be profitable if the NPV is greater than zero. Apparently, the NPV depends on the choice of r (other variables are fixed). A higher discount rate implies a lower NPV. In other words, at low discount rates an investment can be profitable, whereas at high discount rates the same project is not considered worth undertaking.

The Internal Rate of Return (IRR) method uses this dependence of NPV on r . The IRR is defined as the discount rate *which makes the NPV = 0*. If this IRR is higher than the manager's *hurdle rate* then the investment is considered to be profitable. The *hurdle rate* is defined as the minimum return on investment required by management (it is closely related to the discount rate r and to the concept of *cut off point*, see below). The hurdle rate is often arbitrarily chosen, but must in theory approximate the long term weighted average cost of capital. IRR can also be interpreted as the growth rate of an investment.²

The Net Present Value method is theoretically superior to the other criteria for several reasons (see Brealey and Myers, 1991 chapter 5).³ The advantage of NPV over CBR-analysis is that CBR-analysis does not discount the cashflows and NPV analysis does (after all, a dollar today is worth more than a dollar in one year). The main disadvantage of PBP over NPV analysis is that PBP uses a cut-off point (which is often arbitrarily chosen); relevant cashflows that are generated after the cut-off period are neglected, whereas in NPV analysis all relevant cashflows are considered *and* discounted. The advantages of NPV over IRR are many. One of the major problems with IRR is that if there occurs more than one change in sign of the cashflow, the project may have several IRRs or no IRR at all (see Brealey and Myers, 1991 for some illustrative examples).

It looks as if the PBP-analysis does not discount future cashflows, but in fact it does so implicitly. The fact that managers use a (short) cut-off period implies that they are interested in earning back their investment fast and do not care much about cashflows that are generated in the far future. Moreover, there is an equivalence between PBP-analysis and IRR-analysis when the simple case of equal cashflows over time is examined. It can be shown that, for fixed life time, N , the following holds:

¹ The underlying assumption of this methods is that new available cashflows will be re-invested at a minimum rate of return which equals (or exceeds) the discount factor r .

² The same assumption about the return on re-investments is made here (cf note 1), but since the discount rate is the variable to be determined, this assumption is often very unrealistic. Examples of IRR's exceeding 25% are no exception.

³ The following arguments are by no means conclusive, but rather intuitive. For an extensive overview, see Levy and Sarnat, 1988; Brealey and Myers, 1991.

$$PBP = \frac{(1 - \frac{1}{(1+r)^N})}{r}$$

For example we take $N=10$ years. Then it follows that a hurdle rate of 15% equals a PBP of 5 years. This result does not change the fact that PBP cut-off period is still an *ad hoc* rule. However, it shows that there is an *implicit notion* of discounting with those who use PBP-analysis. Nevertheless, given the advantages of NPV over the other mentioned economic criteria, we will henceforth only concentrate on this economic criterion.

3. Rational investment decisions (the certainty case)

In the section above the NPV condition for an investment to be profitable was given: if a single investment project has a positive NPV, it is worth undertaking. Now we will address the question which decision to make when more than one investment alternative is available. The answer is conditional upon the assumptions we make. Traditional economic decision theory assumes first and foremost that the firm is a profit or utility maximizing entity. Within this framework, the investment decision becomes one of *maximizing* (why this is printed in italics will become clear in section 7). The underlying assumptions of this classical theory are the following:

Suppose that there are i investment alternatives in a investment set J . Let further be supposed that all relevant information about all alternatives i are known with certainty and that any project i and k in J are economically independent (e.g. not mutually exclusive). The relevant consequences of investing (the future possible states) are also known in advance. Further, assume that the firm can freely borrow money at the risk-free interest rate (e.g. no budgetary constraints), there are no taxes, no transaction costs and that the manager is also the owner of the firm.⁴

In this situation, especially when the firm has no budget restriction, the *optimal strategy* for the firm would be to invest in all available projects i in J which have a positive NPV, since all these projects have a riskless, positive contribution to total profits. If some of the projects are, however, mutually exclusive, the project with the highest NPV should be chosen.⁵

⁴ In the latter case, the discount rate equals the risk-free interest rate in order to compensate the manager for accepting delayed cashflows (if the money is not invested in a project, it can always be invested risk free in governmental bonds at the risk free interest rate).

⁵ See Bierman and Smidt, 1993 (chapter 5)

If the assumption of having no budget restriction is relaxed (e.g. limited borrowing capacity and imperfect capital markets), the decision problem becomes an integer programming problem (IPP). The firm is no longer free to invest in every alternative, but is forced to make a decision. The *maximization problem* becomes:

$$\text{MAX} \sum_{i \in J} \text{NPV}_i \cdot X_i \quad \text{s.t.} \quad \sum_{i \in J} I_i \cdot X_i \leq B$$

$$X_i = \begin{cases} 1, & \text{if project } i \text{ is implemented} \\ 0, & \text{else} \end{cases}$$

where NPV_i is the NPV of project i , I_i is the initial investment of project i and B is the total investment budget. If the budget is very large, it does not have to be a binding constraint, but if it is not large enough to cover all investment projects, some of them will not be implemented ("*capital rationing*"). This can be a first reason why firms do not invest in all profitable energy conservation projects. If a firm has a fixed budget and more projects with high NPVs (high opportunity costs) than the budget allows for, it is perfectly *rational* not to invest in a energy conservation technology even though the expected return is higher than the hurdle rate. Firms which have a relatively low energy bill are, generally speaking, expected to have few possibilities to generate sufficiently large *incremental* cashflows (in the form of a reduced energy bill) to overcome the initial investment. Therefore, a small energy bill can be seen as a (rational) barrier to invest in energy conservation technologies.

When the decision of replacement is to be made, the manager is forced to compare the new technology with the old technology. If the new technology has a NPV which is greater than zero, it does not automatically imply that it should replace the old technology, because the old technology can still generate cashflows. To make a sound replacement decision, the *incremental cashflow* of the new technology should be analyzed. In the case of energy efficient technologies, it is important that the efficiency is expressed as the relative improvement of the new equipment over the old equipment. If the energy efficiency is small compared to the initial investment and the new equipment brings about higher operation and maintenance costs than the old equipment (due to the experience a firm has with the old technology), it can be perfectly *rational* not to invest in the new technology.⁶

⁶ Book value of the old equipment is not relevant for the replacement decision, because it is no cashflow (the expenses to buy the old machine have been made already). Therefore, depreciation motives are in this case (with no taxes) not relevant, see Bierman and Smidt, 1993 (chapter 7). For problems concerning the introduction of tax schemes and inflation, see Brealey and Myers, 1991 (chapter 6) and Copeland and Weston, 1988 (chapter 3).

4. Rational investment decisions under uncertainty

In real world situations, investment decisions under certainty do not exist. The reason why this situation was introduced in the previous sections was to show that under ideal circumstances the NPV method is theoretically the best method and the decision problem is one of maximization. In this section the certainty assumption is relaxed and two sorts of risks are discussed: firstly, the risk associated with undertaking a single investment (technology); secondly, the risk involved in adding a new technology to an already existing production process. However, it is still assumed that a firm can adequately assess the risks involved.

4.1 Risk assessment for a single investment

The aspect of risk introduces an extra dimension to the decision process. Not only the profitability of a project (expressed as *expected* NPV) is important, but also the risk attached to that specific project becomes a decision factor. The introduction of risk automatically brings about the need to make some assumptions about *the attitude* of a firm towards risk and return. The usual assumptions are: (i) if the returns of two projects are equal, firms prefer the project with the lowest risk attached; (ii) if the risks of two projects are equal, the project with the highest return is preferred. This attitude is called *risk-averse*. Note that this does not imply that all firms have the same *degree of risk-aversion*. Every firm has a subjective trade-off between return and risk. Very often higher returns are accompanied by higher risk. It is a matter of personal opinion how the trade-off is made.

There are three ways to analyze the risk of a single specific investment project: (i) the state-preference method; (ii) valuation methods; (iii) sensitivity analysis. The first two methods are briefly discussed. The third method is beyond the scope of this framework (see Brealey and Myers, 1991 chapter 10 for an introduction to this subject).

State-preference models consider explicitly all alternative cashflow and states sequences. In these models, uncertain cashflows are adjusted for risk. Risk becomes incorporated in the cashflow and therefore the dimension of the investment decision is reduced to one: *Risk Adjusted Present Value (RAPV)*. There are 2 ways of adjusting the uncertain cashflows: 1) by using a risk premium; 2) by estimating *certainty equivalences* of each possible cashflow and discounting against the risk-free discount rate (See figure 1).⁷

⁷ See Bierman and Smidt, 1993 (chapters 17-19).

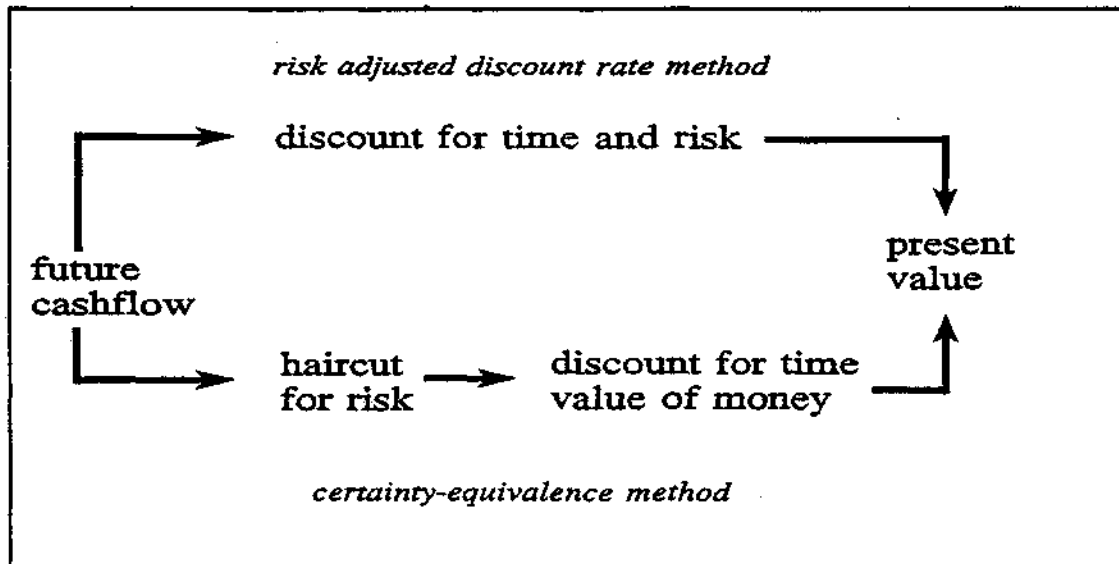


Figure 1. Two ways to incorporate risk into investment decision.
Source: Brealey and Myers, pp 203

Using a (uniform) risk premium is often done by firms, because of its relative ease. Once a risk premium is chosen, the selection and evaluation of investment alternatives is exactly the same as in the certainty case. Obviously, using a risk premium will always mean a higher (implicit) discount rate, which implies that the NPV's of alternatives are lower, and the chance of more non-profitable investment projects becomes higher. In fact, when a very large risk premium is used (e.g. the firm is very risk-averse), many possible technologies become unprofitable. In other words, using a unusually high discount rate can be a barrier for the adoption of new efficient technologies.

Estimating certainty equivalences is theoretically more sound, because every cashflow is considered separately, and no uniform risk adjustment is made. But this is precisely why it is hard to use this method in practise. Estimating certainty equivalences requires probability assessment of all possible states, and on the scarcity of the currency considered (e.g. dollars, guilders) in those states. The scarcity aspect is strongly influenced by market development and the firm's financial position. Together, these elements constitute the *risk-adjustment factors* (R.A.F.). To insure that the certainty equivalent of a certain currency unit is equal to unity, the expected value of the risk-adjustment factor over all states must be equal to unity:

$$E(R.A.F.) = \sum_{\text{all states } i} R.A.F. * P(\text{state } i) = 1.$$

As a consequence, it must hold for any state i that $R.A.F. * P(\text{state } i) < 1$, which implies that the certainty equivalence is indeed always smaller than the certain

cashflow.⁸ Once the certainty equivalences have been assessed, the decision is unambiguous: if the project has a positive risk-adjusted net present value, it should be implemented. Again, the set of profitable alternatives declines as the certainty equivalences become smaller (e.g. the firm is more risk-averse).

The second way to analyze the risk of a single specific project is using *valuation methods*. Instead of considering all alternatives explicitly, valuation methods try to use summary characteristics that are sufficient to describe a project's value. The changes in value of the cashflows are assumed to follow a particular probability distribution. If the necessary parameters of the probability distribution are known (or estimated), then the fluctuations can be predicted. For example, if cashflows are assumed to be normally distributed, then it is sufficient to know the expected cashflow and the standard deviation of the cashflow. This information determines all possible states. This is also called *probability assessment*. The method assumes that the decision maker is capable of making such a probability assessment. The result of the probability assessment is a probability distribution for the NPV of a project. The difference between probability assessment and certainty equivalence is that risk is explicitly accounted for as an extra dimension of the investment decision (see figure 2).⁹

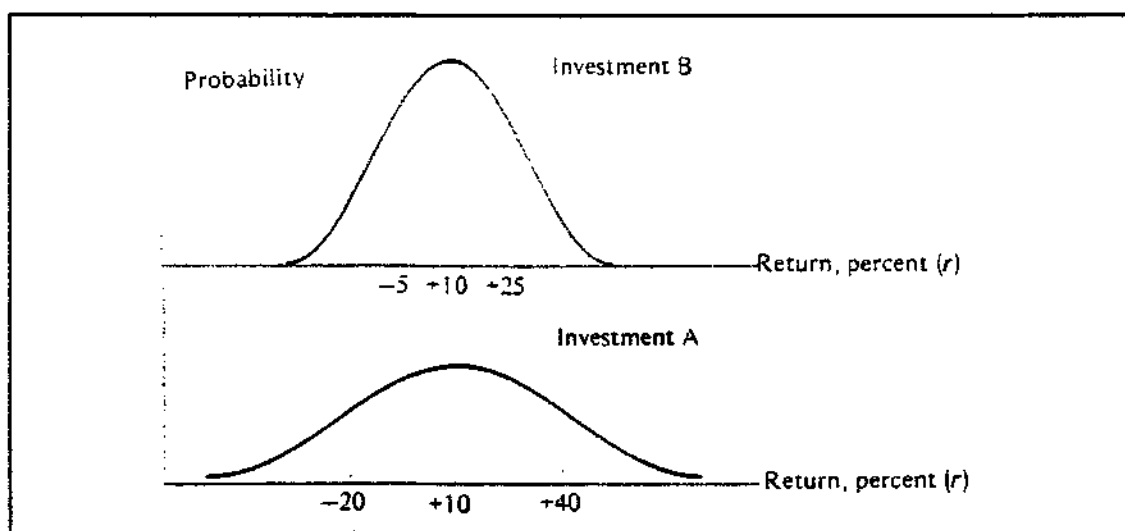


Figure 2. Investment decision with risk expressed as the explicit variation of the expected cashflow. Source: Brealey and Myers.

⁸ We implicitly assumed that there are more than two states with positive probability and positive risk-adjustment factors.

⁹ It is the adjusted NPV versus $E(NPV)$ together with $SD(NPV)$, where $SD(.)$ stands for standard deviation.

A unique decision rule in the two-dimensional case (return and risk) is hard to give because it depends on the degree of risk aversion. For example, an imaginary energy conservation investment project has an expected cashflow of 100 units, but the standard deviation of the cashflows is 100 units. Although the expected cashflow is positive (in the case of certainty, this project would be implemented), there is more than 30% chance that the project will have a negative cashflow. It depends on the trade-off between return and risk whether this project is implemented. Firms that are highly risk averse (e.g. the chance of a negative cashflow is minimized), are slow in adoption energy conservation opportunities. A discussion on the risk-aversion topic can be found in Copeland and Weston, 1988 (chapters 4 and 5). A suggested decision rule can be the following: Implement project i if the expected NPV_i is significantly greater than zero. This can be calculated by dividing the expected NPV by its standard deviation. If this result is greater than the value 2, the chance on a negative NPV is smaller than 2.5%.

Firms can make different probability assessments of different future states, because they have different perceptions of macro-economic developments and their own, firm-specific developments within that economy. With these different assessments it can be perfectly *rational* not to invest in energy efficient technologies, even when engineers claim them to be profitable. For example, a firm's subjective expectation on the future energy prices can lead it to postpone or to reject the implementation of an efficient technology. High levels of uncertainty about future energy prices can therefore be an effective barrier to the implementation of energy efficient technologies.

4.2 Risk assessment for "portfolio's"

In the previous section the risk assessment of a single investment project was analyzed. But a new technology must be implemented in a production process or the investment is part of a portfolio. Then the interaction between the new technology and the already existing capital stock becomes important. Evaluation of additional risk to the firm as a whole as a consequence of implementing a new technology is the subject of this section.¹⁰

Addition of new technology can basically have three effects: 1) total risk of the firm increases; 2) total risk of the firm decreases; 3) total risk of the firm remains the same. The last effect will not be discussed, because the first two effects are more interesting.

¹⁰ We shall treat this subject intuitively, rather than formally. For the formal discussion of this subject, see the portfolio theory of Sharpe.

The effect of addition of an investment to an already existing capital stock depends largely on the expected *correlation* between the capital stock and the new investment. If the expected correlation is positive, portfolio theory says that adding a new technology will increase return (provides that the investment project is profitable *sec*) but will also the total risk of the firm or portfolio. However, if the expected correlation is zero or negative, then adding a new investment could increase return, while decreasing risk *at the same time* (see figure 3). Sandstad *et al.* (1992) say the following about this: "Even though a given investment may have extreme variability of returns -that is, large variance- and thus be "risky" in a naive sense, it should not be considered risky if, in particular, it would tend to "pay off" in exactly those states in which the rest of the portfolio "lost" (Sandstad *et al.* 1992 talking about Lind 1982).

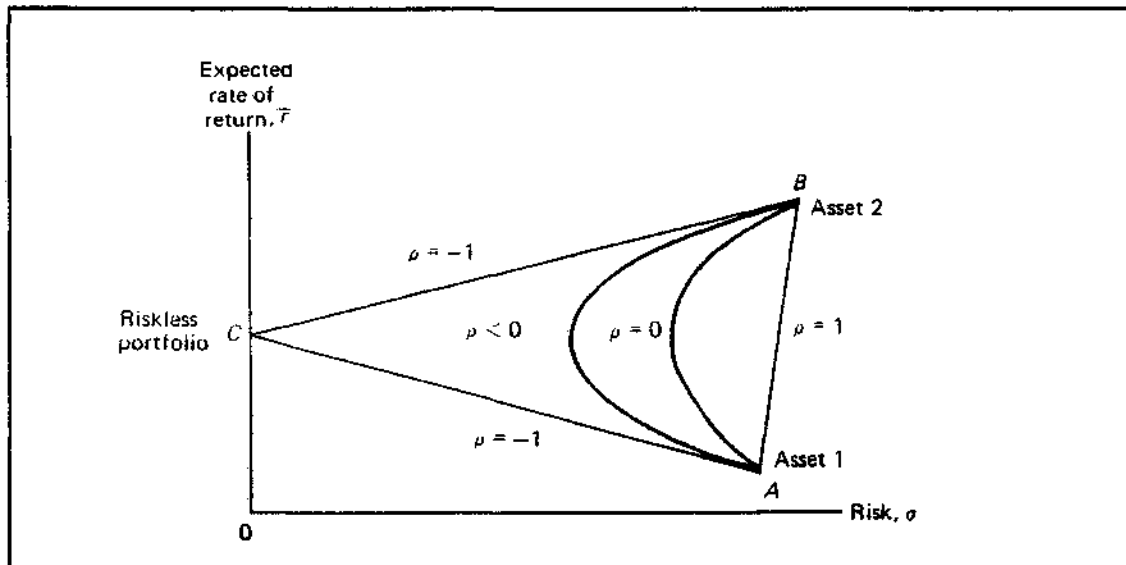


Figure 3. Two securities and different correlations
Source: Bierman and Smidt, 1993

In the case of energy efficiency improvement, an argument can be found for both a negative and a positive correlation. Energy efficient equipment can be seen as having a negative correlation with the already existing capital stock, because the relative performance of it increases as energy prices increase (profits to be obtained are bigger due to high energy prices), while the performance of the existing stock is negatively influenced by higher energy prices. The dependence on energy consumption becomes less due to energy efficiency improvement, and the risk attached to uncertain energy prices becomes smaller (the diversification argument).

On the other hand, it can be argued that since the new equipment is *added* to the already existing capital stock, it will follow the same movements as the existing equipment, yielding a positive correlation. Moreover, if energy efficiency is seen as "core business activity", the correlation will tend to be positive. But

since it is seen as core business, it is usually assumed that the specific risks are smaller due to a better assessment of all possible states and the consequences from those states. When energy efficiency is seen as non-core business, the diversification argument holds, but the specific risk is estimated to be higher. The net effect of these opposite elements will determine, under these assumptions, if an energy conservation measure is implemented.

5. Provisional conclusions

At this point of the analyses we summarize the previous findings and present the paths we wish to pursue from here. First, we introduced a set of strict and unrealistic assumptions to derive that every investment with a positive NPV should be implemented. After introducing a budget constraint, the first reason for not investing in every profitable option was found: a budget that is too small for all profitable projects forces the firm to discard some profitable investments, among which energy conservation technologies. Secondly, uncertainty was introduced, but with the assumption that a firm was capable of assessing all relevant risk factors and possible future states. It was concluded that firms could adjust the cashflows in many ways, such that the expected NPV of a project became negative. This is a second reason why not every profitable investment is implemented (risk-aversion and uncertainty).

Now, we wish to relax some of the assumptions of the classical economic framework, such as the free and costless availability of information and the possibility of full probability assessment on future states. However, the relaxation has two mainstream paths of (techno)economic analysis (see Winter 1969). The first is called "behavioral" theory, which emphasizes the firm-specific decision characteristics. The most important names are Herbert Simon (1955, 1959, 1978, 1979) and Dosi (1988, 1988a). The second stream is "managerialism", which treats information asymmetry and agency problems. Important names are Jensen and Meckling (1976) and Williamson (1963). Another topic in managerialism is the "transaction cost" approach by Williamson. This subject has some interesting commonalities and differences with the theory of bounded rationality. The two mainstream paths will be treated consecutively; a view on transaction costs will conclude the analysis. See figure 4.

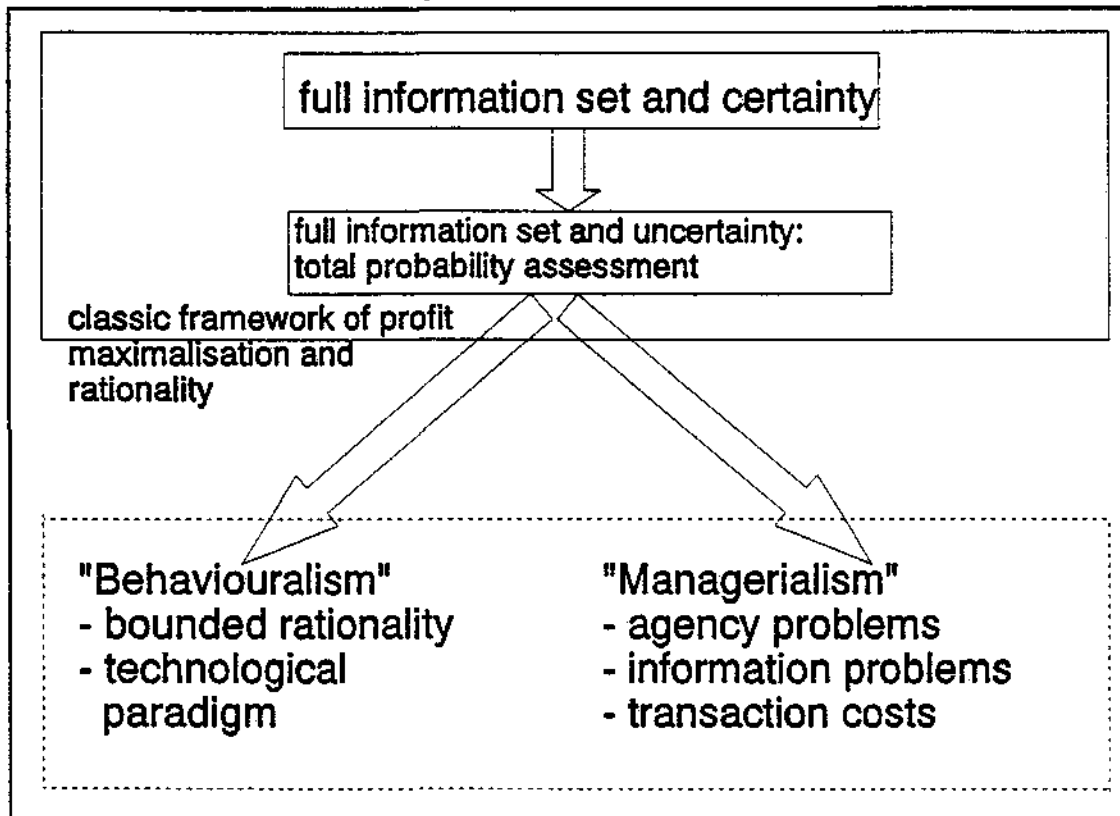


Figure 4. Schematic representation of the structure of the analysis.

6. Bounded rationality

Within the classical framework of profit or utility maximizing individuals, there has already been some room to explain seemingly irrational behaviour by introducing uncertainty and a budget constraint. But we need to go further. In this section the maximizing assumption will be relaxed and will be replaced by a *satisficing* assumption in an investment framework which is called "bounded rationality". Moreover, the perfect and costless information assumption is also relaxed.

One of the main contributors to the theory of bounded rationality is Herbert Simon. The classical theory of maximizing costs and benefits and the assumptions of full probability distributions is highly criticized. Simon presents some arguments why the maximizing framework should be replaced by a satisficing framework. He argues (Simon, 1955, 1979) that firms are unable to:

- (i) attach definite pay offs to each of the possible future outcomes
- (ii) specify the exact nature of the outcomes (so that there is no room for unanticipated consequences)
- (iii) make a complete ordering of pay offs

Moreover, he shows that the assumptions of "global rationality" in decision theory are *sufficient*, but certainly not *necessary* to derive well known economic phenomena. As an example, he shows that the economic phenomena of negatively sloping demand curves can also be derived from bounded rationality (Simon 1979, see also Becker 1962). In other words, he states that the unrealistic assumptions are not necessary, and that relaxing them would not hurt "established economic theory". Moreover, it leaves some space for *human decision behaviour*. Empirical evidence on global rationality shows that only under the strong assumptions of classical decision theory an individual is maximizing its *subjective expected utility (SEU)*; as soon as a more realistic environment is chosen, large deviations from maximizing SEU appear (Simon 1979).

The main contribution of Simon is the introduction of two important concepts: 1) satisficing principles; and 2) search strategies. He argues that these concepts are "a kind of rationality that is compatible with the access to information and the computational capacities that are actually possessed by organisms, including man, in the kinds of environments in which such organisms exist (Simon, 1955)".

The first major simplification he introduces is a different pay off (or profit) function, which can have two outcomes: satisfactory (1) or unsatisfactory (0). He proposes not to try to find the "best" opportunity, but a "good" opportunity.¹¹ Simon calls this the "satisficing principle".

The second simplification concerns the information gathering process. This is related to the satisficing principle mentioned above. It involves information gathering only on outcomes of states for which a satisfactory pay off is expected (call it S'). Then, the search strategy becomes: look for an alternative that "maps" only on S' (for a more formal discussion, see Simon 1955).¹²

In general, Simon's idea of bounded rationality means that he acknowledges the fact that a firm cannot (i) fully process all information on all the available alternatives; (ii) compute all possible future states as a consequence of implementing alternatives; (iii) cannot find a set of weights for comparing the components of a multiple pay-off. Therefore, his decision is essentially bounded and as a consequence, the firm must settle for a *satisfactory* pay-off or profit. In solving the investment decision problem, the firm must rely on simplified search and decision rules, look for sufficient solutions, define sub goals and divide the problem amongst specialists (Simon, 1979; see also Simon 1959, 1978).

¹¹ As an example, he mentions that if a chess player finds an alternative that leads to a forced mate of the opponent, he generally adopts this alternative without worrying whether another alternative also leads to a forced mate.

¹² By mapping, Simon means coarsely assessing the consequences on future outcomes of implementing an alternative.

From a computational point of view, bounded rationality means the difference between search for an optimal solution and a feasible solution. The feasibility restriction is simply adding a linear inequity. The restrictiveness of the feasibility constraint depends on two elements: *the aspiration level* and the *set of "considered" alternatives*. If the aspiration level is set very high, the feasibility restriction will generally be very restrictive (e.g. a satisfactory solution will be close to a theoretical optimal solution). As the set of relevant alternatives becomes smaller, the feasibility inequity becomes more difficult to obtain.

These new insights of decision theory and human behaviour can provide additional reasons why it may be "rational" for a firm not to invest in a seemingly profitable energy conservation option:

- (i) a firm is not capable of processing all relevant information about the existence of energy conservation (a maximum capacity of information storage): there is a knowledge or processing *gap*;
- (ii) a firm is not capable of assessing all (the right) consequences of an energy conservation investment (incomplete information and uncertainty);
- (iii) a firm has already reached a satisfactory pay off, so they have no incentive (relevance) to invest to reach for a better pay off;
- (iv) the selective search strategy of a firm ignores energy conservation investments.

When a new energy-efficient technology is considered there may be lots of uncertainty. Engineers often have more knowledge on the expected advantages and risks of the new technology (see Blok *et al.* 1992), but it remains a question how these results are interpreted by firms. Especially when managers are not familiar with the new technology, they tend to estimate the possible advantages lower, and the possible risk higher than the engineers. In other words, managers make different probability assessments of future cashflows than engineers, which helps explaining why managers tend to less profitable alternative energy conservation technologies (see also the information asymmetry approach).

Another consequence of non-maximizing behaviour, which was mentioned first by Leibenstein and later developed by many other researchers, is called X-(in)efficiency. The term is used to indicate whether or not a firm's costs appear to be above the technological minimum levels.¹³ It is clear that when the costs are above the technological minimum, some inefficiencies appear. The nature of these inefficiencies was unclear to Leibenstein; hence, he named it X (Frantz, 1992). Button and Weyman-Jones state that X-efficiency.. "is a consequence of the nexus of pressure from the external environment on the individual decision maker and the responsibility consequences, or constraint concern, applying to the individual. The lower the intensity of environmental pressure on a decision

¹³ Or alternatively, X-inefficiency is the difference between maximal effectiveness of utilization and actual utilization.

maker, the less is his or her concern with the constraints operating on the organisation, and consequently, the lower is the effort expended" (Button and Weyman-Jones, 1992, pp 440). The proposition which follows from the above is that the looser the effort responsibility consequences, the greater the degree of X-inefficiency. When this proposition is applied to the case of energy conservation, a workable hypothesis can be posed: the absence of external pressure of decision makers can lead to less effort put in exploring energy conservation possibilities; hence, it can pose an effective barrier for the adoption of energy efficient technologies.

Moreover, some of the reasons mentioned above can also be explained by complementary theories that deal with the state of technology and other firm-specific elements. These "technological innovation" theories will be discussed below.

7. Technological trajectories

Simon states that reaching a satisfactory level also depends on the previous pay offs, the experiences of the firm with alternatives, and the previous choice of alternatives. In other words, he argues that the firm-specific environment also determines the set of "considered" alternatives, the search strategy, and the aspiration level. However, a full formal derivation is not presented by him.

Dosi *et al.* (1988a) and Dosi (1988) present a technological innovation theory which also subscribes the idea of *selective search*. The main idea of this theory is that firms, or whole sectors for that matter, search for new opportunities *within a given technological paradigm*. Dosi defines a technological paradigm as a "pattern of solution of selected techno-economic problems, based on highly selective principals derived from the natural sciences, jointly with specific rules aimed to acquire new knowledge and safeguard it, whenever possible, against rapid diffusion to the competitors" (Dosi, 1988, pp 1127).

A closely related element of the theory of technological paradigms is the idea of a *knowledge base*, which is defined as the set of inputs, knowledge and capabilities that investors draw on when looking for innovative solutions. Different knowledge bases can imply different stages of the technological trajectory. Knowledge bases can be efficiently increased by internalizing R&D performances and other innovative search techniques. Among the advantages of internalizing R&D (in contrast to, for example, external consultancy) are: 1) facilitating of information flows; and 2) limiting leaks of information (see Dosi, 1988, and the authors therein).

Consequently, Dosi's hypothesis is that different firms or sectors have different technological paradigms, which account for the fact that some firms do, and other firms do not innovate or adopt certain technologies. The technological

paradigm, together with a set of heuristics, determine what the relevant problems are, and in which direction the solution should be sought. In other words, due to what is called "*the paradigm-effect*", research and adoption processes are driven in a certain direction and are blind to directions that do not fit within it (see figure 5). About the direction in which research and adaption will evolve Dosi says the following: "it has been suggested that major clusters of prevailing technological paradigms...involve the intensive utilization of some crucial input abundantly available at low cost" (Dosi, 1988). For example, in the oil-based synthetic chemistry the use of energy is very important. There one could expect a technological paradigm, focused on energy efficiency. Using this hypothesis, it is possible to explain why some firms or sectors are ignorant about energy conservation possibilities, namely that the relative role played by energy in the total costs is too small to be a priority of innovative research.

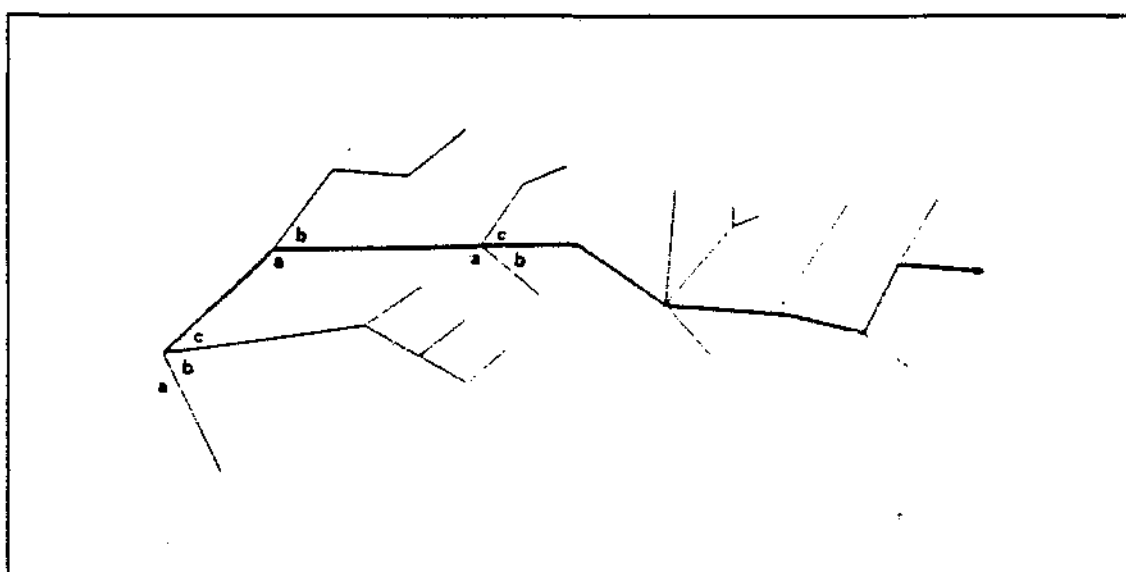


Figure 5. Technological paradigm visualized.

Source: Schot 1993

A second concept of Dosi's theory is that technology knowledge is sometimes very *tacit*, in contrast to the idea that one can "dip freely into a general 'stock' or 'pool' of technological knowledge" (Dosi, 1988). The latter idea is more or less implicitly made by many studies which assess the unexploited potential for energy conservation (such as Blok *et al.*, 1990; Melman, 1990). Dosi, on the other hand clearly states that sufficient information on a certain technology does not imply that this technology can be implemented. Information is seen as a clear *subset* of technology.¹⁴ In innovative technology there are irreducible elements that cannot be sold or easily imitated, but depends mainly on the

¹⁴ As an analogy, Dosi says: "information stands vis-a-vis innovative technology as a subscription to the *American Economic Review* stands vis-a-vis winning the Nobel Prize in economics".

cumulative, augmented abilities and skills, which are often highly tacit. This is quite similar to what Simon said about the pay offs of some investment. Technological innovation investment, therefore, depends very much on tacit knowledge, firm-specific features and existing (cumulated) activities. In relation to the knowledge base and R&D activities, one can argue that external consultancy does not have the ability to convert the tacit knowledge efficiently. Not having an internal energy coordinator (or energy manager) in the case of energy efficiency can mean a tacit knowledge barrier for adoption.

Schot (1991, pp 104) argues that innovation and adaption on one side and the firm-specific environment on the other are highly affected by one another: "it is not a matter of technology adapting to its environment, but also adapting the environment to its technology". As a consequence, Schot predicts that technological innovation is accompanied by adaptations of both technology *and* environment. But the adaptations a firm has to make can be large, and effort and trouble of the adaptations can outweigh the possible gains from the investment. This can be a possible barrier to the diffusion of energy efficient investments. As it has been said before: imitation can sometimes be even more expensive than the actual innovation itself.

The situation characteristics that highly influence the innovation strategy of firms are, according to Dosi (1988; also see Schot 1991, Kemp *et al.* 1993):

- (i) Technological opportunities
- (ii) Appropriability conditions (such as patents, lead time, learning effects)
- (iii) Market inducement factors (such as relative prices shocks)

If all these three components are favourable, innovation will be high. If some of them are unfavourable, innovation processes can be slowed down. These components differ between, as well as within sectors, but they can be helpful in understanding why some firms do, and other firms do not innovate.

Dosi provides a scheme of what he thinks is the actual innovation situation (in relation with the three situation characteristics), see table 1. From it, hypotheses concerning innovation and diffusion at sectoral levels can be derived.

For example, in the science based sectors, the situation characteristics are very favourable. Thus, in these sectors, the innovation processes should be very advanced. On the other hand, one might argue (along with Dosi and Schot) that although innovation may be high, diffusion is not, because of high levels of tacitness and complex innovation structures. Then, the conditions for diffusion are not very favourable. Empirical testing should provide conclusions here.

category	type of innovation	opportunities	appropriateness	skill and knowledge	size	examples of sectors
supplier dominated	process innovation	limited	restricted	incremental improvement/ low R&D	small	textiles agriculture
specialized suppliers	product innovation	abundant	high	tacit knowledge/ low R&D	small	engineering
scale-intensive	product and process	normal	high	high/high R&D	big	metal, glass
science based	paradigm innovation	very high	high	complex, tacit/high R&D	big	chemical industry

Table 1: Classification of innovation opportunities

On the subject of market inducement factors, one can argue that the absence of external pressure reduced the incentive to invest in energy efficient opportunities. Conversely, strong external pressure (for example, what has happened in the chemical sector) can lead to faster adoption of energy efficient opportunities.

At the end of this section, we would like to summarize briefly the findings from "behaviouralism" and its possible barriers:

- 1) there is no relative important role *within* the paradigm for energy conservation
- 2) there is little knowledge of the opportunities *outside* the paradigm
- 3) there is a sufficient level of energy efficiency or energy conservation savings (satisficing principle)
- 4) different (insufficient) knowledge bases
- 5) high degree of tacit knowledge and low augmented skills for adoption/imitation
- 6) wrong set of opportunities, appropriability conditions and market inducement factors (absence of external pressure).

8. Principal-agent problems

A second mainstream of economic analysis is "managerialism". Central in this analysis is the *principal-agent relation*, which exists because of the separation between ownership and management. A principal-agent relation exists "between two or more parties when one designated as the agent, acts for, on behalf of, or

as a representative for the other, designated as the principal in a particular domain of decision problems".¹⁵ The roots of this theory go back to Coase, who stated that the firm could not be seen as an identity, but as a collection of parties, each with their own interests (see Moerland, 1992). Separation between ownership (principal) and management (agent) has great influences on the firm's behaviour (see Jensen and Meckling, 1976).¹⁶ When the manager of the firm is the same as the owner (this is not necessarily the same as a one-man-firm) all decisions will point in the same direction. Behaviour of a firm where manager and owner are different people is often an outcome of the interplay of the motivations of the individuals comprising it, the rules and conventions governing their interaction, and the environment within which the firm operates (DeCanio, 1993). Jensen and Meckling state: "the 'behaviour' of the firm is like the behaviour of the market; i.e. the outcome of a complex equilibrium process" (Jensen and Meckling, 1976).

Although the hierarchy within the firm can be quite strong, it will probably not enough to unite all different motives and actions. Fama and Jensen (1983) distinguished four different levels of the decision making process:

- (i) initiating (generation and development of investment proposals);
- (ii) ratification (choice of the decision initiatives to be implemented);
- (iii) implementation (execution of ratified decisions);
- (iv) monitoring (measuring the performance of decision agents).

(i) and (iii) together are called *decision management*, while (ii) and (iv) are called *decision control*. When different persons at different levels of the decision making process have different motivations or different objectives, the possibility exists that there can be substantial frictions between the levels of the decision making process, hence creating inefficiencies. In our case of energy conservation, an energy coordinator of a large firm can initiate many energy conservation projects, but when the general manager must make a selection, his choice or even personal favour can have a decisive weight on the project selection. It is not unrealistic to assume that general managers have less affiliation with energy efficient projects than energy coordinators. Therefore, a difference in staff function on the *decision management* and *decision control* level of decision making processes can perhaps help explain the difference in energy conservation investments by firms, and can even pose an effective barrier. This hypothesis needs to be tested empirically.

¹⁵ This definition was given by Ross in his article "The economic theory of agency: the principals problem". It was quoted by P. Moerland (1992).

¹⁶ In fact there are two forms of agency theory: the formal and the informal theory. The formal agency theory is normative and focuses upon the contractual relations between principals and agents for different states of information and risk. This part of the agency theory will not be discussed here.

Below we will discuss some reasons why managers tend to be biased in disfavour of energy conservation opportunities, and try to rationalize this behaviour from the managers point of view. After that, we shall discuss the consequences of asymmetric information in the next section.

A first possible consequence of this separation is "a shortsightedness of the management of the firm", which can result in extremely high hurdle rates or short cut-off periods. Managers are often judged and compensated for short term results. Moreover, it often happens that managers are rotated through different jobs or do not intend to stay with the firm for the lifetime of the project. Then, quick cashflows are preferred to long term return. Energy conservation projects are often characterized by this long term cashflow.

A second reason to under-invest in energy conservation opportunities is the low priority given to cost-cutting projects. Ross (1985) argues that "many energy conservation projects' lack of impact of production capacity, product quality and product flexibility is perceived as a reason for giving them a low priority. Cost-cutting projects can be postponed, it is thought, without losing much of the opportunity, whereas market opportunities associated with new or improved products or increased production may be altogether fleeting". Empirical evidence (stated in Van der Doelen, 1988) shows that management is overestimating profits from market opportunities with 40%, while they are underestimating the returns from cost-cutting projects with 10%. Sassone and Martucci (1984) conclude on this: "Thus, there is a bias in top managements' priorities: cost saving proposals are not as interesting as revenue enhancing proposals. And cost saving energy conservation proposals, addressing a relatively small cost category, perceived as risky and capital intensive, may be even less interesting". In addition to these arguments, Baumol (1962) showed that managers tend to maximize *rate of growth of sales* subject to a certain minimum profit constraint. Consequently, one can argue that managers therefore give priority to investments with a *revenue enhancing* character, which is the opposite of *energy conservation* projects.

The problem is also closely related to the technological paradigm theory and the satisficing theory. Management resources are scarce and many opportunities for expanding or improving market share other than energy conservation are present. The direction in which innovation is "triggered" often does not involve energy conservation.

A third problem that is mentioned in economic literature is that of disutility of effort on behalf of management. The disutility stems from two sources: calculating NPV of projects and assessing all information on relatively small projects. Regarding the first disutility, Brealey and Myers say: "Pay back is the easiest way to communicate an idea of project profitability [...] Insisting that everyone commenting on a project do so in terms of NPV may cut off those who do not understand NPV, but who nevertheless can contribute useful information".

Jensen and Meckling (1976) have suggested that the use of pay-back analysis can be contributed to the conflicting interests between managers and owners. Statman and Sepe (1984) have rejected this suggestion on empirical evidence. In theory, therefore, the use of PBP-analysis instead of NPV-analysis should not be a barrier for the adoption of energy conservation options. The second disutility, however, can mean a barrier for the adoption of energy conservation technologies. Some energy conservation projects are relatively small (especially for big firms), and assessing all information can be relatively costly (depending on the distance to core business). Given the time a manager has for making decisions, it can happen that relatively small fixed sums of capital are provided to lower hierarchical decision levels, which leaves top management with more time to carefully analyze the larger projects and the modes of financing them (the satisficing principle). This argument will hold for firms in a poor financial situation. Ross (1985) makes a distinction between "flexible budgeting firms" and "capital rationing firms". Flexible budgeting firms have *decentralized* capital budgeting processes, decisions are made locally and investments are evaluated at a uniform rate of return criterion. Capital rationing firms have critical approval decisions, based on competition among projects for an essential fixed sum. Ross concludes that financially poor firms are often characterized as "capital budgeting firms".

A related problem here is the financing problem of small projects. If a firm is relatively poor and needs to get financial support from outside sources, it is very time consuming and costly to find the support, because outside financiers must be convinced that the project is worth undertaking. This is also related to the problem of information asymmetry between the firm and the outside finance source (see section 9).

A last reason why managers under-invest in energy conservation may be a slight irrational one: Managers only invest in projects of which they have enough knowledge and in projects they enjoy or give them status. This behaviour is called "entrenchment" (see Schleifer and Vishny, 1990). DeCanio (1993) states that "managers will be deterred from initiating risky projects if the personal consequences of failure seem to be much larger than the pay off to success [...] Human capital investment in energy conservation expertise will be low if the compensation and prestige of the managers responsible for energy use (e.g. facilities personnel) are less than the rewards for other positions (DeCanio, 1993, pp 908)".

9. Information problems

A different perspective on investment decision theory and rationality is given by a second consequence of "managerialism". It involves the different states of information and the tacit character of knowledge (cf. the technological paradigm

theory). Information problems can arise in the following situations: 1) the technician knows more than the manager about the performance of a energy conservation project: *ex ante information asymmetry*; 2) the manager knows more than the owners about the return of the project: *ex post information asymmetry*; 3) the manager knows more than an external finance source;

In the first case an information disadvantage is assumed for the manager. The technician claims a higher return than the manager can observe, due to the tacit knowledge of the technician. The technician is not able to adequately express the return and therefore the manager will adjust the stated return downwards or increase the hurdle rate. As a consequence of this information asymmetry, projects that are just above the critical return criterium will not be undertaken.

In the second case an information disadvantage for the owner of the firm is assumed. In this case the manager is assumed to know the real profit of the investment project and the owner cannot observe this real profit. This is the most examined case of information asymmetry (see Antle and Eppen, 1985; Williamson 1988, 1974, 1963; Hirschleifer and Thakor, 1992). In energy terms this is referred to as the landlord tenant problem (Sanstad *et al.* 1992). Antle and Eppen (1985) show that when the manager has an information advantage and the owners cannot observe the true profitability, an *ex ante* efficient firm will have *ex post* inefficiencies. The explanation for this seemingly strange result stems from the fact that the owners set the hurdle rate substantially above the cost of capital to ensure that only the projects with the highest profitability are implemented. The same consequence as in the first case can be witnessed. Nevertheless, it is still an optimal solution for the moral hazard problem (e.g. rational from the owners point of view).

The third case of information asymmetry is the information advantage of the firm with respect to a external financing source. The moral hazard problem can be quite big here. The external source must be convinced that the investment project will actually yield enough to compensate him for the risk of bankruptcy. A bank (or another financial institution) can increase the cost of capital to such a level that it exceeds the return on investment. Leyland and Pyle (1977) show that information about the true profitability of an investment can be "signalled" by funding the investment with enough equity. The incentive to cheat will disappear, because the own interest is too big to cheat. But raising a sufficient amount of equity is often the problem. Therefore, firms that have budgetary problems (e.g. they cannot finance the investment by itself or prove reliable to the bank) are confronted with a higher cost of capital, reducing the number of profitable possibilities.

In general we can conclude that when information asymmetries exist and cannot be resolved, the total set of profitable opportunities for energy conservation is reduced. Information asymmetry can therefore be seen as a barrier to the adoption of energy conservation opportunities.

10. Adaption costs

As a complementary view, the adaption approach takes the adaption as its unit of analysis, instead of the individual (person or firm). The adaption cost approach suggests to take into account all costs to get from one state to another state. The focus, therefore, is on the asset specific characteristics, and not so much on the individual specifics. Williamson (as the main contributor to this theory, 1974) argues that if all relevant adaption costs are incurred, the eventual investment decision will be a rational one. This argument will be tautologic when it is used to explain under-investment when all other arguments stated above have failed. Then the statement becomes: since every argument for under-investing in energy conservation has failed, the adaption costs must be too high for the possible return. It becomes an *ex post* explanation.

It can also be an *ex ante* explanation, but flavoured by managers view on adaption costs. A reason very often mentioned for not investing is that the current equipment is satisfactory and that the extra costs incurred (finding trained personnel, replacement costs, opportunity costs) do not outweigh the potential benefits. Stated this way, the adaption cost motive can be very rational in the eyes of a manager. Additional adaption costs can depend heavily on 1) the specified of the project; 2) the knowledge base (or knowledge deficiency) of the firm. If the project is more specific (as is often the case in energy conservation (cf Zuidema and Farla, 1993) the adaption costs will raise. In other words, additional costs of replacement or investment (other than initial investment costs or operation and maintenance costs) are considered as adaption costs, and if they are high enough, they can be an effective barrier for energy conservation.

11. Conclusions

In this paper we have developed an investment decision framework for energy conservation opportunities. We presented a number of reasons to rationalize under-investment in energy conservation. The starting point of the analysis was "a perfect world", in which under-investment was irrational. After relaxing one assumption after another, new rationales for under-investment became apparent. In table 2 below, we summarize our results. One of the main conclusions we want to draw here is that most of the barriers result from a) an *ex ante* hurdle rate which is set to high (information asymmetry, agency costs); b) incomplete information and probability assessment (technological paradigm; bounded rationality, knowledge gap).

Table 2. Main results

Barrier for adoption of energy conservation opportunities	Theoretical rationale
low expected returns on investment	low priority to cost-cutting projects
high initial cost of information collection	low knowledge base; different technological paradigm
high level of uncertainty due to fluctuation in energy prices	"normal" difference in perception of firms
high level of uncertainty due to distance from core business ¹	different technological paradigm; bounded rationality
too high hurdle rates	information asymmetry; agency problems
absence of problem recognition: EC options unknown ²	technological paradigm;
absence of problem recognition: low energy costs	potential return too small compared to initial investment
liquidity constraints	Many other high opportunities for allocating investment budget
liquidity constraints	Bad financial situation
adverse impact on performance priorities	lack of technological opportunities
X-inefficiencies	Absence of external pressure
lack of openness to innovation	Technological paradigm
No new investments before old ones are fully depreciated	Bad financial position, full competition
too much work, too specific	transactions costs are relatively too high

1. Expressed as product quality, product flexibility and product reliability

2. Both physically and in terms of costs and benefits

Acknowledgements: The author likes to thank J.B. Opschoor, L. Zou and L. van Goor for their very useful discussions and comments on earlier drafts.

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