THE EFFECTIVENESS OF POLICY INSTRUMENTS
FOR ENERGY-EFFICIENCY IMPROVEMENT IN FIRMS
The Effectiveness of Policy Instruments for Energy-Efficiency Improvement in Firms
The Dutch Experience

by

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CHAPTER 1

1 INTRODUCTION

Improvement of energy efficiency is one of the important options for reducing greenhouse gas emissions. According to the Third Assessment Report of the Intergovernmental Panel on Climate Change, hundreds of technologies for improving the end-use energy efficiency make up more than half of the global potential for greenhouse gas emission reduction in the short and medium term (2010 - 2020). (IPCC, 2001; see also WEA, 2000). An important next question is how these options can actually be deployed. More specifically, one may ask what role governments can play by using policy instruments to promote the deployment of energy efficient technologies.

In this introductory Chapter, we will first set out the aim of the research described in this book. Then we will discuss the various policy instruments that may play a role in energy-efficiency improvement. Next the various aspects important for characterising policy instruments will be discussed and the various disciplinary approaches are listed. Finally, the outline of the complete book will be given.

1.1 Aim of the research

According to recent international reports (WEA, 2000; IPCC, 2001) there are substantial potentials for energy-efficiency improvement. Moreover, these potentials often can be achieved at low or negative costs. It is also acknowledged that many barriers exist; this is considered the biggest problem for addressing climate change. The IPCC report states that national responses may deploy a portfolio of policy instruments, including - according to national circumstances - emissions/carbon/energy taxes, tradable or non-tradable permits, subsidies, deposit/refund systems, technology or performance standards, product bans, voluntary agreements, government spending and investment, and support for research and development. Although some general statements can be made about the characteristics of the various policy instruments (e.g. "market based instruments are cost-effective in many cases"), it is important to note that the knowledge about the effectiveness of policy instruments in specific national situations is limited. Policymaking requires a strategy of "act, then learn, then act again".

Energy-efficiency policy making has been widely spread since the early seventies (Farla, 2000). In the past decade we have seen a revival of energy-
efficiency policies, with the application of both old and new instrument types. It is important to learn from these experiences. Improving the understanding of the extent to which policy instruments can help enhancing the energy efficiency is the focus of this book. The aim of the research was to study the applicability (to what extent and how can policy instruments be applied in specific situations?) and effectiveness (do policy instruments lead to actual energy-efficiency improvement?) of some potentially major policy instruments directed at energy-efficiency improvement in firms. The scope is limited to energy-efficiency improvement in firms (i.e. excluding households and the transport sector). Energy use in firms in agriculture, manufacturing industry and the commercial sector makes up more than half of final energy use in industrialised societies. In the research, the focus has been on: economic instruments, voluntary agreements, normative instruments and instruments for R&D promotion (see Section 1.2). There are substantial differences in knowledge on the various policy instruments. E.g. on energy taxation a wide body of theoretical economic literature exist, whereas an instrument like voluntary agreements is relatively new, and the amount of published literature is limited.

So, the starting points for the research is different for the various policy instruments and we hence had to pose quite different specific research questions for the various instruments. These detailed research questions will be elaborated in the various Chapters (3 - 6).

A specific question is how the various policy instruments compare with each other and whether some combinations may perform better than the individual instruments. This question will also be addressed (Chapters 7 and 8).

1.2 Policy instruments for energy-efficiency improvement

If one wants to influence the behaviour of an actor, e.g. to persuade a firm to adopt energy-efficiency measures, in general three basic incentive types can be considered (see, e.g., Van den Doelen, 1989):

- Communication: providing information to the firm in order to change the knowledge about the options or influencing the appreciation of the options;
- Economic incentives: influencing the decision making process of firms by changing the economic characteristics (costs or benefits) of an option;
- Normative incentives: changing the decision making process by declaring specific behaviour compulsory or forbidden.
In practice, most practical policies consist of a combination of these incentive types. Various policies are possible and have been applied. Investment subsidies or tax deduction possibilities (fiscal instruments) for energy-efficiency equipment have been widely applied in energy-efficiency policies in many countries. Energy and carbon taxes are applied in some countries in Europe, but in most cases large consumers are exempted. European Union wide taxes were discussed as of the early nineties, but agreement on this is still pending. Emission trading is heavily discussed in the literature; for greenhouse gas emissions, trading schemes are on the edge of implementation now in various countries and firms. Energy-efficiency standards have hardly been applied for firms, except for the thermal integrity of buildings. Voluntary agreements - also named negotiated agreements or co-operative instruments - are relatively new; for energy efficiency they were first introduced around 1990, but they become increasingly popular in European countries. Support of research and development (R&D) is not one instrument, but can in fact appear in each of the previous forms. R&D subsidies have been in place in virtually all OECD countries, but also here co-operative R&D instruments are increasingly being considered more and more.

In this book we will pay specific attention to:
- Economic instruments, with the emphasis on subsidies
- Voluntary agreements
- Energy-efficiency standards
- Policy instruments to promote R&D

An important reason for focussing on these instruments is that for all these policy instruments experience exists in the Netherlands and other European countries. This means that a lot of empirical material can be gathered on the experience with these instruments.

1.3 The characterisation of policy instruments

Characteristics of policy instruments which are important in making the choice for one specific instruments are (see, e.g., CPB, 1997):
- effectiveness
- cost-effectiveness
- social acceptability.
A policy instrument is effective if it contributes to reaching the target set out by the policy. In general the question to the effectiveness of a policy instrument needs to be split into two sub-questions. The first is: what is the goal achievement - to what extent is the target set reached? The second is the actual effectiveness - what did the instrument contribute to such achievement? In general the effectiveness can be expressed in amounts of energy saved or greenhouse gas emissions avoided.

For determining the cost-effectiveness of a policy instrument the benefits of the policy instrument need to be compared with the costs. The benefits, of course, are energy conservation and avoided emissions, but there may be auxiliary benefits as well (improvement of productivity or product quality). Costs are primarily out-of-pocket expenses, but there may also be other disadvantages (e.g., loss of market position, decrease of product quality).

The cost-effectiveness can be considered from various perspectives: from the point-of-view of the government, from the point-of-view of the firms regulated, or from the point-of-view of society as a whole.

Related to the concept of cost-effectiveness is the concept of efficiency, which is often quoted in economic literature. A policy instrument is efficient if it leads to the lowest costs for society as a whole; in the analysis also external costs may be included. In the analysis of cost-effectiveness the scope often is more limited, since it merely looks at the perspective from the point of view of a specific actor, without explicitly including external costs.

Finally, the social acceptability is important. Policy instruments that may encounter fierce opposition are less likely to be implemented successfully.

In this book some attention will be paid to all these characteristics, but mostly to the first one: effectiveness. This is an especially important question for energy-efficiency policies. Energy efficiency has a historic tendency to improve (Farla, 2000), also without the presence of policy instruments. A policy instrument can contribute to the enhancement of the rate of energy-efficiency improvement. This does not make it easy to separate the effect of a specific policy instrument from the so-called autonomous developments (which are developments that would occur without policy intervention) and from the effect of other policies in place.

It is important to recognise that policy instruments are not working in isolation; there are many other actors involved (e.g. business organisations, energy companies, research institutes). The use of the metaphor policy
Instrument refers to the traditional idea that the government has a toolbox of instruments that it can apply at choice to steer the behaviour of actions into the desired direction. More recent policy research has shown that this so-called rational-instrumental approach is too simple. In practice, more actors turn out to be involved, who all influence each other to some extent. The corresponding metaphor is the system or network (see, e.g., Chapter 5 on voluntary agreements and Chapter 6 on R&D mechanisms).

Policy instruments try to influence existing situations in firms. Also without application of policy instruments, there are mechanisms that govern adoption behaviour of firms. A first step in research is often to get a better understanding of these mechanisms. For energy-efficiency investments, it is especially important to have knowledge on the economic decision making of firms, but other aspects, like information provision and existing government regulation may be important as well. To some degree such knowledge had already been provided in previous research work (Gillissen et al., 1995).

Thirdly, not only the type of policy instrument determines its operation, but perhaps even more important is the way it is applied, i.e. the design of the policy instrument in a specific situation. One important design element is the strength, e.g. the level of a carbon tax or the toughness of an energy-efficiency standard. But other elements are important as well, such as accessibility, information provision and accompanying policies. In some cases, it is even questionable whether suitable applications can be designed for the specific type of policy instrument, e.g. in the case of energy-efficiency standards. In that case design questions have to be studied first.

Note that there are other aspects that may be relevant (e.g., the government cannot be considered as a monolithic institution; there are other influences, like NGOs and public opinion), but those selected here are considered most relevant for practical implementation of policy instruments (see Figure 1.1).

1.4 Disciplinary approaches

It is impossible to study policy instruments in their full richness from a purely disciplinary viewpoint. In this interdisciplinary work analytical approaches from a number of disciplines will be used, including energy analysis, economics, policy theory and innovation theory.
Energy analysis is important as one needs to have detailed knowledge of energy use and energy-using equipment in firms in order to get a good understanding of the replacement of equipment and the introduction of new equipment. It is also important to use methods from energy analysis to measure levels of energy efficiency and the rate of energy-efficiency improvement.

Economic theory is important because it can help, among others, to understand cost benefit decision mechanisms in firms better, as well as the factors which influence these decisions, and the effects of decisions taken on a micro-level.

We use various elements from the theory of government policy in this book; both the rational-instrumental approaches and the network approaches turn out to be helpful in characterising and analysing how policy instruments affect the behaviour of actors.
Innovation theory is especially important as the knowledge mechanisms discovered in this area of scientific research may help improve our understanding of how process innovations in firms develop.

1.5 Outline

Chapter 2 of this book sets out with a description of the theories and empirical knowledge on adoption mechanisms for energy efficient technologies in firms. Chapters 3 to 6 describe the results of the research for the main policy instruments, whereas Chapter 7 provides cross-cutting results on the adoption behaviour of firms. Chapter 8 is devoted to a quantitative simulation of the effectiveness of (the combined application of) policy instruments, using a newly developed simulation model. Chapter 9 provides conclusions and policy recommendations.
CHAPTER 2

2 A FRAMEWORK FOR ANALYSING THE ADOPTION OF ENERGY-EFFICIENT TECHNOLOGIES

2.1 Introduction

Associated with economic development are increases in energy use and harmful emissions. Changes in total emissions can basically be decomposed into three components. The first component is associated with macroeconomic growth that, ceteris paribus, results in increased emissions. The second component is associated with structural change. As economies develop, their sector composition changes. Sectors are characterised by their own intensity and development of emissions over time. Changes in sector composition therefore, ceteris paribus, imply changes in macroeconomic emissions. The final component is technological change. Technological improvements tend to result in reduced emission-output ratios and thus, ceteris paribus, decrease macroeconomic emissions. Over the last decades, world-wide emissions have increased tremendously. These developments have, among others, resulted in concrete policy goals set out in the Kyoto protocol. These goals have prompted countries to develop policies oriented towards sustainable development, sustainable energy use and a reduction of emissions, such as CO$_2$, CH$_4$ and N$_2$O. Adoption of energy-efficient technologies by firms is one of the most important and promising means to reach these environmental goals (see, for example, de Groot, 1999a). A key question in the development of policies is therefore how firms respond to policy measures aimed at stimulating adoption.

---

1 This chapter was written by Henri L.F. de Groot. It draws on a set of papers that was written on the adoption of energy-saving technologies. These are de Beer et al. (2000), Canton et al. (2002), de Groot and van Soest (1999), Mulder et al. (2000), de Groot et al. (2002), and Koetse and de Groot (2000). The chapter benefited from useful comments by Arjen Gielen, Mark Koetse, Machiel Mulder, Peter Mulder, Peter Nijkamp, Martin Patel, and Erik Verhoef.

2 This statement does not deny the importance of developing new technologies. The reason to focus the attention on adoption is that (i) adoption is, in our view, at least equally important in steering technological progress than innovation (for example, Jovanovic, 1997), (ii) adoption behaviour is easier to stimulate directly with policy measures and (iii) insight on barriers to adopt is relatively limited and has - at least in the majority of economic literature - received relatively little attention, due to often pre-supposed rational behaviour that predicts adoption of ‘profitable’ technologies. For a more extensive discussion of the development of energy-efficient technologies and the possibilities for government intervention strategies, we refer to Chapter 6.
of energy-efficient technologies. A good understanding of adoption behaviour is, in other words, a prerequisite for the development of effective policy measures. The aim of this chapter is to build a framework within which adoption behaviour of firms can be analysed. This framework will be used in subsequent chapters to evaluate the effectiveness of policy measures.

It is widely recognised that many of the available energy-efficient technologies are cost-effective at current prices. It therefore seems strange that the diffusion of many of these technologies has in general been very slow up till now (a phenomenon known as the energy-efficiency paradox or the energy-efficiency gap). Empirical studies on adoption rates and diffusion patterns convincingly show that very high implicit discount rates are needed to explain the slow diffusion of technologies (see, for example, Howarth and Andersson, 1993 and Fawkes and Jacques, 1985). In the literature, different possible barriers to adoption have subsequently been proposed in order to explain this paradoxical behaviour. Also, difficulties in measuring costs and benefits of adoption have been proposed as possible explanations for the paradox.

The aim of this chapter is to present a simple, unifying economic framework that incorporates most of the available insights on the complex process of technology adoption. In doing so, we deliberately restrict the attention to a positive analysis aiming at explaining the energy-efficiency paradox. Normative implications will only be mentioned in passing and will explicitly be discussed in Chapters 3-7. The framework forms, in other words, the starting point from which the effectiveness and efficiency of policy instruments aimed at stimulating the adoption of energy-efficient technologies will be assessed in Chapters 3-6. Empirical evidence on the relevance of the framework and the relevance of the barriers presented in the framework and proposed in the theoretical literature will be provided in Chapter 7. It is also at the heart of the model that has been developed to assess the effectiveness of policy measures in the Netherlands which will be the topic of discussion in Chapter 8.

For this aim, we use a simple and stylised adoption framework. At the heart of this framework is the concept of the Net-Present-Value (NPV) which reflects the 'profitability' of technologies. A brief discussion of this concept will be provided in Section 2.2, along with the empirical problems of correctly assessing the true costs and benefits associated with adoption. As is already evident from the previous discussion, the performance of the simple NPV framework in describing and exploring actual adoption decisions is limited. Various extensions or modifications to this basic framework have been provided. These will be discussed in Section 2.3. These modifications
essentially focus on additional factors that influence adoption behaviour and that should be taken into account when analysing adoption behaviour. These factors range from the availability of information and funds to the complex ways in which firms in practice take complex decisions. Section 2.4 concludes with a critical assessment of the usefulness of a modified or extended NPV framework for determining a technology’s profitability and analysing actual adoption behaviour.

2.2 The net-present-value framework

This section explains and discusses the concept of Net-Present-Value (NPV), which is used intensively in assessments of profitability of technologies. It also elaborates on the empirical problems of correctly assessing the true costs and benefits associated with the adoption of new technologies.

2.2.1 The basic framework

As a starting point, we assume that firms are aware of all (relevant) energy-efficient technologies and their characteristics in terms of costs and benefits, that there are sufficient internal and/or external financial resources to finance investment in these technologies, that there is no uncertainty regarding the performance and costs of the technology and, finally, that firms behave rational. In such a world, firms will adopt a technology as long as it adds to their profits. The standard approach for empirically assessing the profitability of technology \( i \) is to determine its NPV (using a critical discount rate \( r \)) which equals: \(^3\)

\[
NPV_i = -I_i + \sum_{t=1}^{N} \frac{S_{it} - C_{it}}{(1 + r)^t}
\]

where \( I_i \) is the initial investment cost of technology \( i \) (at \( t=0 \)), \( N \) is the (economic) lifetime of the installed capital, \( S_{it} \) are the (energy) savings to be achieved by adopting technology \( i \) during period \( t \) (in monetary values) and \( C_{it} \) are operating and maintenance costs during period \( t \) (in monetary values). As can

\(^3\) An alternative measure for profitability is the payback period. This measure determines the number of periods that a technology should function for the accumulated (net) benefits to be equal to the costs of the technology. A critical payback period is the maximal number of periods that firms accept before the technology becomes profitable. The Net-Present-Value and Payback period are directly related to each other as is shown in Appendix I.
be seen, an NPV computation basically compares the initial investment costs with the discounted future (net) benefits of the technology under consideration. Any technology with a positive NPV should, according to this framework, be adopted. From the NPV-formula, we can straightforwardly derive a closely related figure that characterises the profitability of an investment, namely the internal discount rate ($r^I$). This discount rate is equal to the discount rate for which the NPV would be equal to zero. Rational firms will invest in a particular technology as long as the internal discount rate exceeds the critical discount rate imposed by the firm. For practical empirical work, the internal discount rate is a preferable measure to determine the profitability of a technology, as it has the characteristic of being insensitive to the size of the investment (in contrast to the NPV). It can therefore be used to rank and compare the profitability of technologies with different investment costs.\footnote{On the side, we would like to remark at this stage that the rationality, which is assumed in this framework, can be questioned. Empirical research has, for example, revealed that in the Netherlands about half of the firms indicates not to use a Payback period or a critical discount rate when deciding on investment opportunities (see Chapter 3). We will discuss this more extensively in Section 2.3.4 and in Chapter 3.}

The incorporation of market-based policy measures into this basic framework is straightforward. Market-based instruments are those instruments that foster the adoption through market signals. The best-known examples are pollution charges, subsidies, tax deductions, etc. These instruments directly affect the costs of investment and/or the benefits and maintenance costs of new technologies and therefore affect the NPV and hence the decision whether or not to adopt the technology (we will elaborate on this in the chapters dealing with the various policy instruments). Command and control regulations such as standards are less straightforward to incorporate. Technology-based standards are characterised by a limited flexibility for firms in choosing the means of achieving goals and they have a tendency to force firms to adopt a particular behaviour. They can - taking the framework very literally - be considered as standards that attach an infinite benefit to the adopter (and will thus be adopted if enforcement is sufficiently strong). Performance standards are very difficult to incorporate as they yield firms some freedom in how to meet the target that is imposed. One way would be to include the required standard as a constraint in the firm's profit maximisation problem (or cost minimisation problem), as was done in Verhoef and Nijkamp (1999). We refer to Chapter 4 for an in-depth analysis of energy-efficiency standards.
The model discussed so far is static in nature. It cannot explain one of the most prevalent stylised facts in literature on technology adoption, namely the S-shaped diffusion of technologies over time. Two broad approaches can be discerned in the literature that tries to explain the gradual diffusion of technologies (see, for example, Jaffe and Stavins, 1994b). The first combines a gradual improvement of technologies (in terms of lower costs or better performance) over time with heterogeneity among the potential adopters. When the technology under consideration is still in an early phase of development, only those firms that gain relatively much from adoption will invest. As technology gradually improves, more and more firms will find the adoption profitable. The technology will thus diffuse gradually throughout the economy. The class of models that relies on this approach is known in the literature as probit or rank models (see, for example, David, 1969; Karshenas and Stoneman, 1995). Strong empirical evidence exists, showing that firm size and market share are relevant indicators of heterogeneity that add to explaining differences in adoption behaviour (see, for example, Griliches, 1957; Mansfield, 1968). The second approach emphasises the relevance of information. It rests on the assumption that at low rates of penetration, the knowledge about the existence of a technology is also limited. Therefore, the technology is only considered by a limited number of firms. As penetration increases, more firms will realise the potential of the technology and subsequently adopt the technology. The class of models employing this approach is known as epidemic models in the literature (see, for example, Griliches, 1957; Stoneman, 1983).

A well-known problem with this framework is that many energy-efficient technologies have been estimated to be cost-effective (that is, profitable) according to standard NPV computations using ‘reasonable’ discount rates (i.e., discount rates in the range of 10–15%; the interest rate plus a risk premium), but are nevertheless not adopted (we refer to, for example, the report of the Interlaboratory Working Group (1997) for a comprehensive list of such technologies). It is beyond the scope of the current chapter to discuss and assess the complete literature that emerged in trying to explain this so-called energy-efficiency paradox (a term introduced by Shama, 1983). Instead, we will try to categorise the explanations. A first rough distinction is between explanations that stick as close as possible to the basic framework just described and essentially explain the existence of the paradox by relying on the relevance of costs or benefits that are not accounted for in the empirical analyses. These explanations that rely on hidden costs (of which transaction costs are a component) will be discussed in the remainder of this section (see
also Ostertag, 1999). In Section 2.3, we turn to deeper or more fundamental explanations that cast doubt on the assumptions on the basic framework of rational behaviour, absence of uncertainty, etc.

2.2.2 Hidden initial investment costs

Apart from the 'direct' costs of technology, costs of information gathering, research, negotiations on contract terms and of decision-making should also be considered as initial investment costs, which are, however, often difficult to obtain empirically. It is likely that costs used in standard NPV calculations differ from reality in this respect, since these costs will to a large extent be firm specific, depending mainly on economic, organisational and human capital factors (economies of scale, expertise, etc.). It is, for example, likely that standard NPV calculations underestimate these costs for especially Small and Medium sized Enterprises (SME’s) given their limited possibilities for exploiting economies of scale and scope in gathering information (see, for example, Hein and Blok (1995) for an assessment of the degree with which the share of information costs decreases with the size of the investment). When considering the adoption of a technology in isolation, the underestimation of costs tends to result in the overestimation of the degree of adoption. Note that when comparing the adoption of different technologies, it is the difference in hidden costs that matters for explaining adoption behaviour and not the presence of hidden costs per se (see Ostertag, 1999). These differences are relevant when considering, for example, the switch from a technology that is currently being used to a completely new technology on which no knowledge exists in the firm considering the switch.

2.2.3 Hidden annual costs

Also in assessing annual costs, problems can arise. Capital costs including costs of raising funds tend to differ between firms. For example, it is known that SME’s (among which are many starters) generally face higher business risk (see Ballantine et al., 1993). This tends to result in higher interest rates being charged in firm-specific contracts. Empirical information on the precise terms of the contract is often difficult to obtain. Some evidence for this is provided by Ballantine et al. (1993) who show that the level of the discount rate is larger for SME’s than for large(r) companies, corrected for the different risk-return ratios of these two categories.
Costs that also may be underestimated are annual costs of maintenance and operation associated with the technology. Related to this is that many technologies are largely indivisible and are characterised by a minimum (efficient) scale of operation. Or, alternatively, high-capacity appliances are often cheaper per unit of capacity than low-capacity appliances. Also, small firms tend to be short of human resources, know-how and expertise (see, for example, Kleinknecht, 1989). These factors - referring to the limited possibilities of exploiting economies of scale - should appropriately be accounted for when determining the profitability of adopting a particular technology. We refer to Ostertag (1999) for a study in which she illustrates the relevance of such costs for a variety of cases.

A final cost-related problem could be that currently used technologies have to be depreciated before new technologies are purchased. In essence, the annual depreciation costs of the old and not yet fully depreciated technology should be considered as annual costs of the new technology. Results by de Groot et al. (1999) and Velthuijsen (1995) show that this can be an important barrier to implementation of energy-efficient technologies. It should be mentioned however, that this barrier does not influence the discrete adoption decision but rather the timing of adoption. It is therefore possible that it is just a matter of time before certain technologies will be implemented (ceteris paribus).

2.2.4 Hidden annual savings

One of the variables influencing the savings potential of a technology is the total amount of energy currently used in a firm (and the price paid for energy). There is evidence that in many firms the total use of energy and energy costs are too low to be of interest. This essentially means that the energy base over which savings can be made is too low for the technology to ever be profitable (taking into account information costs, set-up costs, etc.). Also perceptions of firms are important in this respect. Even though for firms with a low energy bill certain investments may be profitable, energy costs are often seen as part of ‘other costs’ such as furniture, telephones, etc. and receive little attention in investment decisions. Results by Gillissen et al. (1995) confirm that a small current energy bill is an important barrier. Velthuijsen (1995) also provides

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5 This explanation obviously suggests that NPV calculations are being performed ‘wrongly’ by researchers studying the problem, in the sense that they typically ignore the fact that economic lifetimes are smaller than technological lifetimes. Clearly, most of the issues explored in Sections 2.2.2-2.2.4 can in the end be reduced to measurement issues that are not appropriately controlled for in the applied analyses.
significant evidence that the size of the current energy bill is a factor of large influence in the investment decision. Furthermore, large energy users pay relatively low prices in most countries for energy based on special contracts with energy suppliers, which should appropriately be accounted for in the application of the NPV framework (as is often done in applied work; see, for instance, Chapter 3).

2.3 Extensions of the standard framework

So far, we have strictly considered the simple NPV rule. Empirical evidence has quite convincingly shown that this simple framework does not fully suffice to explain empirically observed adoption behaviour. Though relevant, measurement problems as discussed in the previous section are unlikely to fully explain the lack of explanatory power of the simple framework. In this section, we therefore turn to a discussion of contributions to literature on technology adoption that have provided alternative or additional factors that have to be considered when describing adoption behaviour. Most of these contributions can be seen as extensions or modifications of the conventional NPV framework discussed in Section 2.2.

2.3.1 Information as a precondition

Information is an essential precondition for developing sound investment strategies (see, for example, Howarth and Sanstad, 1995). The gathering of information regarding the existence of technologies is the first essential step in any adoption process. The relevance of information (or the absence thereof) for understanding adoption practices has especially been emphasised in relation to technology adoption by SME's (for example, Kleinknecht, 1989; Gillissen et al., 1995; Velthuijsen, 1995; de Groot et al., 1999). These studies all reveal that a significant part of the total available energy-efficient technologies is unknown and that this information gap is especially large in small firms facing limited competition and spending relatively little on investments (see also Chapter 7). It seems fair to conclude from these studies that size and also the typical environment in which firms operate, contribute to an explanation of the magnitude of the information gap.

Apart from the knowledge on the existence of energy-efficient technologies, many firms also turn out to be uninformed about policy instruments and institutions for innovation support. Kleinknecht (1989) for
example shows that a large number of Dutch companies has been uninformed about instruments and/or institutions which try to stimulate the adoption of environmentally favourable technologies in the Netherlands.

As to the reasons for the (large) information gaps, a number of factors can be discerned. Kleinknecht (1989) refers to the difficulties of finding technical information and know-how, especially for small firms. Others mention a lack of financial as well as human capital resources (see, for example, McGregor and Gomes, 1999; Bianchi and Noci, 1998; Lybaert, 1998). This is consistent with the strong reliance of SME’s on their own accumulated experience when making decisions (Rice and Hamilton, 1979). All these factors are in one way or the other related to the limited possibilities for exploiting economies of scale and scope and can to a large extent explain the large information gap regarding the existence of energy-efficient technologies.

There is an evident role for the government or government agencies to provide the information which has important elements of a public good. This can be done directly by, for example, information campaigns, labelling, etc., or more indirectly via stimulating co-operation among firms by using, for example, negotiated agreements (see Chapters 5 and 7).

2.3.2 Capital as a precondition

A second precondition that has to be met, before adoption can take place, is the availability of capital. There are some strong indications that firms, and especially SME’s, are restrained in their financial resources (often related to specific risks that SME’s face). Kleinknecht (1989) shows that a lack of capital is the most important barrier regarding general innovation investments. Lack of capital not only appeared to be a large constraint in SME’s in absolute terms, it also appeared significantly more important in SME’s than in large(r) firms (see also Winker, 1999). Although these results relate to innovation in general, they are suggestive for lack of capital being an important barrier to investing in energy-efficient technologies as well. More specifically focused on barriers to adoption of energy-efficient technologies in the Netherlands, Velthuijsen (1995) provides evidence on the relevance of financing constraints as a barrier to adoption.

6 The study by Kleinknecht reveals that of firms with 10 to 19 (20 to 49) employees, nearly 60% (50%) considered lack of capital an important barrier.
7 See also Bianchi and Noci (1998) and Hirst and Brown (1990).
Apart from the importance of financial constraints in general, the lack of internal capital appears to be a larger constraint than the lack of external capital (Winker, 1999). This result is confirmed by Gillissen et al. (1995). Their results show the significance of missing financial resources, especially internal ones. It is unclear, however, if and to what extent a lack of internal financial resources is a constraint in itself or whether it reflects the fact that a lack of equity induces credit rationing by banks, thus resulting in an external financial constraint in the end (see Chapter 7 for more empirical evidence).

In case banks and other financial institutions are unwilling to finance seemingly profitable investments, we can conclude that the capital market possibly contains some failures. The assertion of failures in the financial markets should, however, be carefully made since we have limited information on the exact reasons for credit rationing. It is well possible that certain financial requirements (such as liquidity and solvability) prevent banks to lend (more) money because of the overall risk of default, to which the (perceived) risk attached to energy-efficiency investments only contributes to a small extent.

2.3.3 Uncertainty and the option value of waiting

The simple and stylised NPV-framework presented in Section 2.2 assumes the absence of uncertainty. This subsection emphasises the importance of appropriately accounting for uncertainty. The basis logic according to which uncertainty affects the decision whether or not to adopt is simple (see, for example, Pindyck, 1991; Dixit and Pindyck, 1994). Presupposing some degree of irreversibility of the investment, 

\[ \text{uncertainty creates an option value of waiting.} \]

That is, in the presence of uncertainty it pays for a firm to wait for new information to arrive. The NPV that firms require when taking into account uncertainty is larger than the NPV that results in the absence of uncertainty. Firms in others words require a compensation for the uncertainty that they face. This essentially results from the fact that firms want to avoid investing in technologies that ex post turn out to be non-profitable in combination with the fact that more or new information becomes available over time. This logic results in firms putting a mark-up on the critical discount rate that they apply. Box 2.1 briefly explains the theory of investing under uncertainty.

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\[ \text{The idea that investments in energy-saving projects have some important elements of sunkness is widely accepted. Blown-in wall insulation, for example, cannot be resold. In addition, one can rely on Akerlof’s Lemons principle according to which investments cannot easily be resold (see Metcalf, 1994, for this argument).} \]
Box 2.1 Investing under uncertainty.

The aim of this box is to derive in a very simple and basic framework under what conditions uncertainty and growth of the value of a project can result in delaying an investment by fully rational and profit-maximising firms. For this aim, a model is presented that can be seen as a slight generalisation of the model developed in Chapter 3 of Dixit and Pindyck (1994). This exercise serves two related goals. First, it gives some intuitive feeling for the effects that uncertainty has on decisions (not) to invest. Secondly, it enables us to explain the ways in which option values are computed, a concept that plays a central role in theories of investment under uncertainty.

The model that we develop extends the basic framework of Section 2.2.1 to a stochastic setting in which there is uncertainty about future payoffs. Suppose a firm can invest in a project at a cost equal to \( I \). The returns to this project are uncertain and are taken to be equal to the price of the product that can be produced by investing in the project (i.e. there are no operating costs for simplicity and without loss of generality). At time \( t=0 \), the return is equal to \( V_0 \). From time \( t=1 \) onwards, the return equals \((1+u)V_0\) with probability \( q \), and \((1-d)V_0\) with probability \((1-q)\). We assume, without loss of generality, that the project is not profitable if the return ends up low (that is, we assume \( I > V_0(1-d)(1+r)/r \)). The risk-free interest rate is taken to be equal to \( r \). The firm basically has three opportunities. Either it invests immediately, or it will invest tomorrow, or it will never invest. Let us calculate the Net-Present-Value of these three options. Investing immediately yields in expected terms and constant prices of time \( t=0 \)

\[
\text{(B1)} \quad NPV^I = -I + V_0 + q \sum_{t=1}^{\infty} \frac{V_0(1+u)}{(1+r)^t} + (1-q) \sum_{t=1}^{\infty} \frac{V_0(1-d)}{(1+r)^t}
\]

where the index \( I \) indicates that the firm will invest immediately. Waiting one period and investing then will only be done if the return has gone up (since the project was assumed to be not profitable in the case the return decreases). This yields in constant prices of time \( t=0 \)

\[
\text{(B2)} \quad NPV^W = - \frac{q I}{1+r} + q \sum_{t=1}^{\infty} \frac{V_0(1+u)}{(1+r)^t}
\]

In case \( NPV^W > NPV^d \), waiting is optimal for the firm. The costs of waiting consist of foregone revenues at time \( t=0 \). The benefits are that at time \( t=1 \) information is revealed which has value to the firm in that it enables the firm to avoid investing in a project which looks profitable ex-ante but turns out to be unprofitable ex-post. In addition, the present discounted cost of the project is
The difference in the return to the two investment strategies can be called the ‘value of waiting’ and equals

$$NPV^W - NPV^I = I \left[ \frac{1+r-q}{1+r} \right] - V_0 \left[ \frac{r + (1-q)(1-d)}{r} \right].$$

Differentiating this value with respect to the relevant parameters reveals that this option value of waiting positively depends on the sunk cost that has to be made, the potential downward jump in returns, the risk free rate of interest and negatively on the return on the project at time $t=0$, and the probability that the return on the project will increase. It is interesting to note that the option value of waiting does not depend on the size of the potential upward jump in the return on the project. Provided that the ex-post return to the project is positive if the return increases, the firm does not worry about the extent to which the value of the project will increase in its decision whether and when to invest. This is an example of the bad-news principle as spelled out by Bernanke (1983).

In this slightly extended framework of Section 2.2.1, two reasons can be discerned for rational firms to optimally delay their investment in new technologies:

- Growth of value of the project

Let us, for the time being, suppose that there is no uncertainty and that the return to the project will increase during the next period (so the NPV is and will remain positive at any point in time). More precisely, we assume that $q=1$ and $u>0$. In this case, firms will invest at $t=1$ instead of investing immediately if the ratio between the cost of the project and its return at time $t=0$ exceeds some threshold. More precisely, delaying the investment is optimal if $I/V_0 > (1+r)/r$. The optimality of delaying the investment is thus more likely; the larger the cost of the investment project, the larger the interest rate (i.e., the larger the future is discounted off) and the smaller the initial value of the project will be. This can be explained, since delaying the investment yields the firm a gain in terms of a reduced (discounted) cost of the project. If this return is large relative to the cost in terms of the foregone return on the project at time $t=0$, the

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9 A more extended version of such a model in which costs and benefits are surveyed further can be found in de Groot (1999b). Another deterministic (and richer) framework is provided in Jaffe and Stavins (1994a).
firm will favour a delay of the project. One can, of course, easily see that a similar result will apply if the future cost of the project will strongly decrease.\footnote{To illustrate this, suppose that a project yields a certain return in any period equal to \( V_0 \) and that the cost of the project equals \( I \) at time \( t=0 \) and decreases to \((1-d)I\) at time \( t=1 \). In this case, it is easily shown that the project will be delayed in case \( I(r+d)/(1+r)>V_0 \). This result indicates that a sufficient decline in the cost of the project in combination with a large discount rate and a low return that is foregone by delaying the investment will favour delays.}

- **Uncertainty**

We now turn to the effects of uncertainty on the option value of the investment. The expectation and variance of the return at time \( t=1 \) are equal to  

\[
E(V_1) = V_0[q(1+u)+(1-q)(1-d)] \quad \text{and} \quad V(V_1) = E(V_1^2) - E(V_1)^2 = q(1-q)(u+d)^2,
\]

respectively. Now consider the special case in which \( q = d/(u+d) \). In this special case, an equi-proportionate increase in both \( u \) and \( d \) leaves the expected return on the investment as well as the probability of an upward swing in the return unaffected, while it increases the variance of the return. This is exactly the type of experiment we would like to perform when considering the effects of uncertainty of investment behaviour. We have just seen that an increase in the size of the downward jump of the return will result in firms being more likely to delay the investment. Hence, an increase in uncertainty, caused by an equi-proportionate increase in \( u \) and \( d \) (leaving the expected return on the project and the probabilities of upward and downward jump unaffected) will, ceteris paribus, result in more projects being delayed. This is the basic result of the theory of investment under uncertainty. It can be shown to generalise to more realistic and complex settings as shown in, for example, Dixit and Pindyck (1994), Farzin et al. (1998) and de Groot et al. (2002).

The relevance of uncertainties associated with energy-saving technologies is easy to illustrate. First, there is uncertainty regarding the future prices and qualities of currently used and future technologies. If a certain technology has just been introduced to the market, it can be worthwhile for a firm to wait for its price to go down. In this case, a firm has to weigh the savings in costs against the foregone savings of the technology during the period of delay. Second, there is uncertainty regarding the future level and the volatility of interest rates and the interest costs associated with them (see, for example, Calcagnini and Iacobucci, 1997, for the impact of interest rate volatility on investment demand). Again, in case a firm faces large uncertainty regarding future interest rates, it may be worthwhile to delay the investment and wait for new information to arise. Third, the potential savings of energy-efficient
technologies are uncertain. Standard NPV calculations assume the price of energy to be predictable, which is not the case in reality. Moreover, the performance of the technology in terms of energy saving is usually uncertain as well (see, for example, Hirst and Brown, 1990). Unforeseen drops in energy prices and unexpectedly low energy savings can make a technology unprofitable ex-post, opposed to its expected profitability ex-ante. Finally, there is uncertainty regarding future policies. This policy-induced uncertainty is particularly relevant in relation to environmental problems given the uncertainty with respect to the timing and implementation of the Kyoto protocol, subsidy schemes, the stringency of environmental regulation, etc.

Firms can, however, reduce the risk associated with energy-price uncertainty. Other investments, either real or monetary, whose profitabilities are negatively correlated with the profitability of energy-related investments, could provide a hedge against the risk of energy-related investments. The risk associated with energy-related investments is then highly overestimated. Howarth and Sanstad (1995) argue, however, that especially households and small firms’ account for the high Implicit Discount Rates (as a proxy for uncertainty and risk) found in the literature. These economic agents do not have the financial resources and scale of operation to hedge, and therefore must bear the full risk of energy-related investments.

Empirical studies assessing the relevance of uncertainties for explaining investment behaviour have recently been reviewed in Bo and Sterken (2000). They emphasise that uncertainties are difficult to measure, that various measures have been used in empirical practice and that assessing the relevance of irreversibilities is empirically difficult. The empirical evidence that they discuss clearly indicates a negative effect of uncertainty on investments.11

An attempt to illustrate the potential empirical relevance of uncertainty for the diffusion of energy-efficient technologies was made in a study by van Soest and de Groot (2000). They assess the consequences of the liberalisation of the US gas market for the penetration of energy-efficient technologies. On the basis of price developments on the gas market, they hypothesise that the liberalisation has resulted in a drop in gas prices and an increase in the volatility of gas prices. The lower gas prices clearly have a depressing effect on the profitability of investments in energy-efficient technologies. The increased volatility of energy-prices – according to the theory of investing under uncertainty – will increase the option value of waiting which also tends to delay

11 It is beyond the scope of this chapter to discuss the studies that have been done on assessing the effects of uncertainty on investments. We refer the interested reader to, among others, Ghosal and Loungani (2000), Price (1995), Federer (1993) and Huizinga (1993).
the investment in energy-efficient technology. Based on a stylised simulation exercise, they derive that the increased uncertainty decreases the probability that adoption of a postulated superior technology takes place within 10 years from 90% to 79% whereas the lower energy price further reduces this probability to 41%. Although tentative, these conclusions give some feeling for the empirical relevance of the contribution of uncertainty to explaining the slow diffusion of energy-efficient technologies.

Despite the appeal of the logic of the theory of investing under uncertainty, its relevance for explaining the energy-efficiency paradox is not uncontested. Most criticisms relate to the strong assumptions underlying the theory, and which are necessary to explain the high implicit discount rates. Jaffe and Stavins (1994a) emphasise that the theory of investment under uncertainty assumes that the only cost of delaying the investment is the foregone energy saving. This is obviously not always true. Firms that struggle early with the investments may, for example, gain first mover advantages, and learning-by-doing and learning-by-using may be important fruits of early adoption (see de Groot (1999b) and de Groot (2002) for a survey on the potential justifications for early and late action aimed at curbing climate change). Furthermore, they argue that there may be simply no way of disentangling theoretically and empirically the effects of discounting, uncertainty over price developments, and informational and principal-agent based problems on the implicit discount rates. In the end, the conclusion regarding the relevance of uncertainty for understanding the energy-efficiency paradox is that the jury is still out. Empirical evidence exists that strongly indicates the existence of a negative relationship between uncertainty and investments, the contribution of uncertainty to explaining the relatively high hurdle rates is substantial, but at the same time some of the assumptions on which the theory rests can be criticised.

2.3.4 Non-rational behaviour

Our analysis so far presumed rational behaviour of firms deciding on whether or not to invest in technologies. The best-known critique on this framework goes back to the seminal work of Simon (1955). He casts doubt on the possibilities of firms to acquire and process all relevant information regarding current and future possible states of the world that are needed to

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12 A similar remark has been made by Sanstad et al. (1995) on the usefulness of uncertainty-based explanations for high implicit discount rates applied by consumers.
rationally decide on the adoption of a technology. Instead, he proposes that firms often behave according to a 'satisficing principle', where they look for 'satisfactory profits' instead of maximum profits, and apply rules of thumb and routines. This approach has been elaborated upon in the evolutionary theory (for example, Nelson and Winter, 1982).

Some evidence on the relevance of such theories is provided in, for example, Jaffe and Stavins (1995) and Hassett and Metcalf (1995). They show that adoption subsidies, which are granted upon adoption of the technology, are a factor three to eight more effective than 'equivalent' energy taxes which accrue to the firm over the lifetime of the technology. Financial analysis building on the rational-behaviour hypothesis would suggest that they should be the same. The results reveal that adoption decisions are more sensitive to up-front cost-benefit considerations than to longer-term benefits (Jaffe et al., 2000). Non-rational behaviour is clearly the most logical candidate to explain this result.\footnote{Note that also uncertainty can play a role here as explained in Section 2.3.3. Uncertainty ‘implicitly’ increases the discount rate and thereby also increases the weight attached to current benefits as compared to future benefits.}

### 2.3.5 Complementarities among technologies and network externalities

The basic framework of Section 2.2 considered technologies in isolation. This assumption can be challenged on the basis of at least two considerations. First, different technologies within a firm often do not function in isolation. The presence of a particular technology can reinforce the performance of another technology and thus affect the Net-Present-Value of that technology. In general, good arguments can be made for the existence of returns to diversity (an idea building on seminal papers by Dixit and Stiglitz (1977) and Ethier (1982) and subsequently explored intensively in the endogenous growth literature; see, for example, de Groot and Nahuis, 2002; Grossman and Helpman, 1991; Romer, 1990). The consequences of such returns to diversity for the diffusion of energy-efficient technologies were recently explored in Mulder et al. (2000). They show that in the presence of complementarities and gradually improving technologies, firms continue to invest in relatively old technologies which – when considered in isolation – are inferior to newer technologies. This results in only a gradual 'phasing out' of old technologies, instead of the immediate replacement that would be predicted by this type of model when not considering the complementarities.
Second, the performance of a technology in one firm can be reinforced by the presence of that same technology in another firm. In this case, there are network-externalities (see Besen and Farrell (1994) and Katz and Shapiro (1994) for seminal contributions). Network externalities can explain why it is difficult for a diffusion process to get started initially. At the other extreme, technologies subject to network externalities are sensitive to ‘lock-ins’ in inferior technologies once the diffusion process has sufficiently progressed. Theories building on these network externalities have especially been applied so far to issues related to information and communication technologies. They are, however, relevant for understanding diffusion patterns of any sort of technology, including environmental technologies. Reliability and service of suppliers of technologies and economies of scale and scope for suppliers of technologies are just two examples to illustrate their relevance (see, for example, Chapter 6).

2.3.6 Learning and the dynamic evolution of technological performance

In its simplest setting, the framework developed in Section 2.2.1 assumes the costs and benefits of technology adoption as constant over time (or, more precisely, to be independent of the adoption time). This assumption is at odds with a wealth of empirical evidence revealing the gradual decline of costs (or the gradual improvement of performance) of technologies. This empirical evidence has been gathered in studies determining so-called learning curves or experience curves (see OECD/IEA, 2000, for a survey of knowledge on experience curves with regard to energy-efficient technologies). What this literature has shown is that the decline of costs or the improved performance is conditional upon the penetration of the technology. From an analytical point of view, it is relevant to make the distinction between learning that is internal to the firm (that is, the returns only accrue to the firm adopting the technology) and learning that is external (that is, adoption results in an overall decline of the costs that accrues to all subsequent investors in the technology). In the former case – assuming predictability of the development of the technology – the learning effect can be incorporated in the assessment of the profitability of the technology and the standard framework is still valid. In the latter case, however, firms can have an incentive to wait for other firms to adopt and to only buy the technology after it has sufficiently improved (see also Box 2.1). This can create a co-ordination problem in the sense that no firm is willing to start adopting the technology (for example, Fudenberg and Tirole, 1983).
A final (implicit) assumption in the framework of Section 2.2 is that the ‘total’ NPV of a technology is relevant for determining whether or not a technology is adopted. This assumption neglects the potential relevance of the distribution of the benefits of adoption of various actors that are affected by the adoption. There is a wide variety of arguments that can be put forward as to why these distributional issues are relevant for understanding actual adoption behaviour and technology diffusion. These arguments are generally classified under the heading of agency problems.

The simplest and best known example of an agency problem regards the relationship between a landlord and a tenant in which the landlord pays for the investment in, for example, insulation, while the tenant pays for the utilities (and thus reaps the benefits of the investment). Unless the landlord can acquire (a sufficiently large) part of the savings by, for example, increasing the rent of the apartment, he will have no incentive to invest in the insulation. Agency problems can also exist within a firm. A simple example is the situation of a firm with different departments, each with their own budget, in which one department is responsible for the acquisition of equipment and another department is responsible for the payment of utilities. Again, situations can arise in which the department that buys the equipment resists the acquisition of energy-efficient but relatively expensive technologies since these do not pay-off in terms of the performance of the department (see, for example, DeCanio, 1998).

Agency problems can also have important temporal aspects. Take the above example of the landlord and the tenant. It would be optimal for both the landlord and the tenant to agree in advance about a distribution of the benefits of the insulation in such a way that both would be willing to accept the insulation. Signing a contract ex-ante in which the tenant agrees to pay a higher rent once the apartment has been insulated could do this. Signing such a contract is ex-ante profitable for the tenant. However, ex-post he has an incentive to renege on the contract since once the insulation is there, it cannot be made ineffective by the landlord. This problem is known as the ‘hold-up’

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14 The distribution is in a purely rational framework argued to be irrelevant. If the ‘total’ NPV is positive, there is always a distribution of benefits feasible for which none of the actors are the worse. It is in the interest of those actors who are strongly affected in a positive way by the adoption to propose such a distribution of benefits in order to let the adoption take place.
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problem. It is evidently more relevant the larger the difficulties of signing a contract between the parties engaged.

A second class of agency problems arises in the light of the age distribution of the actors involved. This has been emphasised in Canton et al. (2002). Their basic claim is that the adoption of a technology tends to affect different age groups differently. Younger workers are generally more flexible and have more time to recoup the costs associated with the adoption of a superior technology. Older workers on the other hand are less flexible, have already gained experience in working with old, inferior technology and have relatively little time to experience the gains associated with the new technology. This may, for example, partly explain why the QWERTY keyboard is still in use. It is well known that switching to a keyboard with an alternative ordering of keys would improve the efficiency of typewriting. There are, however, costs of transition involved since ‘old’ typists would have to get acquainted with a new keyboard. Therefore, they have an incentive to resist the adoption of the new technology. For ‘young’ people, however, the costs of adoption would be negligible since they would still have to learn to type from scratch.

2.4 Evaluation and conclusion

The economists’ framework for analysing adoption behaviour regarding energy-efficient technologies is often criticised. Arguments against its relevance that have been put forward are that owners and managers of firms lack the time, the personnel and the resources to make decisions on adopting energy-efficient technologies in the manner an economist would expect a rational agent to do. Low planning procedures (Matthews and Scott, 1995), unstructured and unplanned processes, reliance on intuition (Peterson, 1988) and extensive reliance on own accumulated experience (Rice and Hamilton, 1979) seem to be common in most firms. Furthermore, the notion of ‘satisficing’ instead of maximising behaviour in complex environments may sometimes be more suited to describe the reality of decision making in especially SME's (see, for example, DeCanio, 1993). Also the relevance of uncertainties, distributional issues, informational, learning effects and capital constraints are often not incorporated in analyses based on the conventional NPV framework. As indicated in Section 2.3, important steps forward have been made, however, in trying to assess and incorporate the relevance of such factors. This has not resulted in one uniform and integrated framework, but it is easily established that the different theories complement each other.
In the end, we think that the simple framework laid down in this chapter with the modifications and extensions that were proposed, is well suited for describing crucial elements of actual adoption behaviour, which are consistent with insights from empirical research. The extensions focussed especially on the key role of availability of information and funds as preconditions for adoption to take place, the importance of taking into account uncertainties, complementarities and (dynamic) learning effects, and the importance of the division of benefits among the various stakeholders that are involved in the decision-making process regarding adoption of new technologies. These elements are not intrinsically incompatible with NPV calculations, but are often ignored in these calculations primarily due to their theoretical and empirical complexities. Taken together, however, these factors can bring us reasonably far in explaining the energy-efficiency gap and resolving the energy-efficiency paradox.

Using the insights from this chapter, we will now turn to the evaluation of the effectiveness of three specific policy instruments that have been used in the Netherlands. Chapter 3 focuses on subsidies that aim at improving the profitability of technology adoption and also have a function of indirectly providing information on available energy-efficient technologies (a so-called demonstration value). Chapter 4 deals with energy-efficiency standards. It emphasises the difficulties of appropriately designing normative instruments in situations where there is asymmetric information between the regulator (the government) and the firms that will be subjected to the standards. Chapter 5 studies in-depth the effectiveness of negotiated agreements. An important mechanism through which the negotiated agreements result in improved energy efficiency is that it improves the information of firms participating in the agreement on the available technological options. They can help, in other words, in ameliorating the information problems emphasised in this chapter. Asymmetric information is again an important potential problem in effectively designing the agreements. Chapter 6 shifts the attention from technology adoption towards technology development. By means of an in-depth analysis of four technology case studies, the importance of complementary benefits that go beyond energy-efficiency is illustrated. Also the relevance of uncertainties and risk-taking behaviour in these stages of development of new technologies are found to be pervasive. The empirical part is concluded with an overall survey of adoption behaviour of individual firms. This chapter pays attention to the importance of the external environment of firms, both for understanding differences in adoption behaviour as well as for understanding differences in the effectiveness of various policy measures. Also the relevance of firm
heterogeneity in terms of size, energy-intensity, information availability, etc. as argued to be relevant in this chapter are empirically tested. The study is concluded with a modelling exercise in Chapter 8. The model is built on the framework developed in this chapter and fed with empirical regularities established in the several chapters.
CHAPTER 3

3 SUBSIDISING THE ADOPTION OF ENERGY-EFFICIENT TECHNOLOGIES: AN EMPIRICAL ANALYSIS OF THE FREE-RIDER EFFECT

3.1 Introduction

Subsidies are intensively used to steer the adoption of energy-efficient technologies. Their cost-effectiveness is disputed for a variety of reasons. First, in a competitive economy, subsidies increase aggregate emissions, which is essentially caused by the income transfer implied by the subsidy (and the associated entry of new firms or enlargement of existing firms). Subsidies - in other words - do not provide an incentive to reduce aggregate utilisation of energy. Taxes are in this context a more effective instrument in the sense that they result in declining aggregate emissions (for example, Baumol and Oates, 1988). Second, taxes generate revenues that can be used to reduce other distortionary taxes and to increase welfare (see the literature on the double dividend as discussed in, for example, de Mooij, 1999). Third, subsidies involve administration costs that tend to be larger than those for tax measures. These costs increase with the specificity of the subsidy program. Fourth, subsidies are often considered to be inefficient since they involve free riders. In this context, free riders are defined as agents who make use of the subsidy, but would have undertaken the subsidised action anyway - and without any delay (see, for example, Train, 1994). We will use this definition throughout this chapter. Because of these free riders, large public expenditures can be required per unit of effect, raising an issue of feasibility of granting subsidies in the presence of fiscal constraints (for example, Jaffe et al., 2000). Advocates of subsidies emphasise the information constraints that can be overcome by the provision of subsidies. They emphasise the relevance of demonstration effects that can result from subsidy programs. Furthermore, evidence exists that adoption subsidies are a factor three to eight more effective than ‘equivalent’ energy taxes, although financial analysis would suggest that they should be the

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15 This chapter has been written by Rob Aalbers, Henri L.F. de Groot, Ioulia V. Ossokina and Herman R.J. Vollebergh. Senter is gratefully acknowledged for providing us with the data. This chapter builds on a study performed in the context of an IBO (Interdepartementaal Beleids Onderzoek) of the Dutch government. This study was done jointly with Ecofys, Utrecht. Arjen Gielen, Aafke Reinders, Karin Michels and Peter Mulder provided useful comments.
same (see, for example, Jaffe and Stavins, 1995, and Hassett and Metcalf, 1995 for empirical analyses revealing this result). Adoption decisions are thus, according to these insights, more sensitive to up-front cost-benefit considerations than to longer-term benefits (Jaffe et al., 2000). Note that these results suggest that (up-front) taxes on the purchase of inefficient appliances are to be preferred above energy taxes and can be equally effective as up-front subsidies.

The basic aim of this chapter is to determine the number of free riders in the population of agents who participated in two Dutch subsidy programs aimed at stimulating the adoption of energy-efficient technologies, taking into account the potential relevance of informational mechanisms. For this aim, we use two distinct methods. The first method classifies agents on the basis of a confrontation of actual and required profitability of investment projects (in this case, energy-efficient technologies). In this method, agents are classified as free riders if they obtained the subsidy, while judging the technology profitable according to their own investment criteria in the absence of the subsidy. The classification in the second method is based on stated behaviour obtained by a survey. In both methods, the relevance of demonstration effects is determined using survey methods by which firms are asked about their information set before and after the introduction of the subsidy program. The analysis is based on a tax rebate scheme in the profit sector and a subsidy programme in the non-profit sector in the Netherlands. Both methods enable us to explicitly distinguish between (i) firms that had the information about the technology and knew it was profitable (rational firms), (ii) firms that learned about the technology as a result of the subsidy program and then realised that the technology was profitable (information-constrained firms), and (iii) firms for which the technology was not profitable anyway. This distinction allows us to draw conclusions - among others - on the relevance of the demonstration effect that subsidies can have. After the classification, we empirically determine the cost-effectiveness of subsidy schemes by calculating the amount of energy saved per guilder of subsidy. An overview will be given per technology, both with and without controlling for free riders. The results obtained can be used for evaluating and re-designing the subsidies in order to improve their efficiency.

The organisation of the chapter is as follows. Section 3.2 concisely discusses the related literature. Section 3.3 describes the two methods that we use to classify firms. The data are discussed in Section 3.4. Section 3.5 presents the classification of firms. In Section 3.6, we make an attempt to determine the cost-effectiveness of subsidies controlling for free riding and the possibility of
subsidies having a demonstration value. The analysis distinguishes between different subsidised technologies and discusses the possibilities for redesigning and improving the cost-effectiveness of subsidies. Section 3.7 offers a conclusion.

3.2 Literature review

Research by economists on the subject of the effectiveness of subsidies in stimulating the adoption of energy-efficient technologies dates back as far as 1986, when the seminal theoretical paper by Downing and White appeared, comparing the effects of different instruments on technology adoption. A large body of theoretical literature followed the paper on the subject (see Carraro, 1999, for an overview). Empirical studies on the effectiveness of subsidies are scarce. Some exceptions are studies that assess subsidy programs directed on the stimulation of new technology adoption (for example, Ropke and Jorgensen, 1992) and Demand Side Management (DSM) programs in especially the electricity sector (for example, Hirst, 1992, Joskow and Marton, 1992 and Malm, 1996). The studies compare the costs and benefits (in terms of the energy savings) of the programs, and estimate the fraction of free riders in them. The results of the free rider estimations vary considerably (between 17% and 89%), just as the estimation methods do.

Studies estimating the number of free riders can usefully be separated into two groups: those based on surveys and those using non-survey-based methods. Studies of the first group consider the subsidy program participants and determine whether an agent is a free rider on the basis of his answer to the question whether the investment under consideration would have been undertaken anyway (that is, also in the absence of the subsidy; see, for example, Haugland, 1996). A considerable advantage of this approach is the relatively limited data requirements since the analysis is made on the basis of the group of participants in the subsidy program. This group is relatively easy to define, and the authorities supervising the subsidy program usually gather the information concerning its members. The problems with the approach under consideration are those common to ex-post survey-based estimates. Well-known problems include response bias, poor customer recall and the bias associated with survey wording (see Tolkin and Rathburn, 1992, and Krause,

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16 DSM projects directed to energy saving are projects started by electricity companies in order to promote the energy saving by consumers. These projects most often use discounts on the investment costs of energy efficient technologies and information provision (see, for example, Eto et al., 1996).
The studies of the second group aim at estimating the probability that an agent is a free rider. For this aim, they determine the probability of buying the subsidised technology anyway (the pre-disposition to buy the energy-efficient technology) and the probability of participating in the subsidy program. The probability of being a free rider is then simply derived as the multiple of the two latter probabilities. This approach avoids the need to use survey techniques to determine the number of free riders, and thus prevents the problems mentioned above. However, to determine the probability of taking part in the subsidy program, which is necessary for implementing this approach, data are not only required on the subsidy program participants, but also on the non-participants. This raises a difficult issue of the definition of the group of non-participants, and the need to acquire data on them. Also, determining the pre-disposition to buy energy-efficient technologies anyway requires data, that are not readily available. The solution to this data problem may be either using simulated data or using surveys to obtain some intermediary inputs to the analysis. Train (1994) used the former approach. Although it illustrates the mechanisms that are relevant in determining the number of free riders, it does not allow for conclusions about ‘real’ existing subsidy schemes. The latter approach was used in, for example, Malm (1996).

In addition to increasing the benefits (or reducing the costs) associated with the adoption of an energy-efficient technology, a subsidy can also provide information about the existence of (new) technologies to the agents. This demonstration effect of subsidy programs - or alternatively, the attention value effect - has so far to our knowledge not been studied explicitly in the framework of the estimation of the number of free riders. The importance of the effect of information dissemination for technology adoption is, however, widely acknowledged in the literature on technology adoption (see, for example, Dosi and Moretto, 1997; Griliches, 1957; and Stoneman, 1983 for illustrations of the so-called epidemic diffusion models and Chapter 2). Empirical evidence has been provided by Morgenstern and Al-Jurf (1999) and Koomey (2000). The study of Koomey estimated the demonstration effect of a tax credit on the adoption of specific technologies (that is, an effect that is independent of the size of the subsidy and only requires the provision of a subsidy per se). Koomey showed that the demonstration effect was considerable (30% and 24% for two different technologies), and comparable to the estimated direct price effect of the tax credit. The relevance of information effects is, however, not undisputed in the literature (see, for example, Jaffe and Stavins, 1995).

\[17\] See Train (1994) for an extensive discussion of this specific question.
3.3 The approach used

In the introduction, we defined free riders as agents (companies and households) who acquired a subsidy, but would have adopted the subsidised technology anyway and without a delay. Implicit in this definition is the requirement that the subsidy has had no demonstration value (that is, the information set of the agents was not affected by the subsidy). The approach used in the analysis underlying this chapter uses both methods discussed in the previous section to classify free riders. In the first method, we determine the number of free riders on the basis of objective characteristics of the subsidised technologies and information on the critical discount rates (derived from a survey). In the second method, we use a survey to determine the number of free riders based on participants’ perceptions regarding their own behaviour. This section discusses the methods that we have used to determine the number of free riders and the relevance of demonstration value in evaluating the efficiency of subsidy instruments.

In the first method, our classification of agents proceeds in two steps. First, we determine the profitability of a technology both with and without the subsidy. This measure of profitability is confronted with the minimal required profitability as expressed by the firms. If the profitability of the technology without the subsidy exceeds the required profitability, the agent is called a free-rider (not yet controlling for the potential existence of demonstration value). Second, we determine the number of agents for whom the subsidy had demonstration value. The latter is based on information derived from a survey held among the subsidised agents. The combination of the two steps results in our preferred measure for the number of free riders.

The determination of the profitability of a technology is based on an elementary cost-benefit analysis. We refer to Section 2.1 for an explanation of the cost-benefit analysis used in this study and Chapter 2 in general for a critical discussion of the use of cost-benefit analysis in the context of the energy-efficiency paradox. For the subsidised technology, we obtained information from technology experts on the energy savings achieved by adopting the technology (compared to a reference technology if applicable). In

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18 Note that in this measure for profitability we did include other subsidies (that is, other than the EIA or the EINP). We, in other words, addressed the question whether the EIA or the EINP was the subsidy that finally triggered firms to adopt the technology (after already having received other subsidies). Information on other subsidies received was obtained via the survey that was sent to the firms that obtained an EIA or EINP subsidy.
doing so, we controlled for sector-specific energy prices. The costs of adoption were obtained from the application for the subsidy and included installation and operation and maintenance costs. Finally, information was gathered on the (average) economic lifetime of the technology and the critical discount rate or the critical payback period applied by the firm (that is, the investment criterion on the basis of which actors decide whether or not a technology is profitable). The information on critical discount rates was obtained on the basis of a survey (the survey (in Dutch) is available upon request from the authors). On the basis of this information, we determined the rate of return on the adoption of the technology (the discount rate for which the Net Present Value of adoption is equal to zero) or the actual payback period of the technology. We compared these calculated payback periods with the critical payback periods adopted by the firms. On the basis of this method, we were able to classify the subsidised agents in three groups. The first group consists of agents for whom the technology is profitable even without the subsidy. These are labelled as free riders. The second group consists of agents for whom the technology became profitable due to the provision of the subsidy and was thus triggered to adopt. The final group consists of agents for whom the technology is unprofitable according to their investment criterion even after receiving the subsidy. Those are labelled as ‘irrational’. The second step in our analysis is the determination of the number of agents for whom the subsidy had an informational effect or demonstration value. Agents are not necessarily aware of all the technological options available at the moment and/or their characteristics. It is therefore possible that agents started considering the technology only after they were informed about the technology via - for example - the subsidy prospectus. This demonstration value may have been relevant for agents that were classified as free riders in the first step of the analysis. Since the provision of information is a potentially important effect of a subsidy, it is important to single out those

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19 The economic literature that explicitly models adoption and determines the influence of environmental policy instruments on technology adoption usually takes an aggregate perspective. It often assumes some (mostly linear) distribution of the critical investment criteria (see, for example, the theoretical studies of Albrecht, 1999, Saracho and Usategui, 1994, Jorgensen and Zaccour, 1999). For empirical applications, it is relevant to take account of heterogeneity of agents. We therefore obtained data on the individual critical payback period or rate of return by asking the agents directly in the form of a survey.

20 The choice for a critical payback period or critical discount rate was dependent on the investment criterion applied by the firm. As explained in Chapter 2, these measures are equal under appropriate assumptions.

21 A possible reason for the presence of the incomplete information on the existing technological options are the costs of the information gathering (expressed in, for example, trouble, time and money), which are not always outweighed by their benefits; see Chapter 2.
agents. Information on the relevance of the demonstration value was obtained from a survey to which we turn in Section 3.4. Summarising the first method, two conditions must hold for an agent in order to be classified as a free rider. First, her net financial return to the investment before the subsidy should be larger than her critical investment criterion, and second she should have been aware of the existence of the subsidised technology before getting information about the subsidy.

The second method is much simpler than the first one and requires less information. The classification resulting from this method is based on a survey question in which firms had to answer with which statement they agreed most: (i) without subsidy the investment would not have been undertaken; (ii) without subsidy, another technology would have been chosen; (iii) without subsidy, the same investment would have been done at the same time, or (iv) without subsidy, the same investment would have been done at a later time. Clearly, those agents opting for option (iii) are to be labelled as free riders (not yet controlling for demonstration value). As in the first method, we next assessed, based on the survey, for which firms the subsidy had potential demonstration value, resulting in the preferred measure for the number of free riders.

3.4 Description of the data

In this chapter, we determine the fraction of free riders in two Dutch subsidy programs, the Energy Investment Deduction program (EIA) and the Energy Investment Deduction for the Non-Profit Sector (EINP). Both are directed towards achieving energy savings through stimulating the investments in energy saving company assets and sustainable energy. The first program was developed for companies, whereas the second applies to non-profit organisations. Both programs subsidise the purchase of energy-efficient technologies, though in a slightly different way. While the EIA allows a deduction of a predetermined percentage of the investment cost from the

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22 The choice for these two subsidy programs was mainly steered by the availability of data. For these two programs, micro-data were available that allowed us to use the methodology discussed in Section 3.3. For other Dutch subsidy programs, no micro-data are available (see de Beer et al., 2000, for details and analyses of other subsidy programs). Furthermore, the confrontation of the EIA and the EINP allows for confronting the results for subsidy programs focused on profit (EIA) versus non-profit (EINP) organisations on the one hand, and subsidy (EINP) versus tax-deduction (EIA) programs on the other hand. Finally, both programs subsidise the investments in specific technologies (a list of the technologies, which fall under the programs, is published every year by the Dutch authorities). This allows us to analyse the role of specific technologies on the severity of the free rider problem.
taxable profits, the EINP provides a direct subsidy to the investor.\textsuperscript{23} Only investments in energy-efficient technology itself are applicable for subsidisation. Accordingly, Senter (the government institution supervising the subsidy program) is screening all applications. On average, investors obtain a subsidy of 16 to 18 percent of their investment.

The data we used for the purpose of classifying the agents using method 1 fall in three broad classes:

- Data describing the purchased technology, the investment costs, and the subsidy obtained. This information was obtained from Senter;
- Data to assess the costs and benefits of the investment, and its energy saving at the moment of purchase of the technology. These data concern the technological and economic information available to the investor at the time of the investment decision.\textsuperscript{24} Since the analysed subsidy programs subsidise specific technologies, it is possible to obtain the required information on energy savings from experts (in quantity and in monetary terms by applying a sector-specific energy price), and costs and benefits of a reference technology\textsuperscript{25};
- Data on the critical discount rate or payback period and the information set of the firm prior to the introduction of the subsidy program. This type of information was obtained from the survey, in which the agents provide (ex post) information about their decision making process.

The data needed for the second method were straightforwardly obtained from the survey on the basis of the questions as discussed in the previous section.

Table 3.1 describes some of the key characteristics of the subsidy program. In total, 13946 (1181) agents obtained a subsidy in the context of the EIA (EINP) program. These agents were located in 46 (11) sectors of industry and they obtained subsidies for 15 (12) distinct technologies. With regard to the EIA-program, we took a stratified sample of 2352 agents who were sent a

\textsuperscript{23} Among others, this implies that the EIA only works as an (effective) subsidy when the firm applying for the subsidy earns a profit (now or in the future) and that the size of the subsidy depends on the tax regime that applies to the firm under consideration.

\textsuperscript{24} The economic information also includes information on other subsidies obtained after investing in the technology (see Section 3.3).

\textsuperscript{25} For technologies for which a clear alternative is available, we did not consider the costs and benefits of the technology in isolation, but instead compared the costs and benefits compared to the available alternative. In most cases, this boils down to assessing the additional costs of a more energy-efficient technology with the energy savings obtained by investing in this technology.
survey. The response was 622, and was representative for the sample in terms of size, sector and technology (details are available upon request). For the EINP, we sent a survey to all participants resulting in a response of 210.

Table 3.1  Key characteristics of the subsidy programs.

<table>
<thead>
<tr>
<th>Subsidy program</th>
<th>Sectors of industry</th>
<th>Technologies</th>
<th>Original population</th>
<th>Sample</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIA</td>
<td>46</td>
<td>15</td>
<td>13946</td>
<td>2353</td>
<td>622</td>
</tr>
<tr>
<td>EINP</td>
<td>11</td>
<td>12</td>
<td>1181</td>
<td>1181</td>
<td>210</td>
</tr>
</tbody>
</table>

In the remainder of this section, we describe the technologies and the critical payback periods that are being used as investment criteria by the participants in the subsidy programs. Tables 3.2 and 3.3 give an overview of the subsidised technologies. These tables provide information on the average cost of the investment for the particular technology, the investment costs in excess of investment in the relevant reference technology (if applicable), the average amount of subsidy (both from the EIA/EINP and other sources of subsidy), the annual energy savings, and the critical payback periods with and without subsidies. The tables clearly illustrate the huge variation in profitability in the various techniques ranging from highly unprofitable techniques as isolation to highly profitable techniques as flue gas condensers.

Regarding the critical payback periods, a first relevant notion is that in both the EIA and EINP program, over half of the responding participants (55 and 60 percent, respectively) indicated neither to use a critical internal discount rate nor a critical payback period.27 For those firms that did indicate to use critical payback periods, a first relevant notion is that in both the EIA and EINP program, over half of the responding participants (55 and 60 percent, respectively) indicated neither to use a critical internal discount rate nor a critical payback period.27 For those firms that did indicate to use critical payback periods, a first relevant notion is that in both the EIA and EINP program, over half of the responding participants (55 and 60 percent, respectively) indicated neither to use a critical internal discount rate nor a critical payback period.27 For those firms that did indicate to use critical payback periods, a first relevant notion is that in both the EIA and EINP program, over half of the responding participants (55 and 60 percent, respectively) indicated neither to use a critical internal discount rate nor a critical payback period.27 For those firms that did indicate to use critical payback periods, a first relevant notion is that in both the EIA and EINP program, over half of the responding participants (55 and 60 percent, respectively) indicated neither to use a critical internal discount rate nor a critical payback period.27 For those firms that did indicate to use critical payback periods, a first relevant notion is that in both the EIA and EINP program, over half of the responding participants (55 and 60 percent, respectively) indicated neither to use a critical internal discount rate nor a critical payback period.27 For those firms that did indicate to use critical payback periods, a first relevant notion is that in both the EIA and EINP program, over half of the responding participants (55 and 60 percent, respectively) indicated neither to use a critical internal discount rate nor a critical payback period.27

26 Note that the derived payback periods only apply to the average investment as described in the Tables. For individual cases these are, of course, different due to different sizes/costs of the investment and different amounts of subsidies.

27 This result came as a surprise, since we had expected a much larger fraction of firms to adopt an investment criterion like an internal discount rate or critical payback period. On the basis of the available information, it is difficult to assess what the reason is for the huge number of firms indicating not to use a critical discount rate. It can be due to misunderstanding of the question as posed in the survey (which is unlikely since in an accompanying survey by phone no misunderstanding arose), it can be due to the fact that firms consider this information as sensitive (though this is unlikely given the anonymity), or it can be because many firms simply do not use such investment criteria (from literature, we know no other indications of the amount of firms using investment criteria). Clearly, this result warrants further investigation which is, however, beyond the scope of this chapter.
payback periods, the average was 6.7 and 9.4 years, respectively.\(^{28}\) The critical payback periods follow the familiar skewed distribution known from earlier studies as illustrated in Figure 3.1 (for example, Gillissen et al., 1995, and Grüber and Brand, 1991).

\[ PBP = \sum_{t=0}^{T} \frac{1}{(1+r)^t} \] (see Appendix I for details).

\(^{28}\) When agents indicated to only apply a critical discount rate, this was transformed into a critical payback period according to $PBP = \sum_{t=0}^{T} \frac{1}{(1+r)^t}$ (see Appendix I for details).
### Table 3.2 Technology characteristics – EIA.

<table>
<thead>
<tr>
<th>Technology EIA</th>
<th>Average investment</th>
<th>Average investment relative to reference technology</th>
<th>Average subsidy</th>
<th>Average 'other' subsidies</th>
<th>Average savings</th>
<th>PBP without subsidies</th>
<th>PBP with other subsidies</th>
<th>PBP with all subsidies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condenser</td>
<td>84</td>
<td>42</td>
<td>5</td>
<td>30</td>
<td>1.4</td>
<td>1.3</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Energy-conserving cooling and freezing equipment, label A</td>
<td>52</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>2.1</td>
<td>1.7</td>
<td>-0.2</td>
<td></td>
</tr>
<tr>
<td>Frequency converter</td>
<td>27</td>
<td>27</td>
<td>5</td>
<td>1</td>
<td>7</td>
<td>4.1</td>
<td>4.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Lightweight semi-trailer</td>
<td>734</td>
<td>110</td>
<td>35</td>
<td>3</td>
<td>6.1</td>
<td>4.4</td>
<td>-2.3</td>
<td></td>
</tr>
<tr>
<td>Biomass pre-treatment installation</td>
<td>332</td>
<td>332</td>
<td>52</td>
<td>17</td>
<td>8.9</td>
<td>8.4</td>
<td>7.1</td>
<td></td>
</tr>
<tr>
<td>Wind turbine</td>
<td>725</td>
<td>725</td>
<td>33</td>
<td>96</td>
<td>7.6</td>
<td>7.3</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>60</td>
<td>60</td>
<td>33</td>
<td>3</td>
<td>22.2</td>
<td>22.0</td>
<td>18.1</td>
<td></td>
</tr>
<tr>
<td>Energy blinds</td>
<td>84</td>
<td>84</td>
<td>17</td>
<td>4</td>
<td>4.7</td>
<td>4.3</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Energy-conserving cooling and freezing equipment, label B</td>
<td>85</td>
<td>17</td>
<td>1</td>
<td>1</td>
<td>4.8</td>
<td>4.7</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Heat buffer-system</td>
<td>101</td>
<td>101</td>
<td>17</td>
<td>1</td>
<td>7.7</td>
<td>7.6</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous items WKK</td>
<td>502</td>
<td>502</td>
<td>74</td>
<td>45</td>
<td>116</td>
<td>4.1</td>
<td>3.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Generic techniques construction</td>
<td>105</td>
<td>105</td>
<td>17</td>
<td>30</td>
<td>3.6</td>
<td>3.5</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Generic techniques equipment and processes</td>
<td>420</td>
<td>420</td>
<td>61</td>
<td>29</td>
<td>273</td>
<td>1.8</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Total</td>
<td>118600</td>
<td>81800</td>
<td>18000</td>
<td>6100</td>
<td>17900</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.3 Technology characteristics – EINP.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Average investment</th>
<th>Average investment relative to reference technology</th>
<th>Average subsidy</th>
<th>Average 'other' subsidies</th>
<th>Average savings</th>
<th>PBP without subsidies</th>
<th>PBP with other subsidies</th>
<th>PBP with all subsidies</th>
</tr>
</thead>
<tbody>
<tr>
<td>High efficiency glass</td>
<td>296</td>
<td>53</td>
<td>45</td>
<td>2</td>
<td>4</td>
<td>14.0</td>
<td>11.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>Heat recovery from ventilation air</td>
<td>120</td>
<td>120</td>
<td>20</td>
<td>11</td>
<td>37</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Frequency converter 98</td>
<td>75</td>
<td>75</td>
<td>13</td>
<td>5</td>
<td>29</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Heat pump</td>
<td>54</td>
<td>36</td>
<td>10</td>
<td>4</td>
<td>11</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Heat storage in the ground (aquifer)</td>
<td>1262</td>
<td>921</td>
<td>183</td>
<td>0</td>
<td>59</td>
<td>16.0</td>
<td>16.0</td>
<td>13.0</td>
</tr>
<tr>
<td>High efficiency boiler</td>
<td>132</td>
<td>44</td>
<td>21</td>
<td>2</td>
<td>6</td>
<td>8.0</td>
<td>7.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Weather-dependent optimization of the heating of non-residential buildings</td>
<td>67</td>
<td>67</td>
<td>12</td>
<td>3</td>
<td>12</td>
<td>5.0</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Insulation</td>
<td>91</td>
<td>91</td>
<td>15</td>
<td>2</td>
<td>4</td>
<td>27.0</td>
<td>26.0</td>
<td>21.0</td>
</tr>
<tr>
<td>Draught-sealing</td>
<td>88</td>
<td>88</td>
<td>16</td>
<td>1</td>
<td>3</td>
<td>36.0</td>
<td>35.0</td>
<td>28.0</td>
</tr>
<tr>
<td>Energy-efficient lighting system</td>
<td>113</td>
<td>37</td>
<td>19</td>
<td>5</td>
<td>6</td>
<td>6.0</td>
<td>5.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Control system for energy management in buildings</td>
<td>16</td>
<td>16</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Heat registration system</td>
<td>26</td>
<td>26</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>26.0</td>
<td>25.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Total</td>
<td>29000</td>
<td>13600</td>
<td>4700</td>
<td>700</td>
<td>1700</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.5 Results

This section classifies the participants in the subsidy programs into free riders, agents that were triggered to adopt a technology because of the subsidy and so-called irrational agents. This classification will be made on the basis of two distinct methods, which will subsequently be confronted with each other. These methods are as described in Section 3.3. The first method – the critical PBP method – can obviously only be applied for those participants that indicated to apply a critical payback period. As explained in Section 3.3, confronting the actual payback period of a technology with the critical payback period applied by the firm, we can classify the agents into one of the three groups. The results are given in Table 3.4.

Table 3.4 Classification of agents based on Method 1.

<table>
<thead>
<tr>
<th></th>
<th>Free Riders</th>
<th>Triggered to adopt</th>
<th>“Irrational”</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIA</td>
<td>181 (64%)</td>
<td>27 (10%)</td>
<td>73 (26%)</td>
</tr>
<tr>
<td>EINP</td>
<td>57 (68%)</td>
<td>13 (16%)</td>
<td>14 (17%)</td>
</tr>
</tbody>
</table>

A sensitivity analysis has been performed on these results for two reasons. First, the information on energy saved per technology is rather imprecise. Second, we had no information on energy prices at the firm level. Especially for large firms this can be problematic, since those are known to have special contracts with energy suppliers. As an unavoidable consequence, the information on energy savings in monetary units used to classify the agents in Table 3.4 may be imprecise. To illustrate the sensitivity of our classification for these data-problems, we recalculated the number of free riders both under the assumption that energy savings were 20 percent higher than those of our base case and that they were 20 percent lower than those of our base case. When energy savings are 20 percent higher, the percentage of free riders is equal to 72% and 74% in case of the EIA and EINP, respectively. When energy savings are 20 percent lower, the percentage of free riders is equal to 49% and 54% in case of the EIA and EINP, respectively. These figures can be seen as rough estimates for the lower and upper bounds of the percentage of free riders.29

The second method we used to classify adoption behaviour relies on the stated behaviour by agents as indicated in the survey. Based on this method, we found 52% of free riders in the EIA and 51% in the EINP (not controlling for demonstration value). The conclusion on the number of free riders seems less

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29 The results of more extensive sensitivity analysis are available upon request from the authors.
‘pessimistic’ in the method using the stated behaviour. This result comes as no surprise since one expects firms to underreport the extent to which they engage in ‘undesirable’ behaviour (see Section 3.2). There is, however, a more fundamental problem with the comparison of the two methods that becomes clear by considering Table 3.5. A substantial number of agents is classified as free rider on the basis of the critical PBP method, while according to their stated behaviour they are not. More worryingly, a substantial number of agents are classified as free riders on the basis of their stated behaviour, while the critical PBP method suggests they are not.

Table 3.5 Classification of agents on basis of two methods (EIA and EINP combined, EIA in brackets).

<table>
<thead>
<tr>
<th>Method 1</th>
<th>Free Rider</th>
<th>No Free Rider</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Rider</td>
<td>110 (90)</td>
<td>128 (91)</td>
<td>238</td>
</tr>
<tr>
<td>No Free Rider</td>
<td>52 (45)</td>
<td>75 (55)</td>
<td>127</td>
</tr>
<tr>
<td>Total</td>
<td>162</td>
<td>203</td>
<td>365</td>
</tr>
</tbody>
</table>

The analysis so far implicitly assumed away the potential relevance of the demonstration value. On the basis of the survey, we were able to determine the number of free riders for which the subsidy (might have) had a demonstration value. Information was obtained on questions regarding the knowledge of firms about the technology under consideration. For firms that indicated to be unaware about the technology they chose before they were informed about the subsidy, we concluded that the subsidy had a demonstration value. For firms that were informed about the subsidy after they decided to invest in a particular technology, we concluded that the subsidy could not have had a demonstration value. This resulted in the classification presented in Table 3.6.

Table 3.6 Demonstration value.

<table>
<thead>
<tr>
<th></th>
<th>Demonstration value</th>
<th>No demonstration value</th>
<th>Uncertain</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIA</td>
<td>18 (3%)</td>
<td>250 (40%)</td>
<td>354 (57%)</td>
</tr>
<tr>
<td>EINP</td>
<td>8 (4%)</td>
<td>82 (39%)</td>
<td>120 (57%)</td>
</tr>
</tbody>
</table>
3.6 Cost-effectiveness of subsidies

We finally assess the effectiveness of the subsidy instruments in terms of saved energy per monetary unit of subsidy, both with and without accounting for free riders. The results are described in Tables 3.7 and 3.8, where a distinction is made between the different techniques. All results on free riders control for the potential importance of demonstration value. Range values have been reported because of the large group of agents that could not be classified (see Table 3.6). The upper bound of the range for the percentage of free riders reported in Tables 3.7 and 3.8 is derived under the assumption that non of the non-classified agents in Table 3.6 experienced attention value, whereas the lower bound is derived under the assumption that all non-classified agents experienced demonstration value.

The results in Tables 3.7 and 3.8 clearly demonstrate that free-rider effects can be dominant when subsidising particular technologies. From the huge variation in actual payback periods, this should come as no surprise. Evidently, subsidies on technologies characterised by many free riders are not very cost-effective. This ineffectiveness can arise either because technologies are characterised by low payback periods (the so-called low-hanging fruits) or because they tend to be adopted by firms that apply a low critical payback period. At least two observations suggest that the adoption of a number of technologies may indeed be low hanging fruit. First, a number of technologies are characterised by relatively high investment costs of alternatives meaning that the additional investment relative to the alternative is much smaller than the investment itself. Since the subsidies are awarded on the basis of the investment itself instead of the additional investment, the subsidy may in some cases be larger than the additional investment. Second, a substantial number of agents also applied for (and obtained) other subsidies besides the EIA/EINP. In a number of cases, the total amount of subsidies obtained was even larger than the additional investment required (those for which the payback period with all subsidies accounted for is negative). In order to assess the cost-effectiveness of the subsidy schemes, we determine several indicators. The first is the amount of subsidies paid to free riders. The second is the amount of energy saved by installing the subsidised technologies, both with and without controlling for free riders (pseudo-effectiveness and actual effectiveness, respectively). The third is the amount of energy saved per guilder of subsidy granted, again both with and without controlling for free riders. These indicators are again determined for two distinct cases, namely the case in which the firms that could not be classified in Table 3.6 are (i) all free riders and (ii) all non-free-riders. This leads to the ranges for subsidies paid to free riders and the indicators for
the actual effectiveness. Evidently, controlling for free riders substantially reduces the cost-effectiveness of subsidies. For the EIA, cost effectiveness is reduced from 50 kg CO₂ avoided per guilder of subsidy to 20 kg (or 42 kg) when controlling for free riders (the reduction depending on the assumption regarding the agents which could not be classified as having experienced demonstration value or not). For the EINP, the reduction is from 17 kg CO₂ avoided to 9 kg (or 13) again depending on the assumption regarding the agents which could not be classified as having experienced demonstration value or not.

3.7 Conclusions

This chapter analysed the cost-effectiveness of subsidy programs by estimating the number of free riders involved in these programs. The free-rider fractions have been determined for two Dutch subsidy programs, directed towards achieving energy savings by stimulating investments in energy-efficient technologies and sustainable energy. We classify an agent as a free rider if (i) his net financial return to the investment before the subsidy was larger than his critical investment criterion and (ii) the agent was aware of the existence of the subsidised technology before getting information about the subsidy. For this aim, we constructed a unique micro-database linking information on technology characteristics with information on the information set of firms and their investment criteria.

The empirical results support the belief that subsidies, and more specifically, subsidies on the adoption of energy-efficient technologies, may involve a considerable number of free riders. It is essential that this is taken into account when designing the subsidies. The results reveal that the type of technology that is being subsidised is an important factor influencing the probability for an agent of being a free rider. The estimated free-rider fractions differ considerably for different technologies. This suggests that technology-specific subsidies can be substantially improved in terms of their effectiveness by avoiding the subsidisation of technologies that are already profitable without the subsidy. In other words, the characteristics of the subsidised technology have to be an important steering factor when designing subsidy programs. The last recommendation may, however, have to be corrected for possible greater administration costs involved in technology-specific subsidies (although for the subsidy programs considered in this chapter the administration costs are
Table 3.7 Cost-effectiveness of measures – EIA.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Respondents</th>
<th>Percentage of free riders (%)</th>
<th>Subsidy to free riders (kT)</th>
<th>(Pseudo)-effectiveness total (kT)</th>
<th>(Pseudo)-cost effectiveness total (MJ/Dfl)</th>
<th>(Actual)-effectiveness total (kT)</th>
<th>(Actual)-cost effectiveness total (MJ/Dfl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condenser</td>
<td>49</td>
<td>10-51</td>
<td>38-336</td>
<td>2040</td>
<td>1009-1936</td>
<td>114.0</td>
<td>56-108</td>
</tr>
<tr>
<td>Energy-conserving cooling and freezing equipment,</td>
<td>11</td>
<td>27-55</td>
<td>29-61</td>
<td>27</td>
<td>10-19</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Biomass pre-treatment installation</td>
<td>1</td>
<td>0-100</td>
<td>0-209</td>
<td>1471</td>
<td>1285-1471</td>
<td>101.0</td>
<td>62-101</td>
</tr>
<tr>
<td>Insulation</td>
<td>180</td>
<td>20-41</td>
<td>298-681</td>
<td>1025</td>
<td>92.0</td>
<td>9-10</td>
<td>29.0</td>
</tr>
<tr>
<td>Energy blinds</td>
<td>67</td>
<td>25-66</td>
<td>242-586</td>
<td>1187</td>
<td>463-886</td>
<td>66.0</td>
<td>26-50</td>
</tr>
<tr>
<td>Energy-conserving cooling and freezing equipment,</td>
<td>55</td>
<td>27-60</td>
<td>189-528</td>
<td>95</td>
<td>30-72</td>
<td>7.0</td>
<td>2-5</td>
</tr>
<tr>
<td>Heat buffer-system</td>
<td>47</td>
<td>21-60</td>
<td>136-475</td>
<td>900</td>
<td>377-753</td>
<td>50.0</td>
<td>21-42</td>
</tr>
<tr>
<td>Miscellaneous items WKK</td>
<td>55</td>
<td>18-47</td>
<td>626-2284</td>
<td>6842</td>
<td>2957</td>
<td>588.0</td>
<td>254-496</td>
</tr>
<tr>
<td>Generic techniques construction</td>
<td>25</td>
<td>40-48</td>
<td>68-76</td>
<td>1041</td>
<td>868-892</td>
<td>58.0</td>
<td>49-50</td>
</tr>
<tr>
<td>Generic techniques equipment and processes</td>
<td>21</td>
<td>29-62</td>
<td>308-1444</td>
<td>4801</td>
<td>468-3679</td>
<td>329.0</td>
<td>32-252</td>
</tr>
<tr>
<td>Total</td>
<td>622</td>
<td>22-50</td>
<td>2311-7585</td>
<td>20525</td>
<td>8704-17368</td>
<td>1436</td>
<td>599-1206</td>
</tr>
</tbody>
</table>

Note: The table provides a detailed breakdown of the cost-effectiveness of various energy conservation measures, including the percentage of free riders, subsidies, and calculated effectiveness and cost for each technology.
### Table 3.8 Cost-effectiveness of measures – EINP.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Respondents</th>
<th>Percentage of free riders</th>
<th>Subsidy to free riders</th>
<th>(Pseudo)-effectiveness total</th>
<th>(Pseudo)-cost effectiveness total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tj</td>
<td>Tj</td>
<td>kton CO₂</td>
<td>kton CO₂</td>
<td>MJ/Dfl</td>
</tr>
<tr>
<td></td>
<td>kton</td>
<td>MJ/Dfl</td>
<td>kg</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>High efficiency glass</td>
<td>9</td>
<td>22-55</td>
<td>83-179</td>
<td>138</td>
<td>77- 111</td>
</tr>
<tr>
<td>Heat recovery from ventilation air</td>
<td>12</td>
<td>16-42</td>
<td>16-97</td>
<td>365</td>
<td>239-343</td>
</tr>
<tr>
<td>Frequency converter 98</td>
<td>14</td>
<td>28-57</td>
<td>60-81</td>
<td>156</td>
<td>87-103</td>
</tr>
<tr>
<td>Heat pump</td>
<td>5</td>
<td>17-60</td>
<td>2-34</td>
<td>97</td>
<td>40-93</td>
</tr>
<tr>
<td>Heat storage in the ground (aquifer)</td>
<td>3</td>
<td>67</td>
<td>416</td>
<td>125</td>
<td>30-8</td>
</tr>
<tr>
<td>High efficiency boiler</td>
<td>108</td>
<td>30-56</td>
<td>816-1213</td>
<td>744</td>
<td>351-474</td>
</tr>
<tr>
<td>Weather-dependent optimization of the heating</td>
<td>6</td>
<td>33</td>
<td>37</td>
<td>63</td>
<td>4-2</td>
</tr>
<tr>
<td>of non-residential buildings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>704</td>
</tr>
<tr>
<td>Insulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>426</td>
</tr>
<tr>
<td>Draught-sealing</td>
<td>3</td>
<td>9-30</td>
<td>143-226</td>
<td>82</td>
<td>51-81</td>
</tr>
<tr>
<td>Energy-efficient lighting system</td>
<td>33</td>
<td>9-30</td>
<td>143-226</td>
<td>82</td>
<td>51-81</td>
</tr>
<tr>
<td>Control system for energy management in buildings</td>
<td>1</td>
<td>0</td>
<td>0-3</td>
<td>2</td>
<td>2-2</td>
</tr>
<tr>
<td>Heat registration system</td>
<td>5</td>
<td>40-60</td>
<td>41-14</td>
<td>4</td>
<td>1.6-2.3</td>
</tr>
<tr>
<td>Total</td>
<td>210</td>
<td>25-49</td>
<td>1579-2231</td>
<td>1933</td>
<td>1048</td>
</tr>
</tbody>
</table>

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rather limited: they are in the range of 1 to 7% of the total granted subsidies). A trade-off has to be faced between specific subsidy programs with high administration costs but low numbers of free riders on the one hand and generic subsidy programs with high numbers of free riders but low administration costs.

There are obviously many more dimensions along which free-rider effects might differ. For a given subsidy rate, for example, one could hypothesise that free riders are especially dominant among large firms since those tend to benefit more from the adoption of the technology due to economies of scale and scope, lack of capital restrictions reflected in higher critical payback periods, etc. Assessing the relevance of such heterogeneities is left for future research.

4 ENERGY-EFFICIENCY STANDARDS

4.1 Introduction

The regulatory or ‘command and control’ approach has often been the preferred way of achieving objectives in environmental policy, even though the economic approach is becoming more important. The command and control approach consists of the promulgation and enforcement of laws and regulations, prescribing objectives, standards and technologies polluters must comply with. This preference for direct regulation is due to the theoretically high degree of precision and effectiveness possible for this type of instrument. However direct regulation can entail a large number of drawbacks and problem. First of all, there is a large burden of enforcement of direct regulations. An adequate monitoring of compliance with the regulations and the imposition of sanctions in case of non-compliance is necessary. Administrative costs can therefore be inevitably high in this respect. Another drawback of direct regulations is that the public authorities require a great deal of specific knowledge on polluters and their technologies, also entailing large transaction costs. Regulations are not only costly from the government point of view; for the private sector compliance to direct regulations is not efficient in economic terms either, since the regulations do not minimise abatement costs. An additional major drawback of direct regulation is that an incentive for polluters to adopt more environmental practises is lacking; once the polluters comply with the regulations there is no direct need for further emission reductions. Moreover technical progress will not easily become embodied in new regulations. Finally, it is often said that direct regulations may too
new regulations. Finally, it is often said that direct regulations may too easily be subject to bargaining and negotiations between public authorities and the private sector.

Despite the large number of drawbacks, direct regulation plays an important role in energy policies worldwide. However, energy standards for energy conservation or improving the energy efficiency are rarely used in energy policy for firms. In this chapter the focus is therefore on the latter type of instruments.\footnote{Negotiated agreements will be discussed in chapter 5.} Energy standards are defined as regulations that prescribe minimum technical requirements for energy conversion systems and energy end-use systems. Energy standards have often been unilaterally declared by the government, often put restrictions on products or processes at the disaggregated level and offer low flexibility for the companies to comply with.

The aim of this chapter is to explore two main aspects of energy standards. The first is a design question: how can we come to energy-efficiency standards that reasonable from an economic point of view, that are technologically feasible and also improve the environment sufficiently? The second is on effectiveness: are energy-efficiency standards effective? The fact that energy-efficiency standards have not been widely used is the cause of our analysis having an explorative character; not much empirical evidence is available yet to support our analysis.

In this chapter we will first give a categorisation of regulatory policy instruments for industrial energy conservation in the Netherlands (4.2) and then we will explore the current use of energy-efficiency standards for firms worldwide (4.3). Next, we will focus on the design question: what are the guidelines for constructing reasonable standards. On the basis of the ICARUS technology database an analysis will be made of the effects of applying such standards (4.4). Finally, we will explore the effectiveness of energy-efficiency standards in a case study for the Netherlands (4.5 and 4.6).

4.2 Categorisation of regulatory instruments for industrial energy conservation

In the Dutch energy policy the following types of policy instruments are in use that are definitely command-and-control, but in which standard-setting plays a role (see Figure 4.1): long-term agreements on energy-efficiency improvement, benchmarking agreements on energy efficiency, environmental
permits and administrative orders setting requirements on energy conservation and energy labels. Only the latter two are standards as defined in Section 4.1.

The different types of instruments for industrial energy conservation can be divided in the following categories of standards:

1) Process standards specify the characteristics of production processes or the type of emission reduction equipment a polluters must install. Good examples of process standards in the industrial energy policy are covenants or long-term agreements on energy efficiency and the benchmarking covenant. Both instruments set requirements to the energy efficiency of the overall production process.

2) Product standards define the characteristics of potentially polluting products. Product standards are widely applied to set requirements to energy efficiency or energy use of specific appliances and equipment, such as the minimum efficient standards for hot water boilers and energy labelling schemes for refrigerators and freezers (see 4.3).

3) Emission standards prescribe the maximum discharges of pollutants into the environment (from fixed points). CO₂ emission allowances or tradable CO₂ emission permit are not used yet in Dutch environmental policies. However in 2005 a European emission trading scheme for greenhouse gasses is likely to be introduced.

4) Management standards are environmental standards progressively introduced (at an international level) for promoting satisfactory environmental corporate management. Examples of management standards are NEN-EN-ISO and EMAS. Energy management is generally not explicitly integrated in those systems at the moment. Long-term agreements and the Benchmarking agreement are primarily process based standards but also set requirements for the energy management of firms.

Figure 4.1 shows the categorisation of the different regulatory energy policy instruments in the Netherlands and the guidelines for target-setting that were used to set these standards (see Section 4.4).

31 In environmental policies also so-called ambient quality standards are used. These standards set requirements to the quality of the physical environment.
The energy labelling schemes and the energy-efficiency requirements set in the environmental permit and administrative orders are two examples of energy standards for energy end-use systems applied in the Netherlands.

### 4.3 Energy-efficiency standards for firms worldwide

Energy standards for appliances and equipment are widely used, especially in the USA, to improve the efficiency of home appliances and office equipment. They are increasingly being considered for electric motors, home entertainment electronics and lighting equipment.\(^{32}\) At present standards exist in 34 countries.\(^{33}\) The most prominent example in the USA is the corporate-average-fuel-efficiency standard adopted for the automotive sector in 1975. These standards provide flexibility by setting requirements for the sales-weighted average of each manufacturer rather than for individual vehicles. The specific fuel consumption was to decrease from 13 litre per 100 km in 1978 to 8.5 litre per 100 km in 1985. Actual energy use more or less followed these requirements. In the mid-1970s minimum energy-efficiency standards for refrigerators were adopted in California. National standards became effective in

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\(^{32}\) No standards have been designed which prescribe energy requirements for the production of the appliances.

\(^{33}\) See IEA (2000) for an overview of standards and labels that are currently used in IEA countries.
1990. The average rated electricity use of new refrigerators declined from 1725 kWh in 1972 to around 685 kWh in 1993 (Geller and Nadel, 1994).

Also in other world regions energy-efficiency standards for cars and household appliances have been widely used. Japan has adopted minimum energy-efficiency standards for cars, by weight class. Recently, in this country the so-called top-runner approach was adopted for electric appliances. The interesting aspect is that this approach is inherently dynamic because the standard levels are being adapted to the performance of the best available in the market every few years.


In all these cases standards are set for mass consumer goods, that are relevant to households rather than firms.

Another area where standards were widely applied world wide is for the thermal integrity of buildings. These standards were applied first to the residential sector, but also more and more for non-residential buildings. So here we find standards relevant for firms as well.

A world wide survey, carried out in 1992 (Janda and Busch, 1994) revealed that out of 57 countries surveyed, 35 have standards for non-residential buildings. Virtually all OECD countries have such standards, but in some (parts of the) countries they have a voluntary character. In some countries the standards are prescriptive (e.g., prescribing the maximum heat transmission through walls), some are performance-based (giving requirements for the overall energy performance of the building). In most of the cases the standards apply only to buildings in the service sectors, and sometimes they are even more restricted, merely concerning, for instance, office buildings, schools or hotels. Industrial buildings are often not included.

Most regulations are directed at the insulation of roofs, walls and fenestration. In other cases also floor insulation, air infiltration, lighting and mechanical equipment were included. Most countries set the requirements of the standard at a level more stringent than the average practice; however, this turned out not to be the case in all countries.

Regimes for checking compliance differ from country to country. In most cases compliance-checking is part of the approval process, before building can be started. Verification during construction occurs in one third of the countries and verification after construction in half of the countries. Many respondents considered their regulation to be effective, but quantitative information about this subject is scarce.
Appliance standards have been proposed for specific equipment, e.g. for the efficiency of electric motors, but have never, to our knowledge, been introduced somewhere.

4.4 Guiding principles to fix standards

When setting standards decision-makers are confronted with environmental, technological, economical and political constraints. First of all regulations should maintain or improve environmental quality or reduce emissions to considerable extent. Secondly, standards are only enforceable to the extent that technical possibilities are available or are likely to be developed. Thirdly, the implementation of measures to meet the standards should be economically affordable for the industry. Finally, decision-makers have to deal with a number of political constraints, like the equity, acceptability and simplicity of environmental regulations.

In this section we will explore the guidelines for setting energy standards and discuss the possibilities how we can come to reasonable criteria for setting standards from an economic point of view.

4.4.1 Technological criteria

In many environmental laws technological criteria are used as a guiding principle for setting specific environmental standards. Technology based standards refer to the state of the technology that should be applied by the firm subjected to environmental regulation. The energy-efficiency requirements set in environmental permits and administrative orders are primarily based on technology standards. When setting energy-efficiency requirements in the benchmarking agreement and the Long-term agreements technology standards play a less prominent role.

ALARA

Since the introduction in the Environmental Management Act in the Netherlands (1993) the ALARA concept (As Low As Reasonable Achievable) is used as a guiding principle for setting requirements and duties that should contain the necessary conditions to protect the interest of the environment. The ALARA principle originates from the decree ‘radiation protection nuclear energy act’ (Besluit, 1986). In the Environmental Management Act this is described as follows (Environmental Management Act, 1993):
A licence shall be subject to any regulations which are necessary to protect the environment. If any adverse effects on the environment caused by making the licence subject to such regulations cannot be avoided, the licence shall be made subject to such additional regulations as may be necessary to provide the greatest possible protection to the environment from side effects, unless this cannot reasonably be required.

The governmental explanatory memorandum (Tweede Kamer, 1990) provides the following interpretation of the article above:

1. A license should contain the necessary requirements to protect the environment and thus avoid negative environmental impacts;
2. In so far as a negative impact on the environment cannot completely be avoided and the request for a permit is not dismissed, those requirements should be included in the permit providing the best possible protection unless it would not be reasonable to prescribe such conditions. Here it is assumed that the best technical means are used;
3. If it is not reasonable to prescribe such conditions the best practical means must be prescribed as a minimum standard.

**Best Technical Means and Best Practical Means**

In this context a clear definition of the concept of ‘best technical means’ and ‘best practical means’ is required. According to the principle of Best Technical Means, described in article 7.10 paragraph 3 in the Environmental Management Act, the environment must be protected with the best technical means in the case that negative impacts to the environment cannot completely be avoided. The economic capacity of individual firms is in this principle less relevant for the determination of the permit conditions. Moreover, measures must have been implemented at least once: the prescription of these measures in a concrete case must be realistic in technical sense. In this respect a thorough knowledge and up-date of the state of the technique is required. Only if costs of these measures in the sector are considered to be too high, the best technical means cannot be reasonably asked. In that case the best practicable means are prescribed. According to this principle those measures must be implemented that provide the best environmental protection, however taking into account the costs that can in fairness be asked of an average profitable and financial healthy

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34 In Dutch: ‘best bestaande of best beschikbare technieken’.
firm. The prescription of the best practical means is considered as a minimum standard (Tonnaer, 1994).

**State of the Technique**

Since the introduction of the Circular ‘Energy in the environmental permit’ by the Ministry of Housing, Spatial Planning and the Environment (VROM, 1999) the concepts of ‘best technical means’ and ‘best practical means’ are no longer the leading principles for setting energy standards in environmental permits or decrees (administrative orders). Since then those measures must be implemented that meet the ‘State of the Technique’ standards. Measures that meet this standard have been implemented successfully by a company of average financial health in the same branch and those that have been practised on an industrial scale in other processes or demonstration projects.

**Best Available Technique Not Entailing Excessive Costs**

This list of technology standards can be extended with numerous other examples, such as the internationally acknowledged BATNEEC (Best Available Technique Not Entailing Excessive Costs) principle. The technology in question should be *Best* at preventing pollution and *Available* in the sense that it is procurable by the operator of the activity concerned. *Technology* itself includes techniques and the use of techniques, such as training and maintenance. *NEEC* sets out the balance between environmental benefit and financial cost.

### 4.4.2 Environmental performance-based criteria

From the previous section it may be concluded that technology-based criteria cannot easily be applied without taking into account the environmental performance and economic consequences of technical measures. Environmental performance standards set quantitative requirements to the environment improvement of industrial processes and products. This criterion of environmental performance is used in most of the regulatory policy instruments such as the Long-term agreements, benchmarking agreements and energy labels.
4.4.3 Economic criteria

In case the energy-saving measures imposed by the regulations are technological feasible, the crucial elements remains that firms can only comply with these standards if measures are economically reasonable.

In this section we will pose ourselves the question whether it is possible to translate this qualitative criteria of ‘reasonability’ to quantitative criteria (with in mind the application for greenhouse gas emission reduction through energy-efficiency improvement). Some possibilities are the following.

1. The most straightforward solution is to compare the direct financial costs of a measure to its benefits. In case of energy-efficiency improvement the benefits can be expressed in terms of saved energy or avoided carbon dioxide emissions. The general rule then should be that all measures be taken that show specific mitigation costs below a certain value (expressed, e.g., in $/tC or $/GJ).

Use of such a criterion has the important advantage that it - in principle - leads to the lowest costs for society as a whole. However, for individual companies the burden may be substantial if a large part of the emission reduction potential is present within these companies. This is even more the case in a situation where standards are not applied internationally and distortion of competition may occur.

2. Another possibility is to look entirely from the perspective of the private firm and use decision criteria familiar to private firms as a criterion for deciding upon which is best practice and which is not. Examples can be found in Dutch energy conservation policy practices where criteria occur such as the following:
   - all measures should be taken that have a pay-back period less than 5 years (Environmental permit and General Administrative Order)
   - all measures should be taken that have an internal rate of return better than 15% (Benchmarking Agreement)

Although these criteria may be better matched with private firm decision making criteria, it should be noted that, also in this case, the burden - in terms of requirement of investment capital or effect on competitiveness - may be unequally distributed between e.g. energy-intensive and energy-extensive industries. Another disadvantage of these criteria is that it is never possible to prescribe measures that have no benefits (or very minor
benefits related to the investment), although such measures may be very attractive from the point of view of society as a whole.

3. A third possibility is to also start from the point-of-view of the firms and prescribe all measures that do not substantially affect the market position or competitiveness of firms. This approach best reflects the answer to questions of the type: "what are excessive costs?" or: "what can we reasonably ask from firms?" This can be reflected in the phrase ability-to-pay.

Possible ways to apply such criteria are, for instance:
- the share of costs of energy conservation measures should be small compared to the total production costs of a firm;
- the costs of an energy conservation measures should not make up more than a certain fraction of the profit margin of a firm;
- the investment associated with an energy conservation measures should be small compared to the total investment budget of a company (this may apply if access to capital would be an important limiting factor).

The most important disadvantage of such approaches may be that it might be hard to find criteria that are valid in the same way for all the sectors (some sectors may experience harsh competition, whereas in other cases competition is limited or not so much based on costs).

Of course, a combination of criteria may also be applied, measures could e.g. first be selected on the basis of societal desirability, but would not have to be pursued if the total requirements exceed the companies’ ability-to-pay.

4.4.4 The effect of the application of various best-practice concepts

Apart from the theoretical discussion in the previous section on what are the best ways to translate best-practice concepts in practical guidelines, it is also important to examine the practical effects in terms of saved energy and costs for companies. On the basis of ICARUS, the database on energy conservation technologies (De Beer et al., 1994) an analysis of the effect of applying the various criteria was made. We have examined the three types of criteria mentioned in the previous section:
- Private profitability perspectives: all measures with a pay-back period less than 5 years should be taken.
• National costs perspective: all measures with specific mitigation lower than 20 or 100 Euro per tonne CO₂ should be taken.

• Maximum costs perspective: all measures should be taken unless the total costs of the measures exceed a certain fraction (0.2 or 0.5%) of the total costs of a company.

The selection of the latter criteria needs some explanation. It is not clear what can be considered as acceptable levels of costs imposed on firms. To this end we have analysed the costs that, presently, are already imposed on firms due to environmental regulation as a fraction of total production costs. These are presented in Table 4.1. It turns out that for the total industry this fraction is 0.9%, but for the sector with the highest share it is 2.3%. Taking into account that climate change is considered to be an important environmental problem, we assume – as a rule of thumb – that in the end only one of the problems is that costs for climate change are allowed to be about one fifth of these (average or maximum) values, i.e. 0.2 and 0.5%.

The analysis was carried out using the database ICARUS (De Beer et al., 1994). In this database technical and economic characteristics of energy conservation measures are given. In total information is included for 350 measures that together represent the full energy conservation potential of the

<table>
<thead>
<tr>
<th>Industrial sector</th>
<th>Environmental costs as a percentage of total production costs in the sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food, beverages and tobacco industry</td>
<td>0.6</td>
</tr>
<tr>
<td>Textiles and leather industry</td>
<td>1.1</td>
</tr>
<tr>
<td>Paper and board production</td>
<td>1.3</td>
</tr>
<tr>
<td>Petrochemicals production</td>
<td>1.8</td>
</tr>
<tr>
<td>Other chemicals production</td>
<td>2.4</td>
</tr>
<tr>
<td>Building materials production</td>
<td>1.1</td>
</tr>
<tr>
<td>Basic metals production</td>
<td>2.5</td>
</tr>
<tr>
<td>Other metal industry</td>
<td>1.7</td>
</tr>
<tr>
<td>Other industry</td>
<td>0.1</td>
</tr>
<tr>
<td>Total industry</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Many energy conservation measures show negative net costs, even if a 25% discount rate is used. In case of the maximum shares in costs, only the net costs of measures that show positive net costs are included. The results of the calculations are shown in Table 4.2.

The results of these calculations lead to the following observations. The criterion ‘pay-back time less than five years’ leads to similar results as the criterion ‘mitigation costs less than 20 Euro/tCO2’. This is mainly caused by the high discount rate used in the calculation for the latter criterion.

The criterion ‘mitigation costs less than 100 Euro/tCO2’ leads to substantially higher savings than the same criterion with the 20 Euro/tCO2 cut-off. However, the effect strongly differs from sector to sector; this reflects the differences in the distribution of measures over the various cost categories.

Most interesting is the comparison of the last two columns with the former three. We see that for most sectors the use of even the weakest criterion, i.e. ‘share in total costs less than 0.2%’ leads to higher savings than the criterion ‘mitigation costs less than 100 Euro/tCO2’. This means that even high requirements regarding specific mitigation costs do not lead to exceptional costs for most of the sectors.

There are, however, a number of exceptions: the sugar industry, the beer industry, the paper and board industry, the organic and inorganic chemicals industry, the building materials industry and the iron and steel industry. These are generally the more energy-intensive sectors. It is evident that exactly for these sectors the costs associated with achieving substantial energy-efficiency improvement may be considerable; hence, for these sectors (additional) criteria that limit total costs may be useful.

**Conclusions**

It does not seem appropriate to apply private sector profitability criteria for the selection of measures that have to be taken in the framework of energy-efficiency regulation.

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36 This time period is the period 1990 - 2000. Although this represents older data, we are confident that similar results will be obtained for comparable periods. At present a new version of ICARUS is under construction.

37 In the case of the specific mitigation costs alternatively a social discount rate (e.g., 4 - 10%) might have been used in order to reflect governmental time preferences.
Specific mitigation costs may be used as a criterion and do not lead to excessive costs, except for the energy-intensive sectors. Here, such criteria may be backed up by additional criteria that limit total expenditures of the companies concerned.

4.5 The effectiveness of energy-efficiency standards: methodological issues

Most analysts, who have to determine the effectiveness of energy-efficiency standards implicitly or explicitly assume full compliance, see e.g. Swisher et al. (1994) and Blok and Turkenburg (1994).

Such analysis departs from the exact requirements of the regulation, e.g. for what part of the equipment or the companies is the regulation valid; is it valid for the new stock only or also for the existing stock; what energy-efficiency levels or other requirements are imposed. Provided that knowledge is available of the energetic quality of the existing stock, on the relevant distribution of equipment or of firms, on growth and replacement rates, etc., one can determine what the effect of the regulation will be. Hence, the effect of the regulation can be determined, assuming that the behaviour of the regulated will be exactly according to the standard.

In practice, this will not be the case; there may be a number of reasons why full compliance will not occur. Before a regulation really becomes effective, it has to go through various ‘arenas’.

We may distinguish:
1. Compliance by the regulating agency. Once a regulation is accepted by a government, the regulation has to be carried out by some government or government-related agency. In general such an agency has to interact with the regulated companies, e.g. to inform them about the regulation, to elaborate on the regulation for their specific case and to check compliance with the regulation. If this interaction does not occur or not in the way it was projected in the regulation, under compliance at this level occurs.
2. Compliance by the energy user. Also if the regulating agency works according to the prescriptions, it may be that the regulated companies do not behave according to the standards. It may be that the energy user does not comply, e.g. because the system of compliance checking is not strong enough; monitoring prescriptions are inadequate, sanctions are not present, etc.
Table 4.2 Energy conservation by sector that would be enforced by different criteria. The energy conservation is given as a percentage energy conservation that would be achieved in the year 2000 relative to the 1990 frozen-efficiency level.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Criterion</th>
<th>Simple pbp</th>
<th>Specific costs</th>
<th>Maximum share in costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 5 yr</td>
<td>&lt; 20 Euro/tCO₂</td>
<td>&lt;100 Euro/tCO₂</td>
</tr>
<tr>
<td>Horticulture</td>
<td></td>
<td>36</td>
<td>36</td>
<td>37</td>
</tr>
<tr>
<td>Agriculture</td>
<td></td>
<td>35</td>
<td>35</td>
<td>46</td>
</tr>
<tr>
<td>Dairy</td>
<td></td>
<td>39</td>
<td>39</td>
<td>50</td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
<td>20</td>
<td>20</td>
<td>29</td>
</tr>
<tr>
<td>Meat</td>
<td></td>
<td>24</td>
<td>24</td>
<td>37</td>
</tr>
<tr>
<td>Beer</td>
<td></td>
<td>14</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>Starch</td>
<td></td>
<td>14</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>Margarine</td>
<td></td>
<td>28</td>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td>Fodder</td>
<td></td>
<td>30</td>
<td>30</td>
<td>38</td>
</tr>
<tr>
<td>Other Food</td>
<td></td>
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<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Textile</td>
<td></td>
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<td>40</td>
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<td>Wood</td>
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<td>16</td>
<td>24</td>
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<tr>
<td>Paper</td>
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<td>18</td>
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<tr>
<td>Paper converting</td>
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<td>Print</td>
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<td>Organic</td>
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<tr>
<td>Inorganic</td>
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<td>4</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Other chemical</td>
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<tr>
<td>Building materials</td>
<td></td>
<td>17</td>
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<td>36</td>
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<tr>
<td>Iron &amp; steel</td>
<td></td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Non-ferrous metal</td>
<td></td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Other metal</td>
<td></td>
<td>18</td>
<td>14</td>
<td>26</td>
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<tr>
<td>Fertiliser</td>
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<td>Other industries</td>
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<tr>
<td>Buildings</td>
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<td>Commercial Offices</td>
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<td>Non-commercial Offices</td>
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<td>23</td>
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<td>Catering</td>
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<td>21</td>
<td>25</td>
</tr>
<tr>
<td>Health care</td>
<td></td>
<td>17</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Retail trade</td>
<td></td>
<td>19</td>
<td>19</td>
<td>22</td>
</tr>
</tbody>
</table>
3. Technical compliance. A third reason for non-standard behaviour is that for specific equipment the actual energy use may differ from the energy use under standardised test conditions. Although the equipment is installed according to the standard, the actual energy use may not be according to expectations, because the conditions may differ, but also because the installation is not carried out in an adequate way.

4. Rebound effects. A final effect that may play a role is that the behaviour of the regulated companies changes due to the changes in costs of energy services. If an energy service becomes cheaper due to energy-efficiency improvement, the use of this energy service may increase; or more money becomes available for other (possibly energy consuming) expenditures.

4.6 A case study on the effectiveness of energy-efficiency standards in the Netherlands

A key question is of course: are energy-efficiency standards effective? To this end we analyse - as a case study – an energy-efficiency standard that was recently introduced in the Netherlands.

Dutch companies are either restricted by General Administrative Order\textsuperscript{38} (AmvBs) or they are obliged to have a permit by virtue of the Environmental Management Act (‘Wet Milieubeheer’). Licences are designed for specific companies whereas AMvBs are more general regulations for business branches. Both the licenses and the AMvBs cover general restrictions for safety, environment and energy use.\textsuperscript{39} In this section we will evaluate the implementation of AMvBs and thereby focus and the compliance of the regulating agency (see section 4.5).

An evaluation of setting energy requirements in environmental permits was carried out recently by Tholen and Boswijk (2000). The main conclusions are that 1) there is limited technical knowledge for setting energy-efficiency requirements; 2) there is a lack of capacity for issuing and enforcing environmental permits for an effective energy policy; 3) there is lack of support for implementing energy policy measures by firms.

\textsuperscript{38} Translation from Dutch: “Algemene Maatregel van Bestuur”.

\textsuperscript{39} In practice energy is only considered as a relevant issue if the yearly consumption exceeds 25,000 m³ natural gas or 50,000 kWh.
In 1995 plans were made to revise the AMvBs because of a change in environmental policy from a regulative towards a more de-regulative approach. As a result of these changes the companies now have to comply with a duty of care, instead of complying with safety and environmental rules. This means that a company has its own responsibility to operate in such a way that risks, environmental pollution and energy use are as low as reasonable achievable; the government may perform inspections and demand that all reasonable measures must be implemented. State of technique (see section 4.4) and the interference with the company’s normal activities set the boundaries of reasonability (VROM, 1999). This means that all energy saving measures in buildings, facilities and processes that have a payback period of 5, 3 and 3 years respectively should be implemented, unless this cannot reasonably asked. This new regulation is introduced in 1988 for “sport and recreation” and for “hotel and catering” (Milieumagazine, 1999).

To comply with the new duty of care the availability of information on environmental friendly and energy efficient technologies and measures is essential for firms. Different agencies act as intermediate between the government and the companies supplying companies with information and advice. Two examples of these organisations are NOVEM and Infomil. Both publish information brochures on the subject of energy-efficiency measures.

4.6.1 Methodology

The evaluation of the effectiveness AMvBs has been performed through interviews on a municipality level. The questions were presented to the municipality environmental inspection department. The questions are listed in Table 4.3.

In order to get results from different types of municipalities, three sizes of municipalities were selected for the interviews: 5 large (> 100,000 inhabitants), 4 middle (20,000 - 50,000 inhabitants) and 2 small municipalities (5,000 – 10,000 inhabitants).

All eleven respondents work at the environmental inspection department of their municipality either as inspector or as manager of the environmental inspection department. The main results will be reported and clarified in the following section.

40 This change in policy was based on the governmental decision on “Competition, deregulation and legislative quality (MDW)".
4.6.2 Results of the survey

Inspection

Most municipalities inspect the companies according to the so-called BUGM (Implementation of Municipality Environmental Tasks Act) frequently, depending on the environmental impact or hazard of the company. The frequency of inspection varies from once every ten years to twice a year. The inspections are performed in an integral way, meaning that during inspection all environmental aspects are taken into consideration. The respondents made critical comments on the BUGM and the integral approach. Most respondents complained that they are not practical and that the new, less regulatory, environmental policy is more time consuming than the old regulatory approach. The extra time is needed for communication with the companies instead of simply laying down the rules. Of the interviewed municipalities, two (Amsterdam and Amersfoort) have implemented - or are in the process of implementing - new inspection systems.

Dominant sectors

According to the respondents the dominant AMvB sectors are hotel and catering, service and retail, agriculture and offices. This is confirmed by Dutch national statistics presenting leasing and business services, retail and agriculture as the dominant establishments (CBS, 2001).

Knowledge level

According to the respondents the knowledge level of the companies that are subject to AMvB regulation depends largely on the size of the firms; large companies are much better informed than small companies. Respondents mention also that differences among the sectors can be observed. The companies’ information sources, mentioned by the respondents, are the municipalities and the branch organisations. Only two respondents confirm that the companies are in the possession of the information magazines of Infomil. Of the eleven respondents four municipalities confirm receiving questions from the companies concerning the AMvB regulations.

The majority of the municipalities consider their own knowledge on energy conservation to be adequate for setting energy-efficiency standards. However,

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41 Translated from Dutch: Besluit Uitvoering Gemeentelijke Milieutaken.
almost all the respondents indicate that the knowledge level ‘can always be improved’.

**Workload and desired capacity**

The average number of AMvB companies per staff member of the municipal inspection team is about 175. However, the workload varies from 50 to about 400. Furthermore, the results suggest that the workload of the large municipalities is a bit lower than the workload of the middle and small municipalities. However, this could be inaccurate because the workload is expressed only in the number of companies and not in the complexity or size of the companies.

All municipalities indicate that an increase in inspection capacity is considered necessary. The municipalities that made quantitative statements on this issue reported that the capacity should be increased with 20 to 100%. An exception to this might be the relatively high desired personnel increase (300%) in one of the smaller municipalities. The results from the interview suggest that

<table>
<thead>
<tr>
<th>The questions are to structure the conversation. They are not interview questions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Municipality, department, function</strong></td>
</tr>
<tr>
<td><strong>1 Background</strong></td>
</tr>
<tr>
<td>1A How many AmvB companies and how many licenses are in your municipality? (if necessary give an estimation)</td>
</tr>
<tr>
<td>1B What is the most common AMvB sector?</td>
</tr>
<tr>
<td>1C There are different aspects in the AMvBs: Energy saving, water saving, waste prevention, waste separation, and waste water. Could you</td>
</tr>
<tr>
<td>1 Give the hierarchy in which they receive attention</td>
</tr>
<tr>
<td>2 Indicate whether they receive enough attention</td>
</tr>
<tr>
<td>3 Indicate which should receive more attention</td>
</tr>
<tr>
<td>1D How many companies have a relevant energy consumption (&gt;25,000 m³ natural gas /yr or &gt;50,000 kWh/yr)? How do you retrieve this information? (if necessary give an estimation)</td>
</tr>
<tr>
<td>1E What is the most common sector?</td>
</tr>
<tr>
<td><strong>2 Knowledge</strong></td>
</tr>
<tr>
<td>2A What is the AMvB registration procedure and how do the companies receive information?</td>
</tr>
<tr>
<td>2B Are the companies informed? If so, how?</td>
</tr>
<tr>
<td>2C Have the companies received the Infomil documentation? If so, through the municipality?</td>
</tr>
<tr>
<td>2D Do you receive questions from the companies? If so, concerning what subject?</td>
</tr>
<tr>
<td>2E Are there projects being performed or have there been projects that stimulate the environmental care of the companies? If so, what role was there for energy saving?</td>
</tr>
<tr>
<td>2F Are there aspects that need more attention (for example energy-efficiency improvement)? If so, which?</td>
</tr>
</tbody>
</table>
3 Inspection
3A Is there a periodical inspection of the companies? If so, what is the inspection frequency? If not, why?
3B Are the aspects inspected separately or all at the same time?
3C With what frequency and how often are companies requested to perform an energy analysis?
3D Has there been a company that did not comply with the rules? If so on what subject?
3E In the case of non-compliance, does you municipal intervene or is it accepted?
3F What is the personnel and knowledge capacity of your environmental inspection department (if possible specify in for example how many legal, technical, etc.)
3G Is this capacity sufficient to operate? What should the capacity be?

4 Improvements
4A What measures are being taken or have been taken to improve the inspection and communication?
4B Is there, in your opinion, a municipality that has a better inspection and communication system than your municipality?
4C In your opinion, what should be done to improve inspection and communication?

5 Other and additional comments

There is a structural workload problem throughout the municipals. This observation is supported by the fact that the current inspection capacity is based on the outdated BUGM approach, whereas the new de-regulative approach to environmental policies requires much more time consuming implementation and enforcement efforts.

Priority given to energy issues

Most municipalities consider waste prevention and safety as the most important environmental themes. Only three of the eleven respondents consider energy efficiency to be the most important theme in their municipal’s policy. These three municipalities include the large municipalities Almere, Amersfoort and Amsterdam. The other municipalities do not mention energy as an important theme. However, six of these respondents are of the opinion that energy does not receive enough attention.

All but five respondents either do not know if there are companies that have a relevant consumption or, they are of the opinion that there are no AMvB companies within their municipality with a relevant energy consumption. This level can easily be reached by, for example, a hotel. Therefore, the absence of companies with a relevant energy consumption might be correct for the two small municipalities, but it is very unlikely for the middle and large municipalities involved.

This lack of energy-efficiency priority is confirmed by the frequency in which the municipalities have requested companies to perform an energy analysis, and
the estimations made of the number of AMvB companies for which energy consumption is a relevant issue.

Only two respondents mentioned that there have been requests for energy analysis. Amersfoort requires energy analysis in approximately 90% of their inspections (Amersfoort has its own inspection system) and Amsterdam has an average of 500 requests per year (out of 9500 relevant companies).

Recommendations by the respondents

Respondents suggested three dominant improvements. The first is an increase of staff to relief the current workload (mentioned nine times). Secondly the respondents suggest that the procedures for setting requirements must become more clear and uniform (mentioned five times). The third suggestion concerns the improvement of communication between the municipality and the companies (mentioned three times).

Conclusions on the case-study

We have examined regulation directed at small and medium enterprises in the Netherlands. We found that in the overwhelming majority of the cases the responsible agency (i.e., the municipality) is not very active in enforcing compliance. The agency’s knowledge on the problem seems to be limited and low priority is given to energy-efficiency improvement.

The findings suggest that in this case the normative instrument does not seem to be effective (although examining what actually happens in the regulated companies can only provide the final answer to the question of effectiveness). But, anyway the case shows that full compliance of direct regulation should not be taken for granted.

One of the obvious solutions is to increase staffing of the municipal agencies involved. However, it seems more important that in the design of direct regulation, the issue of compliance by the regulating agency (rather than the compliance by the end user of energy) is already taken into account.

4.7 Conclusion

Standard setting is not at all a new instrument in environmental policy, but in the area of energy-efficiency improvement it is relatively new (except for new buildings and specific new equipment).
From this preliminary analysis it turns out that both the design and the implementation of energy-efficiency standards is not as simple as is often assumed.

The basic approach for the design of standards is to use best-practice criteria. We analysed various ways to translate these criteria into practical standards. If we follow the logic of terms like ‘not exceeding excessive costs’ strictly it turns out that, for energy-extensive firms, far-reaching energy-efficiency measures can be called for. For energy-intensive firms governments should restrict themselves in their requirements.

For a specific case of energy-efficiency legislation in the Netherlands, it turns out that the first bottleneck for legislation to be effective lies in the compliance by the regulating agencies (in this case the municipalities). If new legislation is introduced, much more attention needs to be paid to the design of normative instruments and the accompanying implementation and enforcement strategies of the agencies.
5 NEGOTIATED AGREEMENTS

5.1 Introduction

Negotiated agreements - also often indicated as voluntary agreements - can be defined as ‘agreements between government and a sector in the national economy to facilitate voluntary action with a desirable social outcome, encouraged by the government. This action is undertaken by the participant, based on the participant’s self-interest’ (OECD, 1996). Once the agreement has been negotiated parties are bound to (fixed) procedures and rules. Negotiated agreements on energy efficiency in firms have become popular in many OECD countries. They exist in some form in at least in Australia, Canada, Denmark, Finland, Germany, the Netherlands, the United Kingdom and the USA (IEA, 2001).

Among the oldest negotiated agreements on industrial energy efficiency are the Long-Term Agreements (LTAs) in the Netherlands, that have existed since the early nineties. Much of the empirical material presented in this chapter is based on studying the Netherlands’ agreements. Therefore, we will start with a brief introduction to these agreements (Section 5.2).

A negotiated agreement is a policy instrument in which many intervention mechanisms are combined: communication plays an important role, but also economic and normative mechanisms play a role. The mechanisms will be elaborated upon in Section 5.3.

A key question is: are negotiated agreements effective? Do such agreements really lead to action on top of what would have been done anyway? This question will be treated in two steps. In Section 5.4 the goal achievement is discussed; Section 5.5 discusses the effectiveness. Section 5.6 deals with the related question of the cost-effectiveness of the agreements.

Finally, in Section 5.7 provides recommendations, based on the studies that have been performed up to now.

5.2 The Long-Term Agreements in the Netherlands: Institutional aspects, measures and goals

As a result of increasing environmental awareness in the late eighties the Dutch government decided to give stronger and new policy impulses to energy
conservation and the application of renewable energy resources. This decision was embodied in new measures, including Long-Term Agreements, announced in the National Environmental Policy Plan-plus (NEPP-plus, 1990) and the First Memorandum on Energy Conservation (Ministry of Economic Affairs, 1990). The goal set by the government was to stabilise national CO₂ emission in 1994-1995 at the 1990 level and reduce CO₂ emissions by 3-5% by the year 2000 relative to 1989/1990. In order to achieve these environmental objectives, the manufacturing industry had to make a substantial contribution towards reducing energy consumption. In the First Memorandum on Energy Conservation the target formulated for the manufacturing industry was a 20% energy-efficiency improvement by the year 2000 relative to 1989. On the basis of new economic growth forecasts this target was lowered to 19% in the Second Memorandum on Energy Conservation (Ministry of Economic Affairs, 1993).

The LTAs are considered as the most important policy instrument leading to energy conservation in the manufacturing industry. The government formulated two important targets regarding the LTAs:

- Long Term Agreements have to cover 90% of the total industrial energy consumption of the Netherlands.
- The energy-efficiency of the industry has to improve by 20% in 2000 compared to 1989 level.

Target groups for the LTAs are all industrial branches with an energy use over 1 PJ per year. Firms joining an LTA must improve energy-efficiency as far as practically and economically feasible. In return the Dutch government agreed not to introduce new regulation on energy-efficiency and give financial support.

Process leading to an LTA

The process leading to an LTA can roughly be divided in two phases. The first phase leads to the declaration of intent signed by the Ministry of Economic Affairs and the branch organisation(s). The declaration of intent only confirms the wish of both parties to come to an agreement. The second phase start with an inventory on energy reduction options within the sector. Results of the inventory are the input to get to a long-term plan for energy conservation for the industrial sector and a quantitative target for energy-efficiency improvement, which both form the key element of the LTA. At the end of the second phase the LTA is signed by the Ministry of Economic Affairs and the

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42 Excluding feedstocks.
industrial branch organisation(s) and in some cases co-signed by Novem, the Association of Provinces or individual firms. This is the starting point for implementation of the LTA on the individual firm level. Figure 5.1 illustrates the process leading to an LTA.

**Process on Long-Term Agreements**

- **Strategic talk between Novem the Ministry of Economic Affairs and Industrial Branch.**
  - Signing of a **Declaration of Intent**
  - Inventory of organisational and technical energy conservation measures (within some or all firms in the branch).
  - Signing of the **Long Term Agreement**
  - Implementation of the Long Term Agreement

**Figure 5.1** Process on Long-Term Agreements in the Netherlands (Glasbergen et al., 1997).

**Contents of an LTA**

An LTA holds the agreements and obligations for the firms and the Ministry of Economic Affairs. The responsibilities and tasks of Novem and the branch organisation are not officially stated in the agreement.

Firms can join the agreement by signing a letter of accession. The firms are obliged to:

- Target and timetable on the improvement of the energy-efficiency for the industrial branch. General targets set in the LTAs are an energy-efficiency
improvement of 20% in 2000 compared to 1989 level. An energy-efficiency improvement of 20% means a reduction of the EEI by 20% (see Box 5.1).

- Plan of action on how the branch is going to increase their energy-efficiency. The contents of company energy plans and economic viability of the plans have to be added.

- The way in which the agreement will be monitored. Long Term Agreements are monitored by determining the decrease in energy-use per unit of physical product output (the so-called energy-efficiency index (EEI)). In general more than one product is produced; then one aggregated EEI is calculated per sector (see Box 5.1).

- Firms must annually report their results on energy-efficiency improvement to the Dutch energy-agency Novem.

- Individual firms can be excluded from the LTA if they fail to provide an energy conservation plan and annual monitoring results. Firms will be subject to existing regulations, i.e., environmental permits.

In the LTA the Ministry of Economic Affairs officially agrees to give financial support the LTA program and maintain the financial assistance within the framework of the LTA. The Ministry is furthermore responsible for the co-ordination of regulatory measures aimed at energy efficiency in industry, including requirements to obtain permits and energy taxes. The government assures consistency and protection from new regulations aimed at energy-efficiency improvement.

The Branch association is the contracting party in the LTA. The association represents the firms in their sector. The association has mainly an organising and co-ordinating role in implementing the LTA. The branch association draws the firms’ attention to the need for energy conservation in the sector and communicates with and between their members about the LTA.

The Netherlands Agency for Energy and the Environment (Novem) acts as an intermediary between on the one hand the Ministry of Economic Affairs and on the other hand the industrial branch organisations and the firms. In general Novem is charged with:

- the executive responsibility for preparing and advising the firms and the branch on the LTAs.

- co-ordinating and providing technical and financial support to firms and branches for energy conservation projects, research and development and demonstration and pilot projects.
• verifying the aggregate monitoring results in the sector.
• advising the licensing authorities about the LTA and the environmental permit.

Box 5.1 The Energy-efficiency index (EEI).

The monitoring methodology in the LTAs relates the actual energy consumption in a specific year to the energy that would have been needed if no change in the aggregate specific energy consumption had occurred since the base-year 1989. The actual energy consumption is thus compared with the 1989 frozen intensity situation. In formula (for a firm with \( n \) different products):

\[
EEI_j = 100 \times \frac{E_j}{E_{\text{ref}, j}} = 100 \times \frac{E_j}{\sum_{i=1}^{n} (P_{i,j} \times SEC_{i,bj})}
\]

in which: \( EEI \) is the EEI in year \( j \); \( E_j \) is the actual primary energy consumption in year \( j \); \( E_{\text{ref}, j} \) is the reference energy consumption for year \( j \); \( P_{i,j} \) is the physical production amount of product \( i \) in year \( j \); and \( SEC_{i,bj} \) is the specific energy consumption of product \( i \) in the base-year (\( bj \)). The factor 100 is introduced for scaling only; by definition the EEI is 100 in the base-year. The EEI of a whole sector is calculated as the ratio of the total actual energy consumption of the firms and the total frozen-intensity energy consumption of the firms. In formula for a sector \( s \) in year \( j \):

\[
EEI_{s,j} = 100 \times \frac{\sum E_j}{\sum E_{\text{ref}, j}}
\]

Supporting measures and complementary policies

Besides the LTA (energy covenant) there are several complementary policies and supporting measures that influence energy conservation behaviour of firms, see Figure 5.2. First of all, there is a set of policy measures which support the implementation of the energy covenant. The supporting measures are particularly relevant but not exclusively available to firms in the LTA scheme.

The Second Memorandum on Energy Conservation (Ministry of Economic Affairs, 1993) distinguishes the following set of instruments:
1. Energy management: energy audits and monitoring systems designed to support the firms’ energy management.

2. Investment subsidies and fiscal incentives: several subsidy schemes and fiscal incentives introduced to encourage investment in energy saving projects (especially in technologies less familiar to industry), like for example energy recovery and heat pumps.

3. Demonstration: special support schemes drawn up to promote technological innovation.

4. Novem sector programmes: funds made available for the support of energy conservation studies, research & development projects and the support of monitoring and communication.

5. Information and consultancy: various subsidy schemes introduced to encourage firms to use external consultants providing screening, information and consultancy services, including the advisory activities of the energy production and distribution sectors within the framework of the Environmental Action Plan (MAP) and the Environmental Plan for Industry respectively.

This set of supporting measures is considered to be an integral part of the LTA policy mix (see Figure 5.2).

In Figure 5.2 we distinguish two types of government intervention that are not part of the LTA policy mix.

One particularly relevant initiative of the Environmental Action Plan is to encourage co-operation between industry and energy distribution companies in the field of industrial combined generation of heat and power (CHP). According to Blok and Farla (1996), these complementary activities of the energy distribution sector and special investment subsidies for CHP made the most significant contribution to the growth of the CHP capacity in the early nineties. Furthermore, industry has to comply with other regulatory policy instruments within the framework of the national environmental policy. These instruments, which closely resemble those used in the industrial energy conservation policy, include environmental covenants, corporate environmental care systems and environmental permits. The environmental permit is considered as a ‘fall-back’ instrument if firms refuse to comply with the LTA. The complementary effects of these environmental policy instruments on energy conservation are however considered to be limited, since recently these regulatory instruments have paid only little attention to energy-efficiency improvement (Glasbergen, 1997).
5.3 The mechanisms: how do negotiated agreements work?

Three main mechanisms along which LTAs influence energy conservation behaviour of firms can be identified:

1. Profitability/cost reduction
An important decision criteria for making investments is the profitability of the taken investment and the associated reduction in production costs. The LTA policy mix can influence the profitability of the investments or reduce energy costs in the following way. First, subsidies linked with the LTA energy covenant decrease investment cost and thus increase the profitability of energy saving options. Secondly, knowledge diffusion increases the number of profitable energy saving options which were not known before. Third, LTAs can change the strategic policy and operative business goals of firms. Altered business criteria can increase the profitability of energy saving investments (Rietbergen et al., 1999). It must be kept in mind that energy saving investments still have to compete with alternative (even more profitable) investments.

Figure 5.2 Policies influencing industrial energy conservation (investments).
2. Learning, energy management and motivation

Learning implies that the involved actors are involved in a continuous improvement of policy aimed at energy efficiency. At firm level a proper energy management appears to be an important route along which firms initiate new energy conservation projects. Energy management includes the following activities: - the monitoring of energy use in specific parts of the (core) process - and - a systematic search for new conservation options (e.g., company energy plan and new organisational routines). Anchoring energy issues in the overall process management increases the attention paid to energy-efficiency improvement. Furthermore the direct involvement of firm actors increases motivation to reduce energy use. In the branch organizations a similar learning process is discernable. The branch organization has become an organ responsible for channeling communication to its members and between its members and the other in the LTA network. Moreover the branch organizations are now also dealing with energy issues more actively than in the pre-LTA period (Glasbergen, 1998).

3. Communication/knowledge diffusion

An important for barrier for investing in energy saving measures can be a lack of knowledge on new options for energy conservation. The LTAs appear to increase investment in energy saving technologies due to a sharing of information and knowledge among firms, sectors and other relevant actors, like the energy agency. Several activities - such as drawing up sectoral communication plans, generation of new network links and the establishment of energy boards - identify the working of this mechanism. The LTAs have clearly extended and structured communication and knowledge transfer relating to energy (Rietbergen et al., 1999).

5.4 Goal achievement in negotiated agreements on energy efficiency

In this section we describe the relationship between the original policy goals (in terms of energy-efficiency targets) in the LTAs and the goal achievement as presented in the LTA monitoring reports. We distinguish the goal achievement in the negotiation phase and the actual performance
### Table 5.1 Long-term Agreements contracted with industry and their results (Ministry of Economic Affairs, 2000)

<table>
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<tbody>
<tr>
<td>Potato Processing</td>
<td>17-6-96</td>
<td>1-1-01</td>
<td>8.0</td>
<td>20.5</td>
<td>20</td>
</tr>
<tr>
<td>Breweries</td>
<td>10-3-98</td>
<td>1-1-01</td>
<td>3.9</td>
<td>24</td>
<td>27</td>
</tr>
<tr>
<td>Cacao</td>
<td>7-11-98</td>
<td>1-1-06</td>
<td>2.3</td>
<td>12.3</td>
<td>18</td>
</tr>
<tr>
<td>Soft Drinks</td>
<td>11-7-96</td>
<td>1-1-01</td>
<td>0.8</td>
<td>17.4</td>
<td>21</td>
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<tr>
<td>Fruit and Vegetables</td>
<td>17-12-97</td>
<td>31-12-00</td>
<td>2.6</td>
<td>9</td>
<td>17</td>
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<tr>
<td>Coffee Roasting</td>
<td>26-11-96</td>
<td>1-1-01</td>
<td>0.8</td>
<td>21.7</td>
<td>19</td>
</tr>
<tr>
<td>Margarine/Fats/Oils</td>
<td>2-4-96</td>
<td>1-1-01</td>
<td>8.3</td>
<td>18.5</td>
<td>22</td>
</tr>
<tr>
<td>Sugar</td>
<td>3-9-93</td>
<td>1-1-01</td>
<td>6.1</td>
<td>23.5</td>
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<tr>
<td>Meat Processing</td>
<td>8-9-93</td>
<td>1-1-00</td>
<td>4.7</td>
<td>10.7</td>
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</tr>
<tr>
<td>Dairy</td>
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<td>1-1-01</td>
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<tr>
<td>Food and drink ind.</td>
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<tr>
<td>Asphalt</td>
<td>6-11-95</td>
<td>1-1-01</td>
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<td>Cement</td>
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<td>Fine Ceramics</td>
<td>26-4-94</td>
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<td>1-1-00</td>
<td>9.2</td>
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<td>20</td>
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</tr>
<tr>
<td>Paper and Cardboard</td>
<td>4-6-96</td>
<td>1-1-01</td>
<td>31.3</td>
<td>20.9</td>
<td>20</td>
</tr>
<tr>
<td>Textile</td>
<td>8-3-96</td>
<td>1-1-01</td>
<td>3.4</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>Other industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-ferrous</td>
<td>2-12-96</td>
<td>1-1-01</td>
<td>9.6</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Iron and Steel</td>
<td>21-12-95</td>
<td>1-1-01</td>
<td>58.9</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Basic Metal Ind.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold Storage</td>
<td>15-3-96</td>
<td>1-1-01</td>
<td>2.1</td>
<td>21.7</td>
<td>28</td>
</tr>
<tr>
<td>Industrial Laundries</td>
<td>16-6-94</td>
<td>1-1-01</td>
<td>1.3</td>
<td>23.5</td>
<td>20</td>
</tr>
<tr>
<td>Surface Treatment</td>
<td>14-3-96</td>
<td>1-1-01</td>
<td>2.2</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Carpet</td>
<td>26-6-96</td>
<td>1-1-01</td>
<td>1.0</td>
<td>15.7</td>
<td>20</td>
</tr>
<tr>
<td>Iron Foundry</td>
<td>23-6-95</td>
<td>1-1-01</td>
<td>2.4</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>Other Industry</td>
<td>24-6-96</td>
<td>1-1-01</td>
<td>13.7</td>
<td>11.3</td>
<td>20</td>
</tr>
<tr>
<td>Light industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemicals</td>
<td>24-11-93</td>
<td>1-1-01</td>
<td>323.0</td>
<td>22.6</td>
<td>20</td>
</tr>
<tr>
<td>Refineries</td>
<td>1-9-95</td>
<td>1-1-01</td>
<td>145.0</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Total (excl. refineries)</td>
<td></td>
<td></td>
<td>700</td>
<td>20.4</td>
<td>18</td>
</tr>
</tbody>
</table>
The negotiation phase
The government pursued the translation of her policy goals into individual long-term agreements during the negotiations with many industrial sectors. Between 1993 and 1999 up till 30 industrial agreements were concluded. As we can see in table 5.1 it turned out to be possible to agree on a 20% decrease in energy intensity with most of the sectors in the manufacturing industry in the year 2000 compared to the level in 1989. This homogeneous 20% goal is rather strange when we know that an exploratory survey was conducted in most of the sectors to find the (profitable) potentials for energy intensity decrease before the LTA was contracted. From studies on these potentials (De Beer et al., 1994) we know that these may vary significantly by sector.

The LTA for the refineries has an energy intensity reduction target of 10%. Because of this relatively low target for a sector with a large share of the (industrial) energy consumption the energy-weighted average for the 30 sectors is calculated to be 18%.

The total primary energy consumption in 1989 that is covered by the sectors that negotiated an agreement amounts to 653 PJ. The industrial primary energy consumption (including refineries and coking plants) according to CBS amounted to 868 PJ in 1989.43 The industrial energy consumption (1989) in the Memorandum on energy conservation (Ministry of Economic Affairs, 1990) amounts to 902 PJ.44 This implies that 72-75% of the industrial energy consumption in 1989 is covered by the LTAs.45

An overview of the energy consumption by industry group and the share that is covered by the LTAs is given Figure 5.3. The data for this figure were taken from the national energy statistics (CBS, annual publication) and from the monitoring results of the LTAs (Ministry of Economic Affairs, 1999). In

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43 The energy consumption in 1989 according to CBS (annual publication) is corrected on the basis of new information on the energy consumption of the chemical industry in that year.
44 The correction that we applied to the CBS statistical data (cf. previous footnote) is also applied to the data from the Memorandum on Energy Conservation (Ministry of Economic Affairs, 1990). To the data from the Memorandum on Energy Conservation we added the electricity conversion losses, based on the share of electricity consumption in the CBS data.
45 The long-term agreement with the oil and gas (exploration) industry is not included in our data. The reason is that this sector was not considered part of the manufacturing industry in the Memorandum on energy conservation. Adding this LTA would not lead to a higher coverage of the 1989 energy consumption by the LTAs because the energy consumption in the oil and gas industry would have to be added both in the numerator and the denominator of the coverage ratio.
NEGOTIATED AGREEMENTS

this figure we show in which clusters of industry the largest differences between the actual primary energy consumption and the coverage by the LTA occurred. Further examination of these differences, teaches us that there are three reasons for a low coverage:

- Some sectors did not conclude an LTA. We calculated that approximately 90% of the primary energy in 1989 was consumed in the sectors with which an LTA has been concluded.46

- Some firms do not participate in the LTA that is concluded for their sector.47 On average, the firms that participate in the LTAs cover 92% of the primary energy in their sector.

- Definitions of ‘energy consumption’ in the LTAs are in some cases different from the definitions by the Netherlands Central Bureau of Statistics (CBS). These differences cause the overall effect that another 10% of the primary energy consumption in the LTAs’ firms is not taken into account by the LTAs.

Figure 5.3 Overview of the 1989 primary energy consumption by cluster of industry and the coverage by the LTAs (situation 1997).

Figure 5.3: Overview of the 1989 primary energy consumption by cluster of industry and the coverage by the LTAs (situation 1997).

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46 This figure of 90% is regularly quoted by Novem and the government as the overall coverage of the energy consumption by the LTAs.
The cumulative effect of the above three reasons leads to the aforementioned 72-75% coverage of the primary energy consumption by the LTAs.

The most important example of a difference in the definition of energy consumption is found in the basic metal industry. About half of the energy consumption in that sector has been categorised as non-energetic use of energy carriers, unlike the categorisation in the national energy statistics (CBS, annual publication) and in the Memoranda on energy conservation (Ministry of Economic Affairs, 1990, 1993). The non-energetic use according to the LTAs concerns the use of coal and coke in the reduction step of the iron production, and the electricity consumption in electrolytic production steps in the non-ferrous metal industries. A target to decrease the energy intensity by 20% (1989-2000) would not have been possible for the basic metal industry – on the basis of known profitable energy intensity measures (Worrell et al., 1993) – if the total energy consumption (including coal, coke and electricity used for electrolysis) had been taken into account.

**Actual performance**

Up till 31 December 1999 30 LTAs have been concluded with the manufacturing industry (see Table 5.1). Currently more than 1350 firms are participating in the industrial LTAs. The total primary energy use, excluding feedstocks, covered by the industrial agreements amounted to 700 PJ in 1999. In the period 1989-1999 the total amount of saved energy compared to a frozen efficiency energy consumption was about 142,5 PJ (Ministry of Economic Affairs, 2000). In 1999 the average energy-efficiency improvement in 29 industrial sectors amounted to 20.4% compared to the 1989 level, corresponding to an annual average energy-efficiency improvement of 2.3%. Thus, on the basis of these figures the average target of 20% reduction in energy intensity has already been reached. The results for different clusters of industry, however, vary considerably. The chemical industry, accounting for more than 53% of the energy consumption of the Dutch manufacturing industry, is performing better than average, whereas clusters like light industry

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47 For instance, one refinery does not participate in the LTA.
48 Including refineries.
49 The frozen efficiency energy consumption is the amount of energy that would have been used if the energy intensity of (production) processes and activities had not changed. The frozen efficiency energy consumption takes into account structural changes and activity growth within the sectors and firms.
and building materials are far behind schedule. However, the energy consumption covered by these LTAs is a relatively small fraction of the total energy consumption of the industrial LTAs. In Figure 5.4 we see that especially sectors in which many firms are included are lagging behind.

The simple-average goal achievement over all the sectors (relative to the interpolated target) is 84% in 1997. If we weigh the sectors by their energy use, we find an average goal achievement of approximately 100%.

Figure 5.5 shows that there is not a clear relationship between energy intensity and the goal achievement of industrial sectors. Energy-intensive sectors that lag behind are those in the cluster building materials. These sectors are energy intensive but do not perform very well. For the remaining sectors the rule “the higher the energy intensity the better the performance” is valid.

- Some issues on the measurement of primary energy use were open to dispute, e.g., the conversion of electricity to primary energy; whether fossil-derived waste should be included; and which part of the energy use should be defined as feedstock.
- The definition of aggregate production in most long-term agreements was not transparent.
- Both for energy use and for aggregate production the trends in the monitoring results differed from those reported by the national bureau of statistics CBS. Especially uncertainties remain for the chemical industry, which is a problem because of the importance of this sector in the Netherlands' industrial energy use.
- Correction factors could be used for matters like changes in product specification, regulation, outdoor temperature. It turned out that these correction were applied unidirectional, i.e. only if they could improve the reported results. However, the total effect on the results is small.
- Errors occurred in the monitoring reports.

We recommend - for future negotiated agreements - to use better monitoring guidelines and to require more detailed monitoring reports. Furthermore, independent verification of the monitoring results is necessary.
Conclusions on goal achievement

On the basis of the previous subsections we conclude that LTAs have been agreed upon for industrial sectors that together cover 90% of the (primary) energy consumption in manufacturing industry. However, because not all firms in these sectors participate in the LTAs and because of differences in the definition of energy consumption, only about 75% of the energy consumption is actually covered by the LTAs and the monitoring of the LTAs. According to the results that are reported annually in the LTA monitoring reports, the average target for energy-intensity reductions in the year 2000 has already been reached in 1999. On the other hand, a large number of LTAs - that together cover a relatively small part of the industrial energy consumption - is substantially lagging behind the agreed energy intensity reduction rates.
Now that we have estimated to what extent the goals set out were achieved, the next step is to estimate to what extent the long term agreements contributed to these achievements.

One way to isolate the contribution of the LTAs to energy-efficiency improvement is to investigate the additional investment and the related energy savings made by industry. The following three-step bottom-up method has been developed to estimate the effect of LTAs on industrial energy consumption. In this analysis, the LTA is considered as a mix of policies of which the energy covenant (negotiated agreement) is the main element. The energy covenant is supported by accompanying measures like subsidies and fiscal incentives which are assumed to be an integral part of the LTA policy mix. The complementary effects of other energy and environmental policies on energy conservation are not attributed to the LTAs (see Figure 5.2).
Step 1. In the first step, an inventory is made of all the energy-saving measures taken at sector level. The energy-saving measures are attributed to different investment categories, which have been derived from the classification used in the Dutch annual LTA progress reports. The LTA progress reports generally distinguish between the following investment categories:

- **Good housekeeping/energy management.** This category concerns energy-saving measures that have a relatively short pay-back period and do not require large investment.
- **Replacement investments.** These investments are aimed at the replacement, maintenance or extension of industrial equipment. Replacement investments are made primarily for strategic reasons. The profitability of these investments does in general not depend on the energy conservation potential. Energy conservation, related to these investments, often has a process-integrated character.
- **Energy-saving investments (retrofit).** Energy-saving investments concern measures aimed primarily at the improvement of energy efficiency. Hence, the profitability of these investments depends largely on the conservation potential of the energy-saving measure. Examples of such investments are insulation, adjustable speed drives and heat recovery.
- **Combined heat and power generation (CHP).** Investments in co-generation are considered as a separate conservation category, since CHP can lead to a considerable saving of fuel.
- **Other measures.** Finally, some activities come under the heading of ‘other measures’; these include the closing down of firms and NOx emission reduction measures, which can also improve energy efficiency.

Step 2. In the second step it is judged whether and to what extent firms’ investments are encouraged by the agreements. The firms’ investment behaviour is assessed from the perspectives of both experts (a) and firm actors (b).

a) In this study the expert opinions about the investment behaviour of firms are judgements made by the research team about the investment behaviour of firms as well as the judgement made by the steering committee of the project ‘Evaluatie Meerjarenafspraken over energie-efficiency’ set up by Glasbergen et al. (1997). In general, the following guidelines for the assessment procedure are observed:
• Investments in energy-saving measures in the category *good housekeeping/energy management* are assumed to be stimulated almost entirely by the agreements, since the measures do not invoke excessive costs; the measures could have been taken anyway.
• Since *replacement projects* are not primarily implemented for the purpose of energy-efficiency improvement, these investments are considered to be stimulated only slightly by LTAs.
• According to the experts the investments in *CHP* are promoted to a slight extent, since CHP investment is already considerably encouraged by the MAP drawn up by energy distribution companies as well as by the special subsidies for the promotion of CHP investment).
• Since measures in the category *retrofit investments* are aimed at the improvement of energy efficiency and require considerable investment, the experts assume that these measures are largely stimulated by agreements.
• Investments in the category *‘other activities’* are assumed not to be stimulated by the agreements.

In particular cases energy-saving measures can also be ‘considerably stimulated’ by an LTA. For more details on the assessment procedure followed the reader is referred to Glasbergen et al. (1997).

b) In a survey conducted by de Groot et al. (1999), *firm actors* were asked to assess to what degree agreements have promoted investment in ‘good-housekeeping measures’, ‘replacement projects’, retrofit measures’ and ‘CHP-installations’. The survey yielded a data set for about 60 Dutch firms with an LTA on energy efficiency. The data set includes firms in nine different industrial sectors. Figure 5.6 shows the survey response.

More than 90% of the respondents point out that energy-saving measures in the category ‘good-housekeeping’ are slightly to largely stimulated by the LTAs. This judgement contrasts sharply with the opinion of the experts, who assume that good-housekeeping measures are stimulated almost entirely by LTAs. According to 50% of the firms replacement investments are stimulated slightly by the LTAs. This result corresponds very closely to the opinion of the experts. The firms are of the opinion that the retrofit investments are slightly to largely stimulated by the LTAs. This differs from the opinion of the experts who assume that the investments are largely stimulated by the LTAs. More than 65% of the firms with a CHP plant indicate that the CHP investments are largely to almost entirely promoted by the LTAs. The survey response contrasts with the opinion of the experts. The high response in the category ‘not’
stimulated can probably be attributed to the fact that a large number of firms had invested in CHP installations before LTAs were concluded.

*Step 3.* In the third step the qualitative judgements are translated into a weighting scheme in order to calculate the effectiveness of the LTAs in terms of saved energy. The sensitivity of the weighting scheme is tested by considering a low and a high variant.

Table 5.2 shows the three weighting schemes:

<table>
<thead>
<tr>
<th>Degree of stimulation</th>
<th>High</th>
<th>Average</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not stimulated</td>
<td>10%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Stimulated to a slight extent</td>
<td>30%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Considerably stimulated</td>
<td>60%</td>
<td>50%</td>
<td>40%</td>
</tr>
<tr>
<td>Largely stimulated</td>
<td>90%</td>
<td>80%</td>
<td>70%</td>
</tr>
<tr>
<td>Entirely stimulated</td>
<td>100%</td>
<td>100%</td>
<td>90%</td>
</tr>
</tbody>
</table>

1Table 5.2 must be read as follows. The average weighting scheme assumes that 80% of the saved energy is the actual effect of the agreement in the case where investments are 'largely stimulated'. If investments are stimulated to a slight extent, only 20% of the saved energy is encouraged by the agreement, etcetera. The actual effect of all the investments on energy conservation is calculated in this way and aggregated on a sector level.

*Results*

The method outlined in the previous section was applied to the following five industrial LTAs: chemical industries; paper & board industries; glass industries; iron & steel industries and margarine, fats & oils. In 1996 the share of the five sectors in the energy consumption covered by the 29 industrial LTAs was nearly 80%. The analysis of the effects of changes in investment behaviour on industrial energy conservation covers the period 1989-1996.

The total energy saved in the five evaluated industrial sectors amounted to 64 PJ in the period 1989-1996. The average energy-efficiency improvement in the five sectors amounted to about 13.1% in 1996 compared to the level in 1989. This is slightly better than the average result (12.5%) as reported by the Ministry of Economic Affairs.

Figure 5.7 shows the estimated contribution that energy savings in the five investment categories made to the total savings of the five evaluated industrial sectors in the period 1989-1996. The energy-saving data per investment
category were derived from the annual LTA progress reports of the individual sectors. Investment in the replacement of existing equipment contributes the most to the overall energy savings (32%). The investment categories ‘retrofit’ (18%), ‘CHP investments’ (22%) and the category ‘other activities’ (22%) contribute almost equally to the overall energy savings. The remaining 9% of the energy savings can be identified as good housekeeping measures.

Figure 5.6 Survey response.
Figure 5.7 Total and stimulated energy savings per conservation category1,2

1 The Sum of the energy savings is plotted against the secondary axis.
2 Error bars indicate the stimulated energy savings when the low and high weighting schemes were used.

On the basis of the firms’ and the experts’ judgement, it can be concluded that about 30-40% of the energy savings are considerably to almost entirely stimulated by the LTAs, whereas 60-70% of the total energy savings are slightly or not stimulated by the LTAs. The firms indicated that more than one third of their energy savings are not stimulated at all by the LTAs. The experts are of the opinion that about 50% of the energy savings are slightly encouraged by the LTAs. The stimulated energy savings per investment category are depicted in Figure 5.7. The error bars indicate the stimulated energy savings when the other weighting schemes were used. Large differences between the stimulated savings from the perspective of the firms and the experts can be observed in the investment categories ‘good housekeeping’, ‘retrofit’ and ‘CHP’. The total stimulated savings from both perspectives however do not differ very much. The estimations based on the expert opinions indicate that about 27-44% (17-28 PJ) of the energy savings can be attributed to the implementation of the LTAs. When the assessment is based on the firms’
survey response, the percentage of energy savings promoted by the LTAs is about 29-44% (18-28 PJ).

Discussion
The design of the method requires clarification. First, it should be emphasised that, although the overall assessment results do not differ very much, large differences were observed between the firms’ and experts’ judgement regarding industrial investment behaviour. In this respect it is regrettable that the bias in firms’ survey response and possible misinterpretation of survey questions could not be analysed in more detail on the basis of the survey data. Secondly, due to a lack of detailed energy-saving data and information on the purpose of investments the energy-saving measures were classified into only five different categories. A more detailed classification of energy-saving measures (for example distinguishing own CHP and joint venture CHP) and thus an appropriate assessment would probably have led to more accurate results.

With regard to the quality of the results, it should be mentioned that the results depend for a large part on the energy-saving investments made in the chemical industry. The chemical industry is responsible for more than 70% of the total energy savings in the five evaluated sectors. However, if the chemical industry is not taken into account the effectiveness of the LTAs ranges from 41-59% (expert opinion) and 35-52% (firms’ judgement).

An alternative way of isolating the actual outcome of the LTAs is to compare the overall monitored energy-efficiency improvement with the energy-efficiency improvement in the business-as-usual (BaU) case. The BaU scenario reflects the energy-efficiency improvement arising from technological or operational changes that would have taken place anyway, even without the influence of the LTA policy mix. The energy-efficiency improvement in the BaU case can be estimated by simulating the impact that energy investment behaviour of industrial firms had on energy-efficiency improvement in the absence of the LTAs. We have also applied this alternative method to determine the effectiveness; this leads to comparable results, see Rietbergen et al. (2002).

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50 In this respect it is regrettable that in this particular sector there are substantial discrepancies between the energy consumption data of LTA monitoring reports and national statistics, see Farla and Blok (2002). This means that the overall results must be regarded as only preliminary.
Recommendations

Further analysis of the effects of changes in investment behaviour is in our opinion a promising route for further research. This type of analysis can be further enhanced in the following ways. First of all, we recommend that the definition of investment categories should be improved and the level of detail be increased. As suggested in the previous section this could improve the quality of the results. Secondly, we believe that more systematic surveys should be conducted among firms. Although one has to deal with problems like the stated behaviour of firms, we propose to study in more detail the effects of LTAs on energy-efficiency investment behaviour. It would be advisable to take into account the impact analysis of specific supporting measures and complementary policies as well as other incentives for and barriers to further energy-efficiency improvement in the survey. Furthermore, we suggest there should be an ‘on line’ evaluation of the energy conservation projects, since an annual survey would reflect more accurately the dynamic effects of the agreements, such as energy management, technological diffusion and innovation.

5.6 The cost-effectiveness of voluntary agreements

After we have estimated, how much energy saving was stimulated through the voluntary agreements, we may try to determine what the cost-effectiveness of the long term agreements are. We will do that in terms of the amount of money that the government need to spend per unit of carbon emission avoided.\footnote{An analysis of the cost-effectiveness taking into account firms investments, societal costs and benefits could not be made due to the limited amount of data.}

Before we can make that estimate, we need an overview of the costs of the long term agreement scheme. The costs are given in Table 5.3. The total costs in the period 1989 to 1999 amount to 650 million US$, including all subsidy schemes. It should be noted that especially the subsidy schemes contribute substantially to the costs of governments' industrial energy conservation policies: the CHP subsidy in the early nineties, and the EIA (see Chapter 3) up from 1996.
Table 5.3 Cost components of the Long-Term Agreement scheme in the period 1989-1999 (Glasbergen et al., 1997; Rietbergen et al., 1999). 1 US$ was approx. 2 NLG in the period concerned.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidy regulations for feasibility studies and demonstration projects</td>
<td>85</td>
<td>130</td>
</tr>
<tr>
<td>Activities to support the long-term agreements (internal projects by companies, external consultants, etc.)</td>
<td>65</td>
<td>114</td>
</tr>
<tr>
<td>Personnel and associated costs of the energy agency Novem</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>Subsidies for combined generation of heat and power (CHP)</td>
<td>100</td>
<td>106</td>
</tr>
<tr>
<td>Tax schemes (EIA)</td>
<td>-</td>
<td>268</td>
</tr>
<tr>
<td>Total</td>
<td>268</td>
<td>650</td>
</tr>
</tbody>
</table>

Total savings in industrial energy use amounted to 63 PJ up to 1995. It was found that 18-29 PJ were stimulated through the LTA policies and 7 PJ through the CHP policies (including the subsidies) (Glasbergen et al., 1997). In 1999 the total savings had increased to PJ 142.5. Taking into account the fraction of 27-44% stimulated by the long-term agreement policies (see section 5.5) we find total stimulated savings of 38 – 62 PJ.

Using the stimulated savings (section 5.5) and an average emission factor of 73 kg CO₂ per GJ primary energy, we can estimate an avoided CO₂ emission: 2.0 – 2.8 Mtonnes (of which 0.7 Mtonnes through CHP) until 1995 and 3.0 – 4.9 Mtonnes until 1999. Now the specific costs of the instrument can be calculated. We assume that the saving effect lasts for 10 years and that a social discount rate (i.e. 5%) can be used. The result is an estimated specific

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52 This is equivalent to the average specific emission for the energy carriers used in Netherlands’ industry. For savings achieved through combined generation of heat and power, avoided emissions of 100 g CO₂ per GJ saved primary energy were taken (Blok, 1991).
costs of 14 – 21 US$ per tonne of carbon dioxide emission avoided for all the schemes for industrial energy efficiency improvement together until 1999. However, if we strip the costs of the subsidy parts (which anyway is justified for the non-CHP part of the policies until 1995) cost levels around 10 US$/tonne of carbon dioxide result.

This compares favourably with the costs of pure subsidy schemes directed at the same sectors (see also Table 5.4). Although also for these instruments the estimation of the cost-effectiveness is not easy, the estimate is that on average the costs for subsidy instruments typically are twice as high than for the long term agreements. Nevertheless, in their evaluation, Glasbergen et al. (1997) expect that it must be possible to operate long-term agreements with lower costs than those in the Netherlands.

*Table 5.4* The cost per stimulated unit of carbon dioxide avoided for three different instruments. Apart from the long term agreements, in italics results are given for three subsidy schemes (Farla et al., 1995; De Beer et al., 2000, see also Chapter 3). All figures are converted to the same basis: 5% discount rate, depreciation over 10 years, 1 US$ = 2 NLG.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Specific costs ($/tonne CO₂)</th>
<th>Specific costs ($/tonne of carbon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term agreements (until 1995)</td>
<td>10 – 16</td>
<td>40 – 60</td>
</tr>
<tr>
<td>CHP subsidies (until 1995)</td>
<td>17</td>
<td>60</td>
</tr>
<tr>
<td>Total industrial policy: long-term agreements + CHP policy (until 1995)</td>
<td>11 - 16</td>
<td>40 - 60</td>
</tr>
<tr>
<td>Total industrial policy: long-term agreements + CHP policy + fiscal support EIA (until 1999)</td>
<td>14 - 21</td>
<td>50 - 80</td>
</tr>
<tr>
<td>Ibid., excluding costs of EIA and CHP subsidies</td>
<td>7 – 11</td>
<td>30 - 40</td>
</tr>
<tr>
<td><em>Investment Account Act (1980 – 1987)</em></td>
<td>35</td>
<td>130</td>
</tr>
<tr>
<td><em>EINP (for non-profit sectors)</em></td>
<td>75 – 110</td>
<td>275 – 400</td>
</tr>
</tbody>
</table>
5.7 Recommendations on negotiated agreements

The results of our studies on voluntary agreements in the Netherlands (Glasbergen et al., 1997; Rietbergen et al., 2000) and a comparative study on the effectiveness and cost-effectiveness of agreements on energy efficiency in several European countries (Krarp and Ramesohl, 2000) indicate that such agreements can help limiting the growth of energy use in manufacturing industry. The positive and negative experiences obtained from these studies lead us to the following set of recommendations for the design of successful voluntary agreements.

1. Voluntary agreements require a clear negotiation position and a negotiating attitude of the government in order to reach ambitious targets.
2. The targets should be well described with respect to energy-efficiency target and target year.
3. Voluntary agreements require an intensive and long-lasting effort of the government to guarantee the actual realisation of the energy-efficiency improvement. Such additional effort can consist of support of the branch, free energy audits, organisation of information exchange and subsidies for demonstration projects.
4. Monitoring of the improvement of the energy-efficiency improvement should be done by using physical energy-efficiency indicators (e.g. GJ/tonne of product).
5. The monitoring guidelines should be clearly described and the monitoring procedure for each sector should be public. The use of correction factors should be limited.
6. Independent verification of the monitoring results is necessary.
7. Voluntary agreements are not always successful for energy extensive sectors with a large number of companies involved.
6 GOVERNMENT INTERVENTION STRATEGIES IN STIMULATING THE R&D OF ENERGY-EFFICIENT TECHNOLOGIES

6.1 Industrial energy-efficiency improvement in the long term

Thus far, the attention in this book was directed to stimulating the adoption of commercially available technologies. Such options may prove sufficient to reach short and medium term targets. Reaching longer term targets, like those for a period of 50 to 100 years ahead requires not only the further adoption of the technologies mentioned, but also the development and adoption of innovative technologies. Blok et al. (1996a), De Beer (1998) and Martin et al. (2000) have shown that the long-term potential for energy-efficiency improvements in various energy-intensive manufacturing industries is considerable.

De Beer (1998) for instance analysed the opportunities for future energy-efficiency improvement according to a structured method, including: (i) process and energy analysis; (ii) technology identification; (iii) technology characterisation. The results of this work provide for an overview of the potential for energy-efficiency improvement for selected sectors in manufacturing industry (see Table 6.1).

Table 6.1 shows that it is possible to bridge about half of the gap between the present best technologies and the thermodynamic minimum with identified new technologies.

The identification of such technologies and the needs for energy-efficiency R&D is one thing, stimulating their development and contributing towards a successful introduction of such options is another. A strong R&D effort in the area of energy end-use efficiency is required to facilitate the adoption of existing options on the one hand and to develop innovative technologies which are more-and-more energy-efficient on the other hand (Blok et al., 1996b). Stimulating the development of such technologies is an interesting government option: if government can effectively contribute towards the development of such technologies the final effect can be large, because once the technology has

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53 This chapter was written by Esther Luiten.
achieved a proven state of performance it can be adopted in a large number of firms. The potential impact on energy consumption is large.

Table 6.1 Overview of present best-practice technology, and identified potential for improvement in terms of specific energy consumption (in GJ/tonne) for some industrial energy functions.

<table>
<thead>
<tr>
<th>Relevant future technologies</th>
<th>Specific energy consumption levels (SEC)</th>
<th>Present best practice technology</th>
<th>Thermodynamic minimum</th>
<th>Combination of best identified future technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/board (paper drying)</td>
<td>2.3 – 8.6</td>
<td>0.0</td>
<td>0.6 – 4.3</td>
<td>Impulse technology*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Condebelt drying</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dry sheet forming</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Airless drying</td>
</tr>
<tr>
<td>Primary iron and steel production</td>
<td>19.0</td>
<td>6.6</td>
<td>12.5</td>
<td>Smelt reduction*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strip casting*</td>
</tr>
<tr>
<td>Secondary steel production</td>
<td>7.0</td>
<td>0.0</td>
<td>3.5</td>
<td>Combination shaft furnace</td>
</tr>
<tr>
<td>ammonia production</td>
<td>33.0</td>
<td>24.1</td>
<td>28.6</td>
<td>Membrane reactors</td>
</tr>
<tr>
<td>Nitric acid production</td>
<td>26.8</td>
<td>3.2</td>
<td>15.3</td>
<td>Gas turbine or SOFC integration</td>
</tr>
</tbody>
</table>

Government R&D support is the traditional policy instrument for governments to stimulate R&D. This is also the case in stimulating industrial energy-efficiency R&D. The current situation in energy R&D is not very shining. Government R&D expenditure has been declining since the mid-1980s in response to lower real energy prices, budget austerity and changing attitudes to

54 See for instance the overview study of International Energy R&D in Industrialised Countries (Ashton and Dooley, 1994); the database constructed by Meuleman et al. (1996); and the more recent country studies on Energy R&D (see http://energytrends.pml.gov).
the role of government in the economy\(^55\) (IEA, 1996; IEA, 1997). The trend of liberalisation in the energy sector is likely expected to further suppress energy R&D expenditure and to direct R&D towards shorter-term R&D (Graaff et al., 2000; Dooley, 1998). In spite of these trends in energy R&D, government energy-efficiency R&D programmes have experienced the most consistent budget growth of all energy R&D technology areas (see Table 6.2 and Figure 6.1).\(^56\) Industrial energy-efficiency R&D programmes appear to be receiving preference over building or transport related energy-efficiency R&D programmes (Dooley et al., 1998, WEA, 2000, Luiten and Blok, 1999).

Table 6.2 Overview of government energy R&D expenditure in several energy technology areas (IEA, 1997).\(^57\)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial energy-efficiency R&amp;D</td>
<td>201</td>
<td>135</td>
<td>154</td>
<td>383</td>
</tr>
<tr>
<td>Other energy-efficiency R&amp;D</td>
<td>731</td>
<td>520</td>
<td>290</td>
<td>567</td>
</tr>
<tr>
<td>Other energy R&amp;D</td>
<td>14087</td>
<td>10410</td>
<td>8396</td>
<td>8026</td>
</tr>
</tbody>
</table>

\(^{55}\) The performance of energy R&D is highly concentrated in a very small number of countries. The top 9 countries account for 95% of the industrialised world’s supported energy R&D. The US and Japan are the two countries with by far the largest government energy R&D expenditure (Dooley et al., 1998; IEA, 1997).

\(^{56}\) The International Energy Agency (IEA) collects and reports public R&D expenditure in energy R&D within the OECD countries (IEA, 1997). The IEA data are the best energy R&D data available, although it should be realised that there are difficulties in data collection and data processing (see Dooley et al., 1997). The energy R&D data are at best an input measure and say nothing about productivity. Furthermore, it should be noted that that ‘R&D that affects energy end-use’ is not the same as ‘energy-efficiency R&D’ as distinguished in IEA statistics (Dooley, 2000).

\(^{57}\) Countries included are Canada, Denmark, Germany, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, and the US. On average 85% of the reported industrial energy-efficiency R&D is included; in the case of energy-efficiency R&D and energy R&D 87 and 89% respectively were included (IEA, 1997).
Blok et al. (1996b) compared the R&D needs for energy-efficiency improvement and the actual government R&D support. They find that current R&D practice on industrial energy efficiency covers only part of the innovative technologies identified. Hence, they conclude that the amount of government expenditure on industrial energy-efficiency R&D is far from sufficient. It is also recommended that government should support developments over long time frames in order to guarantee continuity independent of economic cycles. This conclusion of Blok et al. (1996b) – in combination with governments’ interest in supporting energy-efficiency R&D – underline the need for an evaluation of government intervention strategies to develop the long-term potential for energy-efficiency improvement.

In Chapter 2 it was stated that a good understanding of the behaviour of firms in implementing commercially available technologies is required for developing and designing effective policy instruments. An ‘extended’ net present value framework was presented in order to understand the paradoxical behaviour that cost-effective energy-efficient technologies are not widely implemented. A similar statement can be made regarding R&D towards energy-efficient technologies. A good understanding of firms’ behaviour and decisions in developing innovative energy-efficient is required for developing and designing effective policy instrument for steering R&D. The framework

Figure 6.1 Government energy R&D expenditure trends 1980 and 1995 (IEA, 1997). We have only included the eleven OECD countries for which data were available for each year.
presented in Chapter 2, including the suggestion that this framework can be the starting point from which the effectiveness and efficiency of policy instruments can be assessed, is, however, not directly applicable to R&D and technological development. Whereas Chapter 2 reflects that understanding the behaviour of firms in implementing energy-efficient technologies is steadily growing, such insight is not yet available regarding the R&D development of innovative technologies. Why do actors initiate, pursue or stop the R&D development of innovative energy-efficient technologies? What affects actors’ decisions in such R&D activities? And, of course, how susceptible are actors to governments’ attempts to stimulate or direct such technologies?

In this chapter we move beyond the identification of innovative energy-efficient technologies and R&D needs as for instance done by De Beer (1998) and Blok et al. (1996a). The aim of this chapter is to gain insight into actors’ behaviour and arguments for developing innovative energy-efficient technologies. We increase our understanding in order to make a preliminary evaluation of government intervention strategies. We will also shortly explore the possibilities of alternative intervention strategies than government R&D support.

In Section 6.2 we introduce four detailed technology case studies. Three of the four case studies were identified by De Beer (1998) (see the * in Table 6.1). The fourth one is a ‘historical’ industrial energy-efficient technology that has been commercially available for 20 years. In Section 6.3 we elaborate upon the possibilities for government intervention.

6.2 Innovative industrial energy-efficient technologies

6.2.1 Four technology case studies

Table 6.3 introduces the four technology case studies. All four technologies are sector-specific technologies that affect the core of the conventional energy-intensive production process. This explains why they are identified as major innovative technologies for the potential energy-efficiency improvement in the first place (in studies such as De Beer et al., 1998; Martin et al., 2000). In this chapter, we focus on two manufacturing industries: paper and board making and iron and steel making. A more extended description of the case studies can be found in Luiten (2001).
Table 6.3 The four industrial energy-efficient process technologies.

<table>
<thead>
<tr>
<th>Technology case study</th>
<th>Sector</th>
<th>Start R&amp;D</th>
<th>What does the technology do to the conventional production process?</th>
<th>How does the technology improve the specific energy consumption (SEC)?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoe press technology</td>
<td>Paper/ board</td>
<td>around 1970</td>
<td>Replaces part of the wet pressing section of a paper machine.</td>
<td>More water removed in a mechanical way, so less energy needed for evaporation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>innovation 1980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impulse technology</td>
<td>Paper/ board</td>
<td>1975-1980</td>
<td>Replaces part of the wet pressing section of a paper machine.</td>
<td>More water removed in a mechanical way, so less energy needed for evaporation.</td>
</tr>
<tr>
<td>Strip casting technology</td>
<td>Primary + secondary steel</td>
<td>1975-1985</td>
<td>Links casting and rolling of liquid steel.</td>
<td>Reheating of cast steel is no longer needed.</td>
</tr>
</tbody>
</table>

Each of the four technology case studies tells its own story about the way a specific energy-efficient technology developed. Box 6.1 – Box 6.4 give a description of the four technology case studies. For each technology case study, 1) the composition of the networks, 2) the materialisation of the technology and 3) the arguments for developing the innovative technology were analysed. These three issues will be dealt with in a cross-case study analysis in the remainder of this section (see section 6.2.2 till 6.2.4).
A shoe press can replace part of the conventional pressing section in a paper machine. Instead of a steel roll a flexible belt is used. This increases residence time and improves dewatering performance of the press section. Energy is saved through the reduced heat demand in the subsequent drying section.

The development of the technology took about 13 years (1967-1980). The technology network consisted of one micro-network and for a long time even of one firm. Although the idea for extending pressing time was acknowledged by other paper researchers and engineers, only the people at the US paper machine supplier Beloit continued to believe that such a new press design could be engineered. The shoe press implied a major change to the conventional roll press from an engineering point of view. In spite of the various setbacks and the difficulties in achieving an engineering solution, the R&D activities were continued with dedication and belief. When Beloit had implemented a shoe press in their pilot paper machine, a board manufacturer and a fabric supplier – both well-known business partners to Beloit – became involved. The fabric supplier was involved to come up with a feasible belt at the moment that the first commercial shoe press for a board machine was already decided upon. They succeeded in time. Without the belt, innovation (1980) would have been delayed.

Only by then, three other major machine suppliers started R&D activities. They developed improved shoe press designs with a ‘closed’ belt. Their designs were introduced in 1984, 1986 and 1990. The closed shoe press design proved a better performance at higher machines speeds. This is important because since paper-making has become a continuous operation machine speeds have increased (they will continue to do so into the future).

The major argument for developing shoe press technology was to increase the machine capacity of existing board machines and to reduce the capital intensity of new board machines. During the eighties, the innovative technology was applied to board grades only. Although machine suppliers claimed advantages for other paper grades too, the first shoe press was implemented in a lightweight paper machine in 1994 only. When conventional wet presses limited a further increase of machine speeds the shoe press became a proven technology in paper machines too.

Beloit addressed the US Department of Energy to cover the risk of innovation in 1980. They were interested because of the technology’s energy-efficiency improvement, though they were too slow in fulfilling the request. Beloit, the major innovator and continuous believer in the feasibility of shoe press technology, was eager to introduce the technology anyhow.
Figure 6.2 Technology network of shoe press technology. *Cursive* = suppliers. Normal = paper manufacturers.

Figure 6.3 Technology network of impulse technology. In italics = suppliers. Normal = paper manufacturers. Underlined = (national pulp and paper) research institutes and universities.
Box 6.2 Impulse technology: Government R&D support allows continued R&D effort.

Douglas Wahren conceived the idea of impulse technology in 1970. He anchored impulse R&D activities at the US national pulp and paper research institute 10 years after his first idea of impulse technology. The institute’s vice-president was excited about the new mechanisms of dewatering; impulse technology was thought to ‘drive’ water out of the paper sheet by combining heat and mechanical pressure in wet pressing. Wahren contacted people at Beloit. Impulse technology was seen as a logical next step after the shoe press. A first micro-network emerged when the US machine supplier Beloit and the Canadian national pulp and paper research institute also initiated R&D activities. Both research institutes claimed an increased energy-efficiency to acquire government R&D support. The US government granted 60 to 65% of the US institute’s R&D activities. The Canadian government financed 45% of the Canadian institute’s R&D activities. Within the North-American micro-network, four attempts to commercialise the technology failed (1989, 1993, 1994 and 1999). In the first attempt, delamination of the paper sheet turned out to be a stumbling block. In later attempts, paper manufacturers could not be convinced to take the risk; it turned out that more R&D was needed, delamination was not completely solved (1993); lightweight paper machine makers were not used to using shoe presses yet (1994); and the advantages of the current design were not convincing for board grades (1999). Due to these failures, Beloit’s interest in the technology was gradually lost. Beloit’s researchers managed to continue R&D, though with a lower priority and backed-up by both IPST’s and Paprican’s R&D efforts. The North-American micro-network came to an end when Beloit’s mother firm filed for bankruptcy (in 1999).

A second micro-network emerged in Sweden from 1990 onwards. A Swedish government representative offered the national pulp and paper research institute financial R&D support in starting the development of this energy-efficient technology. After six to seven years of planning, talking and negotiating, a major R&D programme was started. The Swedish government financed roughly 40% of the R&D programme and the rebuilding of the pilot paper machine at STFI. In 2001, only the Swedish micro-network is still active.

The major argument for developing impulse technology was an increased machine capacity in existing paper and board machines and a reduced capital intensity in new paper and board machines. Wahren’s original dewatering claims became less strong over time. Actors’ arguments for investing in impulse technology, thus, also changed. Paper properties were increasingly stressed. However, more than 25 years of R&D activities have not yet resulted in a proven technology. 15 years of government R&D support did accelerate the technology’s development, though the national institutes’ R&D activities drove government R&D support instead of the other way around. In fact, the technology’s prospects are unclear; its energy-efficiency improvements are uncertain; its feasibility – in its current design – is debated.
Box 6.3 Strip casting technology: Serious efforts at the edge of breakthrough.

The original roots of strip casting technology go back to the 19th century. Bessemer, one of the classical inventors of the steel industry, applied for a patent in 1857. Between 1857 and 1975 some localised R&D efforts took place, though only after 1980 a robust and large technology network emerged. The eleven micro-networks were remarkably homogeneous, generally being composed of a large steel-maker - in most micro-networks a stainless steel manufacturer or an integrated steel maker with a stainless steel division - and a machine supplier or engineer (see Figure 6.4). The steel manufacturers took the lead. Six of the eleven micro-networks are still active. Three of them operate strip casting technology at an industrial scale. They needed about fifteen years to achieve this state.

The major argument for developing strip casting technology has been to reduce the capital intensity of hot rolling. Bessemer was already aware of the huge advantages of direct casting in terms of shortening the steel production process. The introduction of conventional continuous casting (1952), maturing of this conventional technology, the steel crises in the seventies, and the rise of stainless steel and mini-mills had to occur before strip casting technology became the centre of casting R&D activities. Between 1975 and 1985, researchers and engineers started looking for more compact casting technologies. During the early eighties, a process emerged in which a number of factors – among others the claim of success of one of the leading US stainless steel producers – added momentum to strip casting R&D activities.

Six of the eleven micro-networks received government R&D support. In three micro-networks, government R&D support was more than 40% of the total expenditure. However, these three micro-networks stopped their R&D activities or deliberately continued R&D activities at a pilot scale. The three micro-networks that are ahead in developing strip casting technology did not get (or only marginal) external financial R&D support. The effect of government R&D support in developing strip casting technology has been minimal. The development proved to have a strong momentum of its own. Strip casting affects the core of steel business and its development was only loosely motivated by energy-efficiency considerations or by the availability of external R&D support. The three most ‘advanced’ micro-networks may commercialise strip casting technology within two or three years (most likely in carbon mini-mills or stainless steel firms). All the other micro-networks and the steel industry in general are waiting to see how their casters will perform.
Figure 6.4 Technology network of strip casting technology. In italics = suppliers. Normal = steel manufacturers (note that Nucor is a mini mill steel operator). Underlined = research institutes.
CHAPTER 6

Figure 6.5 Technology network of smelting reduction technology. Corex, AusIron and Tecnored are initiated by machine suppliers or engineers. Romelt is developed by a Russian research institute. Hismelt is developed by a mining firm. DIOS, CCF, DSM and Jupiter are initiated by integrated steel manufacturers. In three micro-networks, mini-mill steel operators became involved in a later stage of the technology’s development.

Box 6.4 Smelting reduction: A double perspective – ‘locked out’ and ‘niche’ application.

The idea of smelting reduction technology has been known since the 1930s. Only from 1975 a technology network emerged. By then, the performance of other innovative iron-making technologies disappointed and the threat of future (capital-intensive) replacement of obsolete coke ovens became pressing. From 1975 onwards, R&D efforts were undertaken. Only one of these early efforts achieved commercial application, i.e., Corex. Corex is still the only smelting reduction process that is commercially available, though its techno-economic characteristics limit wide-scale operation. Some of the early efforts evolved into micro-networks that studied ‘second generation’ processes. The technology network, consisting of nine micro-networks, was heterogeneous (see Figure 6.5). Integrated steel manufacturers dominated four micro-networks. Machine suppliers, mining firms and research institutes were also involved.
Various types of actors had various technical preferences due to earlier (R&D) experiences. Not all smelting reduction processes are likely to improve the specific energy consumption of iron-making.

Three micro-networks stopped R&D activities; these were all initiated by integrated steel manufacturers. The composition of the technology network, thus, changed over time. Integrated steel manufacturers lost interest whereas mini-mill steel makers became in later stages. The major argument for integrated steel firms to develop smelting reduction technology was to produce hot metal at lower costs. A lower capital investment – one avoids expensive coke ovens and replaces the capital intensive blast furnace – and the use of less expensive non-metallurgical coals promised a substantial reduction in cost price. Energy-efficiency improvements and avoided capital investment for reducing other environmental harmful emissions merely provided integrated steel manufacturers with additional arguments. Integrated steel firms lost interest because the existing capital stock was continuously improved and they did not need additional iron-making capacity. The cost price reduction of smelting reduction technology decreased over time. The threat of replacing capital intensive coke ovens early in the 21st century was postponed. Smelting reduction technology was ‘locked out’ by continuous improvements in the existing capital stock of integrated steel firms. The future of smelting reduction technology is still open; mining firms and steel mini-mills are still interested.

Environmental regulation was not decisive in initiating R&D efforts. Eight of the nine micro-networks were financially supported by various governments. In three micro-networks – DIOS, CCF and DSM –, R&D support has been larger than 40% of the total expenditure. Two of these three micro-networks were multi-partner co-operative R&D efforts. Government R&D support did enlarge the technology network. Governments also supported smelting reduction processes that are likely to be energy-efficient. However, R&D support did not accelerate the technology’s development so far. Actors’ intentions for being involved in multi-partner government supported co-operative R&D efforts were different from actors intentions in pursuing a R&D effort on their own. To conclude, the changes in the technology network reflect the dynamics in the development of smelting reduction technology. The case study illustrates the dominant influence of the existing capital stock in constraining technological development in integrated steel making; this limited the effect of government R&D support (so far).

In the remainder of this section we compare the four technology case studies regarding three issues: networks (6.2.2), materialisation (6.2.3) and promising performance characteristics and the technology networks’ momentum (6.2.4).
6.2.2 Networks

The composition of the technology networks within which the four energy-efficient technologies were developed is summarised in Table 6.4.

Table 6.4 Technology network and micro-network characteristics.

<table>
<thead>
<tr>
<th>Technology case study</th>
<th>Shoe press technology</th>
<th>Impulse technology</th>
<th>Strip casting technology</th>
<th>Smelting reduction technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of technology networks (measured in number of micro-networks)</td>
<td>1</td>
<td>2</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Total expenditure (million US$)</td>
<td>5</td>
<td>35-40</td>
<td>500-700</td>
<td>600-700</td>
</tr>
<tr>
<td>Leading micro-networks in R&amp;D</td>
<td>Not relevant</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Micro-networks still active</td>
<td>(2)¹</td>
<td>1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Composition technology network</td>
<td>Machine suppliers: 85%</td>
<td>Machine suppliers: 30% National P&amp;P research institutes: 55%</td>
<td>Steel firms: 75% Machine suppliers: 20%</td>
<td>Steel firms: 30% Machine suppliers: 40% Mining firms: 15% Research institutes: 15%</td>
</tr>
<tr>
<td>Exchange between micro-networks?</td>
<td>No</td>
<td>Primarily through patents and publications</td>
<td>Contacts → active monitoring</td>
<td>Contacts → active monitoring</td>
</tr>
<tr>
<td>In how many micro-networks did actors co-operate?</td>
<td>1</td>
<td>2</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

¹ After Beloit introduced the shoe press to the market, two more micro-networks emerged. Beloit is no longer in business (its mother firm filed for bankruptcy).
Table 6.4 illustrates that the two paper technology networks and the two steel technology networks differ in their size and in the total expenditure on R&D. The number of actors that is able (both technically and financially) to continue such an R&D effort and actually commercialise an innovative technology is smaller in the paper industry than in the steel industry. The manufacturing firms in these two sectors also differ in their ‘pattern’ of innovation. The large integrated steel manufacturers actively invested in R&D, whereas the paper firms ‘waited’ for technologies to be delivered by the international machine suppliers.

The four technology case studies illustrate that it is not likely that there is such a thing as a minimum size of the technology network in order to guarantee commercialisation of the technology. The smallest technology network was the most successful. Smaller technology networks are, however, more vulnerable for disruptions.

Table 6.4 indicates that in all four technology networks, firms played an initiating and dominant role. Note that the direct contribution of universities and public research institutes in developing the four energy-efficient technologies was marginal.

The micro-networks were rather stable entities that continued R&D over fairly long time periods. Whereas there was some knowledge exchange among various micro-networks, R&D activities were organised in micro-networks (see 6th row in Table 6.4). The actors in micro-networks are usually aware of the other-micro-networks; they monitored other micro-networks’ R&D activities, their (claims of) successes and their failures.

Finally, Table 6.4 shows that in the majority of the micro-networks, firms co-operated. Co-operation extended itself most often beyond national borders. Actors did not have large problems in finding competent actors to co-operate with. If there were problems, this typically occurred in the demonstration stage of a technology’s development.

6.2.3 Materialisation

A second issue is the materialisation of the technology. How much time did it take to develop the four technology case studies (so far)?

---

58 Note that not all micro-networks in developing the two steel technologies did spend a similar budget. The most ‘advanced’ micro-networks spent the most (typically around 100 million US$).
Table 6.5 indicates the current stage of development of the four innovative technologies. The shoe press is a proven technology\(^{59}\). Both impulse and strip casting are operational at such a scale that commercial application is the logical next step. Whereas this is a likely thing to happen in developing strip casting, prospects are more uncertain in developing impulse technology. The majority of the smelting reduction processes still have to prove feasibility at an industrial scale before commercial application can be considered (apart from the Corex process).

**Table 6.5 Materialisation characteristics.**

<table>
<thead>
<tr>
<th>Technology case study</th>
<th>Shoepress technology</th>
<th>Impulse technology</th>
<th>Strip casting technology</th>
<th>Smelting reduction technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology network stage</td>
<td>13 years</td>
<td>&gt; 20 years</td>
<td>about 20 years</td>
<td>10 years (Corex) &gt; 20 years (2nd gen.)</td>
</tr>
<tr>
<td>Exploration stage</td>
<td>15 years</td>
<td>10 years</td>
<td>120 years</td>
<td>45 years</td>
</tr>
<tr>
<td>Number of steps in upscaling</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2 (Corex) 3 (2nd gen.)</td>
</tr>
</tbody>
</table>

The second row in Table 6.5 shows the number of years that were needed to achieve these current stages of development within the four technology networks. For both impulse technology and smelting reduction, it is difficult to assess when the technology may be commercialised. If Valmet sees any perspective in continuing the Swedish micro-network’s R&D activities (this depends on Valmet’s stakes in other innovative technologies and the R&D results), innovation may take place in 2003-2004 at the earliest. If not it will take at least till 2010, if R&D activities are continued at all. Application of smelting reduction technology in integrated steel firms may take place between

\(^{59}\) The technology was first introduced to board machines (1980-1994). It took 14 years for the technology to be applied to light-weight paper grades.
2005 and 2010 if the technology is proven within mini-mills and if there are steel firms that need to expand their iron-making capacity. Otherwise application will be delayed till after 2010 (till the time that existing coke oven really have to be replaced).

It is quite remarkable that all four innovative energy-efficient technologies were ‘known’ before the technology network really took off. The third row in Table 6.5 indicates the duration of the so-called exploration stage. It took decades (up to more than a century) before a robust technology network emerged. A combination and mutual reinforcement of factors was needed for actors to acknowledge that an innovative technology may be an interesting ‘next-step-to-take’. We suggested four factors to explain why a technology network emerged at a certain moment in time. A first factor is that actors recognise the economic advantage of the innovative technology. This is a critical condition, though not a sufficient one. A second and very important factor is the technical need or match with the existing conventional production process. All four innovative technologies were closely linked to the conventional sequence of process technologies. A third factor is progress in R&D and, finally, contingent elements play a role. The technology network only emerges when the technology falls within an actor’s or actors’ horizon as an improvement that is economically attractive and technologically feasible for improving the performance of the conventional production process (see also Table 6.3).

Once a technology network emerged, commercialisation was still not around the corner. In most cases, two or three steps in up-scaling the technology had to be taken to prove its feasibility (see last row in Table 6.5). This is the only way to gain manufacturers’ confidence in the performance of the technology. Each step takes at least five years; a duration of ten to twenty years is not extraordinary.

6.2.4 Promising performance characteristics and the technology networks’ momentum

The second column in Table 6.6 summarises the major ‘promising’ performance characteristics of the four innovative energy-efficient technologies. All four technologies promised a reduction in costs of a ton product. However, the reduction in energy costs was only of marginal importance for developing the four ‘energy-efficient’ technologies (see third
row in Table 6.6). All four technologies affect the core of the production process; in developing such process technologies, improvements in energy efficiency are most often no more than a positive side-effect.

*Table 6.6 Promising performance characteristics.*

<table>
<thead>
<tr>
<th>Technology</th>
<th>Case study</th>
<th>What was the promising performance characteristic?</th>
<th>Was energy-efficiency a decisive argument?</th>
<th>How does the technology match to the historic direction in technological development?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoe press technology</td>
<td>Increased dryness in wet pressing → increased machine speed or reduced capital intensity → reducing cost/ton</td>
<td>No</td>
<td>Reinforces the historic trend of continuously increasing paper machine speed</td>
<td></td>
</tr>
<tr>
<td>Impulse technology</td>
<td>Increased dryness in wet pressing → increased machine speed or reduced capital intensity → reducing cost/ton</td>
<td>No</td>
<td>Reinforces the historic trend of continuously increasing paper machine speed</td>
<td></td>
</tr>
<tr>
<td>Strip casting technology</td>
<td>Compact casting technology → reduced capital intensity (both MM and IM) → reducing cost/ton</td>
<td>No</td>
<td>Preference for more compact IM / steelmaking processes since 1970s → strip casting fits in for IM → opportunity for compact MM route</td>
<td></td>
</tr>
<tr>
<td>Smelting reduction technology</td>
<td>Compact iron technology → reduced capital intensity (IM) or higher quality raw material (MM) → reducing cost / ton</td>
<td>No (but design characteristic)</td>
<td>Preference for more compact IM / steelmaking processes since 1970s → smelt reduction fits in for IM → new iron source for MM route</td>
<td></td>
</tr>
</tbody>
</table>
In all four technology case studies, actors referred to the dominant business logic of the majority of steel and paper firms to explain the dominance of reducing production costs on the R&D agenda for developing process technologies. In achieving these lower costs through technological development, actors were heavily constrained by the sunk investments in the existing paper-making or steel-making production process. This brings regularity in technological development in manufacturing industries; the existing system is further optimised (see fourth column in Table 6.6). Whereas all four technologies optimise the existing system – they are seen as a next-step-to-take –; they promise a step-wise improvement of the overall performance of the existing production process. If the promise of increasing machine capacity (in paper) and of a more compact production facility (in steel) had been too small, the major and complex R&D efforts would not have been undertaken.

The last column in Table 6.6 shows that there was the least doubt in the perceived performance of the technologies that developed the most smoothly. This observation is related to differences in momentum among the four technology networks; not all four technologies developed with the same drive (see Figure 6.6 and the technology case descriptions in Box 6.1 - Box 6.4). We introduced the concept of momentum - known in innovation studies from the analysis of large technical systems - to characterise the overall dynamics of a technology’s development. A technology network has a large momentum when it causes the observers to assume that an innovative technology materialises autonomously (Hughes, 1983).

Although the concept seems simple, it is not easy to measure momentum. In our analysis, we assume that the network around a technology has a high momentum if: R&D activities are continued; actors continue to see the technology as an obvious next-step-to-take; actors continue to articulate confidence in the performance of the technology; and if the technology is further materialised (e.g., regular steps in up-scaling occur).\textsuperscript{60}

\textsuperscript{60} Note that there is no one-to-one relation between momentum and the stage-of-development. Even in an early stage of development the momentum may be high and in a later stage it may be low.
The momentum of a technology reflects the confidence of actors in the future perspectives of the innovative technology. It reflects the confidence of actors that a technology continues to be an interesting option to be developed. The technology remains the ‘next-step-to-take’ in spite of possible developments in the conventional production process and trends and changes in the manufacturing industry.

For a technology network to maintain its momentum, actors have to be confirmed and reconfirmed regularly in their expectations regarding the perceived promising performance characteristics. The (gradual) materialisation of the technology, R&D results, claims of success (of other actors), large difficulties and failures, but also improvements in conventional process technology and changes in the industry, affect actors’ confidence in the future perspectives of the technology, and, thus, affect the momentum of a technology network.

### 6.3 Government intervention strategies

In this section we turn to the effect of government intervention in stimulating the development of the four energy-efficient technologies. Financial R&D support was the most widely used intervention strategy. The understanding that technological development is the result of interaction between actors instead of a linear sequence from science to market, creates
possibilities for alternative intervention strategies. Such intervention strategies are scarce in our case studies (see bottom row Table 6.7), and, therefore, leads to some tentative indications only.

Table 6.7 Government intervention.

<table>
<thead>
<tr>
<th>Technology case study</th>
<th>Shoe press technology</th>
<th>Impulse technology</th>
<th>Strip casting technology</th>
<th>Smelting reduction technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total expenditure (million US$)</td>
<td>5</td>
<td>35-40</td>
<td>500-700</td>
<td>600-700</td>
</tr>
<tr>
<td>Government R&amp;D support (million US$)</td>
<td>- 0%</td>
<td>15 - 40-45%</td>
<td>40 - 5-10%</td>
<td>165 - 25-30%</td>
</tr>
<tr>
<td>Number of micro-networks supported</td>
<td>- 2/2</td>
<td>6/11</td>
<td>9/9</td>
<td></td>
</tr>
<tr>
<td>Other intervention strategies</td>
<td>- Co-operative R&amp;D¹</td>
<td>Co-operative R&amp;D¹</td>
<td>Co-operative R&amp;D¹</td>
<td></td>
</tr>
</tbody>
</table>

¹ Impulse technology - IEA Annex on Impulse Technology within the Implementing Agreement on Pulp & Paper. Strip casting technology - Bessemer Consortium, Canada (50% government R&D support); CMU project, US (70% government R&D support); European Coal and Steel Community RTD Programme, Europe (financial R&D support on networking meetings). Smelting reduction technology - Steel Initiative / DSM process, US (75% government R&D support); DIOS, Japan (67% government R&D support); ECSC RTD programme (CCF / Hoogovens and British Steel, 40% R&D support).

² Agreement on generating economic added value to iron resources by new technologies (mining company HIsmelt, Australia). Agreement on industrial energy-efficiency (Hoogovens / now part of the Corus Group, The Netherlands).

³ Note that support by the European Coal and Steel Community RTD Programme (ECSC) is included in these budgets. The budget for the ECSC’s RTD programme is gathered by a levy on the steel price in Europe.

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61 We distinguish a matrix of government intervention strategies: push (R&D) – pull (market); generic – specific. All policy instruments, such as voluntary agreements, technology forcing standards, facilitating and network initiatives, etc., can be characterised along these two dimensions. A third important dimension is the degree to which the interaction among various actors in R&D and innovation and to which stakeholders or actors are involved in formulating and designing intervention strategies (think for instance of setting R&D priorities).
It is not likely that regulation on environmental issues and energy efficiency is of decisive impact on developing core process technologies as the ones being analysed. The case study on smelting reduction technology illustrates that the incentive generated by environmental regulation (on coke ovens) provided the integrated steel firms with an additional cost advantage for the innovative technology. However, the incentive was too small to initiate the considerable R&D effort. The fact that energy-efficiency was not an important argument for developing the four process technologies (see Table 6.6) reinforces the impression that the incentive of regulation should be considerable to have any effect in stimulating or R&D. Regulation did provide researchers within a firm with an additional argument for creating firm-internal support for initiating or continuing R&D.

The case study of smelting reduction technology also provided some tentative evidence for possibilities of agreements on technological development. Firms that had a direct agreement with the government showed a certain commitment to the government. This suggests that it may be an interesting route to come towards R&D agreements with a selective number of firms in order to develop technologies for improving energy-efficiency in the manufacturing industry. The empirical research makes also very clear that such R&D agreements only make sense in case of specific actors (that have a clear stake in R&D in relevant areas).

Furthermore, in the majority of the co-operative R&D programmes - all of them were financially supported by government -, firms merely aimed at exploring the possibilities of a technology’s promising potential rather than bringing the innovative technology towards commercialisation. Insisting on co-operating was not always a feasible strategy. Co-operation was most effective in pre-competitive R&D; at this stage, actors’ stake was to learn in interaction with other competent actors.

Table 6.7 shows that government R&D support has been substantial in developing impulse technology and smelting reduction technology (more than 25% of the total expenditure). In the other two case studies, the share is zero or marginal (though not in absolute terms). It is interesting to note that government started R&D support only when the innovative technology was already in the so-called technology network stage (see Section 6.2.3). Energy-efficiency improvement was a major argument for government to grant R&D support in all four case studies. As was noticed already, energy-efficiency improvements were not a decisive argument for developing the technologies. The ‘promise’ of an improved energy-efficiency was used in all four technology case studies to mobilise external (government) R&D support.
Table 6.8 Effect of government R&D support.

<table>
<thead>
<tr>
<th>Technology case study</th>
<th>Shoe press technology</th>
<th>Impulse technology</th>
<th>Strip casting technology</th>
<th>Smelting reduction technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additionality</td>
<td>-</td>
<td>2/2</td>
<td>3/11</td>
<td>5 (3)/9¹</td>
</tr>
<tr>
<td>Acceleration</td>
<td>-</td>
<td>yes</td>
<td>no</td>
<td>not so far</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>-</td>
<td>debate</td>
<td>likely</td>
<td>IM: likely MM: depending on what raw material is replaced</td>
</tr>
</tbody>
</table>

¹ In five micro-networks R&D support was additional. In 3 micro-networks, the smelting reduction process is likely to be energy-efficient.

In Table 6.8 the effect of R&D support is evaluated according to three specific issues. Did R&D support lead to additional R&D activities (that are activities that would not have been performed without financial support)? Did R&D support lead towards an accelerated materialisation within the entire technology network? And thirdly, is the technology once it is commercially available likely to improve specific energy consumption (indicated as effectiveness)?

The descriptions on government R&D support in Box 6.1 - Box 6.4 and the evaluation in Table 6.8 illustrate that effective spending of government R&D support is not easy. On the one hand, firms usually recognised the advantages of the technology to their business and identified the potential of a technology to improve the existing production process. Government R&D support was not always additional, or only additional in micro-networks that were (intentionally) not operating at the frontier of the technology’s development. On the other hand, in some micro-networks government intervention was effective; R&D support was additional and led to enlarging technology networks. Figure 6.7 summarizes the discussion on the effect of government R&D support. It shows a relation between the momentum of a technology network (see also Figure 6.6) and the effect of R&D support. The four technology case studies are located on the curve.
Figure 6.7 The effect of government R&D support as a function of the momentum of a technology’s development. The grey symbols indicate these technologies’ former momentum.

The momentum of the technology networks developing strip casting technology and shoe press technology was high, so that government R&D support barely had an effect. The momentum of the technology networks developing smelting reduction technology and impulse technology was lower. The additionality of government R&D support was higher if firms were less inclined to develop and commercialise the technology themselves.

6.4 Conclusions

Energy-efficient technologies – methodological findings

If we look at energy-efficient technologies a first important finding is that indicating innovative technologies as ‘energy-efficient’ technologies implies that specific characteristics of a technology are stressed and made explicit whereas others are not. There may be technologies that are ‘pure’ energy-efficient technologies, though large number of (commercially available and innovative) energy-efficient technologies do more than saving energy alone. This is not a remarkable new insight, though the four case studies all stress the
un-importance of energy-efficiency as a reason for developing them. When analysing or stimulating energy-efficient technologies one should better take into account the ‘other advantages’ of energy-efficient technologies. Researchers have to be aware how their way of looking at energy-efficient technologies affects their assumptions, analyses and final recommendations.

A second finding is that data availability on technology’s energy-efficiency improvement and especially investment cost is most often limited. Research on energy-efficiency should use the data that are available, though they should be precise in the value and reliability of the data used. Often data available are indicative – it is often simply not possible to make a full cost account; lab and pilot scale energy data are often only indicative of energy use in a commercial facility - and flawed with optimism (the actors developing the innovative technologies have their reasons for doing this) or surrounded by large uncertainties.

A third important finding is that the difference between retrofit and replacement is most often fuzzier than is often assumed in research efforts as for instance De Beer et al. (1994). In industrial practice, upgrading existing facilities is much more common than building entirely new production locations (although there is a difference among various geographical regions). In a way each innovative technology in the manufacturing industry is an ‘incremental’ improvement of the existing production process. The incremental improvements can be more or less ‘radical’. The ‘radical incremental’ improvements can be locked out by the more ‘incremental incremental’ improvements simply because technologies performance changes over time. This has for instance consequences for the reference technology defined by energy analysts. It would be useful to develop a more thorough understanding on the differences among energy-efficient technologies and how this affects investment behaviour for firms.

Understanding R&D development in mature industrial sectors

In this chapter we tried to move beyond the identification of innovative energy-efficient technologies. The aim of this chapter was to gain insight into actors’ behaviour and arguments for developing innovative energy-efficient technologies.

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62 If we look at the total number of shoe presses implemented (since 1980), we estimate that 25-35% of the shoe pressing is installed on entirely new paper or board machines.
The detailed analysis of four sector-specific innovative process technologies for the manufacturing industry and the insights generated by comparing them lead to some important policy-relevant conclusions.

First, technological development in the manufacturing industry is heavily constrained by the existing production process. The innovative technology has to be recognised as the ‘next-step-to-take’. The development of innovative technologies tends towards ‘system optimisation’ rather than complete renewal of the production process.

Second, technological development in the manufacturing industry is a slow process; it takes considerable time. It is striking that all four technologies were known (long) before a robust technology network emerged. The capital intensity of the sectors and the business pressure typically slow down technological development of manufacturing industries. The number of innovative technologies being developed (for a specific stage in a production process) is limited. The number of firms able to commercialise such technologies is not extremely large. Note that the direct role of universities and public research institutes in developing the energy-efficient technologies has been limited. There is no business logic in developing a large number of innovative technologies at the same time. The majority of the manufacturing firms become interested when the technology is ‘proven’.

Third, stimulating the development of industrial energy-efficient technologies effectively is not easy. We delivered quite some evidence that firms were willing and perfectly capable of doing these jobs themselves. Government has not shown to be the initiator in formulating long-term R&D needs for the development of innovative energy-efficient technologies. However, effective intervention occurred too.

Fourth, there is considerable variety in technology networks. The general promise of innovative industrial energy-efficient technologies veils a large heterogeneity. There was variety in the size of the technology networks, the type of actors involved, the geographic distribution of R&D activities, and the momentum of the technology networks. There is no ‘one size fits all’ strategy for effectively stimulating the development of industrial energy-efficient technology.

It is important to note that the scope of our analysis: ‘innovative process technologies in mature industries’ limits the validity of the conclusions. It may well be that for specific technologies (like cross-cutting technologies) or specific sectors (e.g., light industries) the outcome of a similar analysis would be different. However, it should be emphasised that the heavy industries still represent about half of world industrial energy use and that innovative process
technologies represent the majority of the future energy-efficiency improvements in these sectors.

*Increasing the effect of government intervention?*

The key-question clearly is how can government improve the effect of various intervention strategies.

Taking into account the conclusions about R&D and technological development in manufacturing industries there are two important dilemmas regarding the role of government in stimulating technological development that should be mentioned briefly.

First, should government stimulate the development of such energy-efficient process technologies at all? One may argue that R&D was primarily driven by market considerations and, thus, developing these innovative technologies is a primary job for the firms operating in these markets.

Second, if government decides on intervention, should government adopt a generic or specific intervention strategy? The empirical evidence suggests a dual position regarding this issue. On the one hand, it occurred several times that government did not have the knowledge to evaluate the performance and perspective of the innovative energy-efficient technology. The risk of government failure in implementing specific intervention strategies is large. On the other hand, the conclusions above imply the need of more specific intervention strategies to increase the effect of government intervention.

In spite of these dilemma’s the societal importance of further improvements in industrial energy-efficiency and the somewhat disappointing effect of government intervention in stimulating the development of such technologies encourage us to look for suggestions on how to improve the effect of government intervention.

The diversity between the manufacturing industries and various technology networks call for government intervention strategies that are better tailored to the networks of a specific industry. Government should have knowledge of the (international) technology networks and of the role and capacities of actors that government can address before deciding if and how to intervene. We, thus, come with the following recommendations for improving the effect of government intervention directed at technological development for the manufacturing industry.

- Government has to consider its access to actors that are able to make a difference in developing industrial energy-efficient technologies. It is
important to know in what research areas or technology fields a country can make a difference in the international arena.

- National governments can increase their access to actors by joining their forces at an international level. A suggestion is to come to R&D contracts or R&D agreements with actors that can make a real difference in the energy-efficiency performance of innovative technologies for the manufacturing industry. One can also think of international R&D programmes. Another international strategy might be that international bodies map the technology networks of major energy-efficient process technologies.

- If national governments do not have direct access to micro-networks, government may deploy indirect intervention strategies. Government can for instance choose for more stringent voluntary agreements on industrial energy-efficiency or create a regular information provision about the performance of innovative energy-efficient technologies to the national manufacturing industry (and to themselves). It is still a question whether such indirect intervention strategies really stimulate (or accelerate) the development of new energy-efficient technologies.

- Information about the momentum of various technology networks is a valuable first proxy for the question whether government should intervene at all. For effective government intervention, momentum should not be too low neither too high (see Figure 6.8).

![Figure 6.8 Schematic representation of the influence of momentum on the effect of government intervention.](image-url)
Long-term government R&D commitment is required for developing energy-efficient technologies. If government is granting long-term R&D support, it has to be attentive to changes in the international technology network. Such monitoring information is needed to decide whether to continue R&D support or not.

The fact that actors’ and governments’ agenda differ is not a reason not to stimulate the development of industrial energy-efficient technologies. However, governments have to protect their own agenda. Government should have a thorough - and independent - insight into energy-efficiency improvements and into the other (more) promising performance characteristics. One has to be critical in evaluating claims on energy-efficiency improvements; claims should not be taken for granted and not be evaluated in isolation.

In stimulating the development of industrial energy-efficient technologies governments need a certain degree of flexibility in designing a tailor-fit strategy. It is, for instance, not in each manufacturing industry recommendable to involve or to focus on the energy end-users in granting R&D support. Or, in specific cases, it should be possible to support (expensive) demonstration facilities.

Intervention strategies that affect the demand for technological innovation (such as for instance regulatory and economic instruments) are not likely to induce an accelerated development of energy-efficient process technologies. Such instruments articulate the importance government attributes to industrial energy-efficiency.

Intervention strategies that initiate networks and require co-operation between different types of actors can be useful, but have their own pitfalls too. One has to consider the stakes of the actors and the target group of actors addressed in order to evaluate what the added value of co-operation and interaction may be.

There is much to gain for government if they can accelerate the moment that a robust technology network emerges. It would, thus, be interesting for governments to find a way to activate R&D towards technologies that are still in the exploration stage. A suggestion is to stimulate ‘variation’ in a protected environment by financially supporting researchers with a thorough knowledge of the manufacturing process and with a success record in developing process technologies.

To conclude, stimulating the development of industrial energy-efficient technology remains an opportunity for government in mitigating greenhouse gas emissions. However, the fact that an innovative technology is labelled as
energy-efficient is not enough ground for effective government intervention. One has to look beyond industrial energy-efficiency. It is of great importance to develop government intervention strategies that support, strengthen and affect actors and networks and, in this way, redirect technological development in the manufacturing industry to less energy-intensive directions.
CHAPTER 7

7 INSTRUMENT CHOICE AND ENERGY-EFFICIENCY IMPROVEMENT BY FIRMS: AN EMPIRICAL ANALYSIS

7.1 Introduction

Environmental quality and resource management has become a prominent challenge in a modern economy. The complexity involved has prompted a series of diverse policy initiatives, ranging from market oriented instruments (like taxes, subsidies and tradeable permits) to command and control measures (ranging from voluntary agreements to standards). Some of these instruments were illustrated in Chapters 3-6 of this book and discussed in terms of their effectiveness and desirability when considered in isolation (see Tietenberg et al., 1999, for a general overview). In practice, many policy initiatives are hindered by much uncertainty (see, for example, Roberts and Spence, 1976, and Adar and Griffin, 1976), so that a clear choice for price-based instruments – as opposed to quantity-based instruments – is difficult to make.

Against this background, the aim of this chapter is to investigate how investment behaviour, responsiveness and attitudes towards environmental policy, as well as barriers to the adoption of readily available energy-efficient technologies, vary over sectors and with firm characteristics. The results are based on a survey among Dutch firms. Detailed systematic empirical studies at a sectoral or firm level are rather scarce in the Netherlands. Some years ago, Velthuijsen (1993) and Gillissen et al. (1995) performed a questionnaire among firms, in which they also focused on energy use and related investments. Our research broadens their scope in that we do not only focus on investment behaviour, but also on the stated response to and attitudes towards a set of specified policy instruments. Our new data set allows in addition for a more detailed analysis of the role of various types of uncertainty in investment decisions, which, according to investment theories as developed by, for example, Dixit and Pindyck (1994), may be a major explanatory factor for seemingly irrationally high revealed internal discount rates in investment evaluation (see, for example, Johnson, 1994, and Chapter 2). It thereby aims at broadening our understanding of decision-making on energy use in companies

63 This chapter is based on De Groot, Verhoeof and Nijkamp (1999). Research assistance by Caroline Rodenburg is gratefully acknowledged.
and energy gaps as have been widely documented in the literature (see Chapter 2 for a review).

The survey was held in the spring of 1998 among Dutch firms. These firms were randomly selected from the register of the Chambers of Commerce and were more or less equally distributed among the most energy-intensive sectors of the Dutch economy, namely the chemical industry, basic metals, metals and machinery, food, paper, horticulture, construction materials, and textiles. The extensive survey contained a detailed set of questions about energy use, investments, the firm’s competitive position in the market, internal decision making, its attitude towards and adoption of energy-efficient technologies, as well as its attitude towards and responsiveness to Dutch environmental policy. The statistical results also incorporate a body of empirical knowledge on the expected effects and social acceptability of energy policies, two major determinants for the choice of environmental and energy policies.

Our analysis is presented in five separate sections. Section 7.2 discusses the survey and gives a description of the firms and sectors included in the sample. Section 7.3 considers the investment behaviour of firms, along with the perceived barriers to investing in cost effective energy-efficient technologies (in the context of the so-called energy-efficiency paradox). In Section 7.4, attention is shifted to the firms’ stated reactions in response to an increase in energy taxes on a national level (with no rebatements). Section 7.5 discusses the attitudes towards environmental policies in the Netherlands. Section 7.6 contains an evaluation of the results and presents the policy conclusions emerging from our empirical analysis.

7.2 The survey

The survey resulted in a data set of 135 companies (i.e., plant locations) established in the Netherlands. Firms in nine sectors of the economy were randomly selected, and received a 15 page survey in May 1998. Confidentiality was guaranteed. The survey asked firms about their characteristics (such as size, profitability, sector to which it belongs, number of employees, and export share), their energy use (in monetary and volumetric equivalents), their investments (in general, and purely aimed at energy-efficiency improvements), their position in the market (measured by, for example, strength of competition, location of competitors, how the firm compares to competitors in terms of size, sales, profitability), their focus in policy making (importance of short- and long-run profitability, reduction of labour and energy costs, improvement of
environmental image, increase in sales, etc.), their expectations about the
development of costs of inputs, their knowledge, implementation and use of
energy-efficient technologies, their attitudes towards and willingness to accept
energy policies of various types (such as voluntary agreement, taxes at national
and international level, subsidies, standards), and their R&D behaviour
(expenditures, degree of co-operation and outsourcing, size of R&D staff,
criteria for project selection, etc.). Firms were divided over the following nine
sectors: the chemical industry, basic metals, metals, machinery, food, paper,
horticulture, construction materials, and textiles. In the remainder of this
chapter, we will distinguish 7, more aggregate sectors, namely the chemical
industry (18 % of the sample; further labelled as CHEM), basic metals (10 %;
BASEMET), metal products (11 %; MET), food (14 %; FOOD), paper (7 %;
PAPER), horticulture (24 %; HORT), and the rest (REST) consisting out of
machinery, construction materials and textiles.

The overall response rate was 4.2 %. Response rates per sector differed
considerably. They ranged from 1.46 % in the textile industry to 8.73 % in
horticulture. Although admittedly low, such a response rate is common for this
kind of extensive survey research (compare, for example, Vicini, 1998). A first
rough analysis of the data gives no reason for suspecting serious selection
biases in the sample. Furthermore, for the ultimate goal for which the survey
was held, namely studying how decision making, barriers and attitude towards
policy vary over different firms and sectors, we suspect no serious effects of a
potential selection bias. Clearly, some caution is needed when generalising the
results. Data on size in terms of employees, energy intensity, and profitability
were confronted with available evidence from the Dutch Statistical Bureau
(CBS) in ‘De Nederlandse Energiehuishouding, Deel 2’ (Table 9). Although
the data are not fully comparable (our measure of size is the number of people
working in a firm, independent of whether they work part-time or not, and the
CBS reports gross returns before taxation while we have data on net
profitability), they suffice to express some confidence in the representativeness
of our data set. The means reported in Table 7.1 do not differ significantly from
the reported sector averages by the CBS for energy intensity and size (at a
significance level of 5 %). Also, the relative order of magnitude of these
variables according to the CBS is comparable to the order of magnitude in our
sample. From the respondents within the firms, 75% was associated with
energy, investment and/or technological management. Only 11% of the firms
that responded had an energy co-ordinator, from which we may conclude that
firms which are already explicitly working on their energy management are not
over-represented in the sample (compare Gillissen et al., 1995; Table 6.3).
More detailed information on this analysis is available upon request from the authors.

Table 7.1 summarises relevant information on some key characteristics of the firms in the various sectors under investigation. The categories according to which firms are distinguished are their share of energy costs in total sales, their investments as a share of sales, their profits as a share of sales, the number of employees, their perception of competition (ranging from limited (score 1) to intensive (score 3)), and the location of their competitors (ranging from mainly in the Netherlands (score 1) to virtually all abroad (score 4)). A first statistical experiment concerned the explanation of the above set of firm characteristics from a set of sector dummies. Statistical significance in the table indicates that a particular firm characteristic deviates significantly from the sample average in the industry under investigation. The parameters reported in the table were estimated using Ordinary Least Squares (OLS) estimation, where the dependent variable was the deviation of a firm’s score from the sample average, and the

<table>
<thead>
<tr>
<th>FIRM CHAR.</th>
<th>OBSERV</th>
<th>Sample average</th>
<th>CHEM</th>
<th>BASE MET</th>
<th>MET</th>
<th>FOOD</th>
<th>PAPER</th>
<th>HORT</th>
<th>REST</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBSERV</td>
<td>135</td>
<td>24</td>
<td>13</td>
<td>15</td>
<td>19</td>
<td>10</td>
<td>33</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>ENQ</td>
<td>0.10</td>
<td>-0.01</td>
<td>-0.06</td>
<td>-0.08</td>
<td>-0.07</td>
<td>-0.06</td>
<td>+0.14</td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td>INQ</td>
<td>0.11</td>
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<td>-0.02</td>
<td>-0.07</td>
<td>-0.06</td>
<td>+0.09</td>
<td>+0.09</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td>PRQ</td>
<td>0.03</td>
<td>+0.02</td>
<td>+0.05</td>
<td>+0.03</td>
<td>+0.08</td>
<td>+0.09</td>
<td>+0.09</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td>LABOUR</td>
<td>279</td>
<td>+285</td>
<td>+758</td>
<td>233</td>
<td>+111</td>
<td>-218</td>
<td>-253</td>
<td>-227</td>
<td></td>
</tr>
<tr>
<td>COMP</td>
<td>2.42</td>
<td>+0.13</td>
<td>+0.17</td>
<td>-0.28</td>
<td>-0.05</td>
<td>-0.12</td>
<td>+0.21</td>
<td>-0.30</td>
<td></td>
</tr>
<tr>
<td>COMPIN</td>
<td>2.23</td>
<td>+0.99</td>
<td>+0.85</td>
<td>-0.23</td>
<td>-0.87</td>
<td>+0.33</td>
<td>-0.16</td>
<td>-0.70</td>
<td></td>
</tr>
</tbody>
</table>

*/**/***: significant at the 0.1/0.05/0.01 level (two-sided t-test) in OLS regression with sector dummies

VARIABLE DESCRIPTIONS64

OBSERV Number of observations;
ENQ Energy intensity (expenditures on energy as fraction of sales);
INQ Investment ratio in 1997 (total investments as fraction of sales);
PRQ Profit ratio (total profits as fraction of sales);
LABOUR Number of employees (full time and part time);
COMP Degree of competition on sales market (1=limited, 2=average, and 3=strong);
COMPIN Location of competitors (1=mainly in Netherlands, 2=less than 50% abroad, 3=more than 50% abroad, 4=virtually all abroad).

64 A complete overview of all variable descriptions is given in Appendix II.
INSTRUMENT CHOICE: AN EMPIRICAL ANALYSIS

From this table, it is evident that horticulture is the most energy intensive sector with relatively small firms, and invests - relative to profits - significantly more than firms in other sectors. In addition, competitive forces in horticulture are perceived as strong (especially on the national market). The chemical sector and the sector producing basic metals can both be characterised by larger-sized firms and by the fact that most of their competitors are located abroad. In contrast, firms in the food sector and machinery, construction materials, and textiles indicate that most of their competitors are located in the Netherlands.  

7.3 Investment behaviour and barriers to investment

We will now turn to the stimuli and barriers concerning firm investments in energy-efficiency improvement. In one of the central parts of the survey, firms were asked about their investment behaviour, and the factors that they perceived as preventing them from investing in energy-efficient technologies that were considered, but that were nevertheless not (yet) adopted.

The share of total investments that is spent on technologies that are purely aimed at energy-efficiency improvement is on average slightly below 10%. Although low at first sight, these shares do not significantly differ from the share of energy costs in total sales. This result seems to suggest that energy-efficiency improvement is just one of the criteria on which a new technology is

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65 The column variables reported in Table 7.1, referred to as ‘firm characteristics’ in the sequel, appear to be often strongly correlated. Especially the degree of competition and the location of competitors are strongly positively correlated, while the profit rate and the energy intensity are strongly negatively correlated. This may create statistical problems in the multiple regression estimation of models, due to the presence of multi-collinearity. We will evade this problem in the remainder of this chapter by restricting the reported results to simple regressions. The focus is therefore on the overall impact, not the marginal effect, of these variables on the response variables studied. In the same vein, we will report separate estimations of the effect of (the full set of) sector dummies on the response variables. In the context of the type of questions studied, the advantage of this approach is that the ‘full’ effect of the independents on the dependants is determined. The interpretation of marginal effects is probably less relevant from a policy perspective, in particular because the independents considered simply are correlated in reality. The estimation results obtained with multiple regressions would cloud these correlations. Moreover, it should of course be acknowledged that the data set is simply too small to allow for multiple regressions taking all possibly relevant variables on board, in particular if more advanced statistical techniques such as 2SLS were used.
judged and that there are other complementary benefits such as increased capacity and improved product quality that are considered along with energy-efficiency (see also Chapter 6). Still, most firms in the survey indicate that energy efficiency is an important factor in their investment decisions. Furthermore, Figure 7.1 reveals that, at least in the firms’ own perception, there is no systematic under- or overestimation of the relative importance of energy efficiency in overall investment decisions. It is therefore possible that further energy-efficiency improvement may still take place by incorporating energy efficiency as a decision variable when installing new machines or buildings. This conclusion was further confirmed by asking firms about their future investment behaviour. It turned out that most firms expect the total investment budget to remain largely constant (or to increase slightly). This also holds, but to a lesser extent, for investments purely aimed at increasing energy efficiency. However, the importance of energy efficiency in investment decisions is expected to increase (albeit slightly). One may therefore conclude that, according to the respondents, energy efficiency gradually becomes an integrated and important aspect of the overall evaluation of investment opportunities (we will return to this below when we discuss barriers to investments).

<table>
<thead>
<tr>
<th>Importance Level</th>
<th>% of Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very important</td>
<td></td>
</tr>
<tr>
<td>Important</td>
<td></td>
</tr>
<tr>
<td>Moderately important</td>
<td></td>
</tr>
<tr>
<td>Unimportant</td>
<td></td>
</tr>
<tr>
<td>Completely unimportant</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 7.1](image)

*Figure 7.1* Relative importance of energy efficiency in general investment decisions.
Before proper investment decisions can be made, adequate knowledge is required on the various alternative investment opportunities. Lack of information is a principal source of market failures that can account for sub-optimal investment behaviour (see Chapter 2). To obtain knowledge on suitable technologies, most firms turn out to rely on specialist publications. Also direct contacts with suppliers, the industrial board and colleagues appear to be intensively used to gather information. Formal organisations like the government and NOVEM (the Netherlands agency for energy and the environment) play only a minor role in providing firms with information on energy-efficient technologies. As far as perceived knowledge is concerned, about 30% of the firms indicate that they are not, or only to a minor extent, aware of existing new technologies that are not yet being used in practice by any firm. Of course, a smaller percentage of 20% has only limited knowledge on technologies that are currently used by other firms. These results suggest that future policy can improve upon the situation by providing firms with relevant information on investment possibilities in energy-efficient technologies. The public-goods nature of information provides good arguments for such a governmental role in providing and disseminating information. At the same time, firms’ perceptions on the role of NOVEM in stimulating the diffusion of information cast some doubt on the potential effectiveness of the government as a driving force behind information dissemination. This suggests that the government should use existing intermediaries closely related to the sector such as branch organisations to this end.

It is often argued that small firms are in a particular disadvantageous position in obtaining strategic information on new and already existing technologies. In order to obtain information on whether the perceived knowledge varies over sectors and over firms with particular characteristics, we have regressed the perceived knowledge on sector dummies and firm characteristics. The results are shown in Tables 7.2a and 7.2b. In Table 7.2b, we report simple ordered probit estimates. 

66 Ordered probit estimation properly takes account of the fact that the independent variable can take on only discrete values. The interpretation of the coefficients in the Table 7.2b, however, is difficult (this is a notorious problem with ordered probit estimates; see for example Greene, 1997). This is exactly the reason for using OLS when considering the sector dummies: the estimated parameters can easily be interpreted as the sector-specific difference in average score (compared to the entire sample). In the text, when discussing ordered probit results, we restrict the analysis to the sign and significance of the obtained parameter values. More detailed information on the estimates is available upon request from the authors.
Table 7.2a Perceived knowledge on available technologies: sectors, OLS.

<table>
<thead>
<tr>
<th>KNOWLEDGE</th>
<th>CHEM</th>
<th>BASE</th>
<th>MET</th>
<th>FOOD</th>
<th>PAPER</th>
<th>HORT</th>
<th>REST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Know_exist</td>
<td>3.18</td>
<td>+0.34</td>
<td>+1.44**</td>
<td>+0.03</td>
<td>+0.11***</td>
<td>+0.25**</td>
<td>+0.20***</td>
</tr>
<tr>
<td>Know_new</td>
<td>2.79</td>
<td>+0.61</td>
<td>+1.21**</td>
<td>+0.04</td>
<td>+0.10***</td>
<td>+0.29***</td>
<td>+0.27***</td>
</tr>
</tbody>
</table>

*/**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in OLS regression

VARIABLE DESCRIPTION
Know_exist knowledge on already existing technologies that are currently being used by competitors (5 pt. scale; 1=no knowledge, 3=reasonable knowledge, 5=good knowledge);
Know_new knowledge on new technologies that are not yet being used in practice (5 pt. scale; 1=no knowledge, 3=reasonable knowledge, 5=good knowledge).

Table 7.2b Perceived knowledge on available technologies: firms’ characteristics, simple ordered probit.

<table>
<thead>
<tr>
<th>KNOWLEDGE</th>
<th>Sample average</th>
<th>Energy quote</th>
<th>Investment quote</th>
<th>Profit quote</th>
<th>Size</th>
<th>Competition</th>
<th>International orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Know_exist</td>
<td>3.18</td>
<td>+0.34</td>
<td>+1.44**</td>
<td>+0.03</td>
<td>+0.11***</td>
<td>+0.25**</td>
<td>+0.20***</td>
</tr>
<tr>
<td>Know_new</td>
<td>2.79</td>
<td>+0.61</td>
<td>+1.21**</td>
<td>+0.04</td>
<td>+0.10***</td>
<td>+0.29***</td>
<td>+0.27***</td>
</tr>
</tbody>
</table>

*/**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in simple ordered probit regression. Bold estimates indicate that the sign of a significant parameter in the simple regression is ‘robust’: no significant parameter of the opposite sign is found for this variable in multiple regressions.

Several results shown in the tables are noteworthy. First, the firms’ knowledge (as experienced by the firms themselves) on both new and already employed technologies is particularly high in the chemical industry, while it is low in the metal and food industry. Second, such knowledge is especially high in large firms that invest heavily and are faced with strong competition. This last result is particularly interesting, as it reveals that there is some truth in the argument that competition indeed functions as an incentive generating mechanism, forcing firms to obtain strategic information. Although it has to be acknowledged that the causality might run both ways, the positive correlation between knowledge and total investments is also conform our expectation. These results are in clear contrast with Gillissen et al. (1995), who conclude that the information gap is largely sectorally determined. Our analysis reveals that the information gap is particularly large in small firms facing limited competition and spending relatively little on investments. There is some sectoral effect in that firms with these characteristics are over-represented in the food and basic metals industry, and underrepresented in the chemical
industry. Our results are largely in line with Gruber and Brand (1991) who performed a study on, among others, knowledge on technologies in German small and medium-sized firms. For the government it is important to know that knowledge dissemination can be focused on specific categories of firms.

Although knowledge about and expected profitability of available technologies are necessary conditions for implementation of new technologies, they are not sufficient. There may be a host of barriers that could prevent the firm from (immediately) investing, thus resulting in an ‘energy gap’. The optimal timing of the adoption of new technologies is an important issue in the economic literature (see, for example, Farrell and Saloner, 1986; Choi, 1994; Koski and Nijkamp, 1998). The evolution of the installed base of adopters of a new technology and the associated costs and benefits of waiting for a new technology are a major source of uncertainty. Figure 7.2 shows the relative importance of barriers to adoption. Scores range from 1 (barrier is completely unimportant) to 5 (barrier is very important). The responses shown here concern technologies about which firms had indicated earlier in the survey that they are aware of their existence, that were considered as being profitable, but that were not implemented yet. Three main categories of barriers can be distinguished, namely (i) general barriers related to the overall decision-making process of firms with respect to production and investment, (ii) financing constraints, and (iii) barriers that are related to uncertainty about, for example, future technology, prices and policy developments, and the quality of the new technology.

The most important barrier for firms is the existence of other investment opportunities that are considered more promising or important. Also resistance to replace existing machinery turns out to be an important obstacle. This suggests that in the future, considerable improvements can still be made, once old machinery is going to be replaced due to obsolescence (compare Fawkes and Jacques, 1987). Also, the relatively small amount of money spent on energy is acting as a barrier to investing in new technology. This can be an indication that the costs of acquiring information and incorporating the new technologies within the firm often exceed the expected savings on the energy bill. Or, stated alternatively, energy-extensive firms apparently have no incentive to consider the possibilities for energy-efficiency improvement. Lack of financial means to finance the investments turns out to be a problem of relatively minor importance; once a technology is considered to be (sufficiently) profitable, firms are able to collect the necessary funds to make the investment. Uncertainty is of intermediate importance. A fear that firms have is that future technologies will be significantly better or cheaper. This
tends to induce a postponement of investments (see Chapter 2). Part of the uncertainty is also related to policy and results from uncertainty about future subsidies or environmental requirements. Again, this type of uncertainty results in the postponement of investment. These results all suggest a decision-making process that is rational and consistent with cost-benefit analysis (as explained in Chapter 2). This suggestion is further reinforced by Figure 7.3 showing that cost savings due to lower energy use are the most important driving force for investing in energy-efficient technologies. Policy measures like subsidies and fiscal arrangements may therefore be supportive in steering investments towards higher energy efficiency.67

The next step in our analysis is to test whether the barriers to investing in energy-efficient technologies differ between sectors (Table 7.3a), and according to firm characteristics (Table 7.3b). The estimation technique used in Table 7.3a is comparable to the technique underlying Table 7.2a, while the estimation technique employed in Table 7.3b is comparable to the one in Table 7.2b.

It is evident from Table 7.3a that there are only a few barriers that play a systematically different role in different sectors. The only two sectors that stand out somewhat are the basic metals sector and horticulture. The general barriers play a relatively important role in the sector producing basic metals. It appears from the results that current installations are thought to be sufficiently efficient from an energy point of view and that the willingness to replace them is (therefore) fairly low. An opposite pattern can be found in horticulture. In this sector, current installations are thought to be insufficiently energy efficient and there are no problems in that current installations initially have to be replaced which can be explained from the high energy intensity of this sector. Problems do exist in this sector however, in that organisational constraints prevent the introduction of new technologies. Organisational constraints can be thought of as difficulties in incorporating the technology in the existing production process due to, for example, a lack of capable employees, a lack of internal knowledge or a lack of physical space. The importance of organisational factors for understanding the energy-efficiency paradox has been stressed by, for example, DeCanio (1993).

The extent to which barriers to invest to invest in energy-efficient

67 Note that this result is not inconsistent with earlier statements that energy costs are just a small part of total investment costs and are only one aspect of a technology that is taken into account when deciding on whether or not to adopt a particular technology. It does, however, indicate that coherent and extensive cost-benefit analyses including complementary effects are required for a proper understanding of actual adoption behaviour.
Figure 7.2 Barriers confronting firms when introducing new technology (score 1 is ‘totally unimportant’, score 5 is ‘very important’).
Figure 7.3 Relative importance of motives in deciding whether to implement new energy-saving technologies (score 1 is 'totally unimportant', score 5 is 'very important').
technologies vary with firm characteristics is described in Table 7.3b. The results in this table shed light on the sources of heterogeneity that are important for understanding differences in firms’ investment behaviour (see, for example, Jaffe and Stavins (1994) who have emphasised the importance of heterogeneity for understanding the energy-efficiency paradox and the pattern of diffusion of conservation technology). As one would expect, the general barriers play less of an important role in energy-intensive firms (except for the organisational barriers, which is strongly driven by the fact that horticulture is energy intensive and faced with organisational barriers). A surprising result is that weight attached to barriers by firms making large profits is relatively large. Especially the barriers associated with uncertainty seem to refrain profit making firms from investing. A potential explanation for this result is that the profitable firms in our sample tend to be the energy extensive firms. As we saw before, these firms attach more weight to the various potential barriers to invest in energy-efficient technologies. Another (theoretic) explanation may be that more profitable firms do consider uncertainty more explicitly when making investment decisions. Economically better management would then jointly explain both the high profitability and the consideration of uncertainty. A similar argument could explain why these firms less often state that energy efficiency is less important per se.

Similarly surprising is the fact that large firms attach a relatively large weight to general barriers (except for organisational barriers, which may again reflect the fact that horticulture is characterised by organisational barriers and relatively small firms). Finally, competitive forces turn out to affect the importance of reasons for not adopting energy-efficient technologies. In particular, more competitive firms tend to be faced relatively stringently with organisational barriers and also tend to abstain from technology adoption due to various sources of uncertainty (especially the fact that technologies may become cheaper in the future which makes it advantageous to wait).

7.4 Responsiveness to policy changes

Having discussed the investment behaviour of firms, we now turn to a discussion of how firms state that they would respond to the introduction of an energy tax. In particular, we asked firms to state the likelihood that they would react to an increase in energy taxes on a national level, with no rebatements of the revenues generated, by: lowering or increasing production, changing the production mix towards less energy intensive goods, charging customers with
the increased costs, introduce and adopt energy-efficient technologies, develop energy-efficient technologies, change to other energy sources (wind or solar energy), leave the market by either shutting down or evade the tax by moving abroad, or do nothing and accept the loss. In the next section, we will consider the related question on the extent to which firms find particular policies acceptable.

Figure 7.4 gives some insight into the expected reactions (under the assumption of no rebatements). Firms are likely to react by (faster) introduction of energy-efficient technologies or charging the customers with the additional costs. Also changes in the product mix are considered as a useful option. In any case, taxes will result in a reaction of firms given that the ‘no reaction’ option received the lowest score.

Tables 7.4a and 7.4b yield insights into whether the reactions on an energy tax vary with firm and sector characteristics.

Table 7.4a reveals that the reactions on the introduction of an energy tax are significantly different from the average reaction in the chemical sector and the horticulture. More specifically, the employment of alternative energy sources is a less viable alternative for the chemical sector than for other sectors, while it is more viable in horticulture. There is a strong tendency in the chemical sector to either decrease production in reaction to the introduction of an energy tax or to evade the tax by moving abroad. In horticulture, charging customers with the costs is no alternative, which can be understood from the fact that firms in this sector are strong price takers, prices being determined on the auction. This price-taking behaviour in the horticulture is further illustrated by the fact that especially in this sector, firms are more strongly inclined to increase rather than decrease their production after imposition of a tax. For a practical price-taker, a tax means that the profit margin decreases, and a larger turnover is necessary to cover fixed costs. The alternative of moving abroad is also strongly considered in the paper industry. This alternative is not seriously considered by the food industry and the machinery and textiles, which can be

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68 The result that a production increase is, in general, considered a more appropriate response to an energy tax than a production decrease seems at odds with textbook models of a firm’s response to environmental taxation (for example, Baumol and Oates, 1988). It could reflect that firms anticipate a larger equilibrium production level, due to other firms leaving the market. A less academic explanation would be the one given in the main text: firms would have a certain target profit level, and will try to sell more after imposition of a tax. This would reflect that firms consciously or unconsciously assume that their average variable costs are constant, and do not consider the fact that higher sales with a given demand curve require lower prices. It would validate the ‘folkloristic claims’ that firms do not think and act marginally.
Table 7.3a Barriers for implementation of energy-efficient technologies: sectors, OLS.

<table>
<thead>
<tr>
<th>BARRIERS</th>
<th>Sample average</th>
<th>CHEM</th>
<th>BASE</th>
<th>MET</th>
<th>FOOD</th>
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<th>REST</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENERAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OthIm</td>
<td>3.74</td>
<td>-0.10</td>
<td>+0.48</td>
<td>-0.03</td>
<td>+0.59</td>
<td>-0.24</td>
<td>-0.44</td>
<td>-0.34</td>
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<tr>
<td>AhRe</td>
<td>3.51</td>
<td>+0.09</td>
<td>+0.71</td>
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<td>-0.01</td>
<td>-1.01</td>
<td>-0.61</td>
<td>+0.74</td>
</tr>
<tr>
<td>EnCo</td>
<td>3.35</td>
<td>+0.35</td>
<td>+0.03</td>
<td>+0.08</td>
<td>+0.15</td>
<td>-0.35</td>
<td>-0.17</td>
<td>-0.55</td>
</tr>
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<td>LoPrio</td>
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<td>+0.25</td>
<td>-1.08</td>
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</tr>
<tr>
<td>CurEf</td>
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<td>-0.50</td>
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<td>NowIm</td>
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<td>+0.04</td>
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<td>Organ</td>
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<td>+0.29</td>
<td>-0.33</td>
<td>-0.67</td>
<td>-0.33</td>
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<td>FINANCE</td>
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</tr>
<tr>
<td>IntBu</td>
<td>2.66</td>
<td>-0.10</td>
<td>+0.45</td>
<td>+0.63</td>
<td>+0.17</td>
<td>+0.34</td>
<td>-0.46</td>
<td>-1.16</td>
</tr>
<tr>
<td>ExtBu</td>
<td>2.22</td>
<td>-0.22</td>
<td>-0.34</td>
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<td>+0.58</td>
<td>+0.28</td>
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<tr>
<td>UNCERTAINTY</td>
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<td>UnQua</td>
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<td>-0.21</td>
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<td>Sub</td>
<td>2.54</td>
<td>-0.14</td>
<td>-0.17</td>
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<td>-0.11</td>
<td>+1.46</td>
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<tr>
<td>Cheap</td>
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<td>Overv</td>
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<td>+0.29</td>
<td>+0.63</td>
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<td>+0.23</td>
</tr>
<tr>
<td>Wait</td>
<td>2.35</td>
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<td>-0.52</td>
<td>+0.36</td>
<td>-0.35</td>
<td>+0.35</td>
<td>+0.05</td>
</tr>
<tr>
<td>Norms</td>
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<td>+0.07</td>
<td>+0.17</td>
<td>-0.73</td>
<td>+0.51</td>
<td>+0.17</td>
<td>-0.03</td>
<td>-0.33</td>
</tr>
</tbody>
</table>

*/**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in OLS regression

VARIABLE DESCRIPTIONS

OthIm Other investments more important;
AhRe Technology can only be implemented after existing technology has been replaced;
EnCo Energy costs are not sufficiently important;
LoPrio Energy efficiency has low priority;
CurEf Current installations are sufficiently efficient;
NowIm Currently introducing the specific technology;
Organ Difficult to implement due to internal organisation;
IntBu Internal constraints on the budget;
ExtBu Problems with external financing;
UnQua Uncertainty regarding the quality;
Sub Better to wait for subsidies;
Cheap Technology will become cheaper;
Overv No good overview of existing technologies;
Wait Better to await experience of colleagues;
Norms Maybe new technology will not satisfy future standards.
### Table 7.3b Barriers for implementation of energy-efficiency improving technologies: firms’ characteristics, simple ordered probit.

<table>
<thead>
<tr>
<th>BARRIERS</th>
<th>Sample average</th>
<th>Energy quote</th>
<th>Investment quote</th>
<th>Profit quote</th>
<th>Size</th>
<th>Competition</th>
<th>International orientation</th>
</tr>
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<tr>
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<tr>
<td>OthIm</td>
<td>3.74</td>
<td>+0.32</td>
<td>-0.65</td>
<td>-7.65***</td>
<td>+0.14</td>
<td>+0.24</td>
<td>+0.01</td>
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<td>AflRe</td>
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<td>-1.17*</td>
<td>+0.14</td>
<td>+2.35</td>
<td>+0.08</td>
<td>+0.05</td>
<td>+0.01</td>
</tr>
<tr>
<td>EnCo</td>
<td>3.35</td>
<td>-1.21</td>
<td>-0.02</td>
<td>+1.10</td>
<td>+0.04</td>
<td>-0.13</td>
<td>+0.14</td>
</tr>
<tr>
<td>LoPrio</td>
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<td>+1.17</td>
<td>+0.53</td>
<td>+0.03</td>
<td>-0.04</td>
<td>-0.04</td>
</tr>
<tr>
<td>CurEf</td>
<td>3.00</td>
<td>-0.73</td>
<td>+0.54</td>
<td>+2.25</td>
<td>+0.06</td>
<td>-0.26</td>
<td>+0.15</td>
</tr>
<tr>
<td>NowIm</td>
<td>2.96</td>
<td>-0.37</td>
<td>+0.74</td>
<td>+3.26</td>
<td>+0.04</td>
<td>+0.13</td>
<td>-0.01</td>
</tr>
<tr>
<td>Organ</td>
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<td>+1.45*</td>
<td>+0.65</td>
<td>-0.46</td>
<td>-0.12</td>
<td>+0.63</td>
<td>-0.08</td>
</tr>
<tr>
<td><strong>FINANCE</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IntBu</td>
<td>2.66</td>
<td>-0.60</td>
<td>-0.47</td>
<td>+0.28</td>
<td>+0.17***</td>
<td>+0.11</td>
<td>+0.15</td>
</tr>
<tr>
<td>ExtBu</td>
<td>2.22</td>
<td>-0.43</td>
<td>-1.17</td>
<td>+0.27</td>
<td>-0.01</td>
<td>-0.24</td>
<td>-0.09</td>
</tr>
<tr>
<td><strong>UNCERTAINTY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UnQua</td>
<td>2.71</td>
<td>-0.73</td>
<td>+0.39</td>
<td>+2.35</td>
<td>-0.05</td>
<td>+0.18</td>
<td>-0.09</td>
</tr>
<tr>
<td>Sub</td>
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<td>-1.31</td>
<td>+0.10</td>
<td>+7.51***</td>
<td>-0.03</td>
<td>+0.22</td>
<td>+0.16</td>
</tr>
<tr>
<td>Cheap</td>
<td>2.48</td>
<td>-0.80</td>
<td>-0.93</td>
<td>+4.02*</td>
<td>-0.00</td>
<td>+0.60</td>
<td>+0.01</td>
</tr>
<tr>
<td>Overv</td>
<td>2.38</td>
<td>-0.96</td>
<td>-0.39</td>
<td>+1.09</td>
<td>-0.04</td>
<td>-0.17</td>
<td>-0.09</td>
</tr>
<tr>
<td>Wait</td>
<td>2.35</td>
<td>-0.65</td>
<td>-0.47</td>
<td>+8.02***</td>
<td>-0.03</td>
<td>+0.47</td>
<td>+0.01</td>
</tr>
<tr>
<td>Norms</td>
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<td>-1.91</td>
<td>+0.12</td>
<td>+0.58</td>
<td>+0.03</td>
<td>+0.09</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

*/*/*/* indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in simple ordered probit regression. Bold estimates indicate that sign of significant parameter in simple regression is ‘robust’: no significant parameter of the opposite sign is found for this variable in multiple regressions.
Figure 7.4 Behavioural response to an increase in national energy taxes with no rebatements (score 1 is ‘totally unlikely’, score 5 is ‘very likely’).
Table 7.4a Reactions on introduction of energy tax on national level with no rebatement: sectors, OLS.

<table>
<thead>
<tr>
<th>REACTIONS</th>
<th>Sample average</th>
<th>CHEM</th>
<th>BASEMET</th>
<th>MET</th>
<th>FOOD</th>
<th>PAPER</th>
<th>HORT</th>
<th>REST</th>
</tr>
</thead>
<tbody>
<tr>
<td>AltEn</td>
<td>2.47</td>
<td>-0.51**</td>
<td>0.01</td>
<td>-0.11</td>
<td>0.28</td>
<td>0.47</td>
<td>0.39</td>
<td>0.08</td>
</tr>
<tr>
<td>Shut</td>
<td>2.14</td>
<td>+0.19</td>
<td>-0.45</td>
<td>0.29</td>
<td>0.05</td>
<td>0.53</td>
<td>0.07</td>
<td>-0.44</td>
</tr>
<tr>
<td>DevET</td>
<td>2.64</td>
<td>-0.14</td>
<td>+0.36</td>
<td>-0.26</td>
<td>-0.33</td>
<td>-0.22</td>
<td>+0.29</td>
<td>+0.06</td>
</tr>
<tr>
<td>ImpET</td>
<td>3.49</td>
<td>-0.31</td>
<td>-0.07</td>
<td>+0.05</td>
<td>+0.32</td>
<td>+0.08</td>
<td>+0.15</td>
<td>-0.14</td>
</tr>
<tr>
<td>Price</td>
<td>3.19</td>
<td>+0.41</td>
<td>+0.35</td>
<td>+0.67*</td>
<td>+0.34</td>
<td>+0.52</td>
<td>-0.88***</td>
<td>+0.46</td>
</tr>
<tr>
<td>PrMix</td>
<td>2.55</td>
<td>-0.09</td>
<td>+0.07</td>
<td>-0.19</td>
<td>+0.20</td>
<td>-0.12</td>
<td>+0.28</td>
<td>-0.35</td>
</tr>
<tr>
<td>Nothing</td>
<td>1.56</td>
<td>+0.05</td>
<td>-0.02</td>
<td>-0.28</td>
<td>-0.06</td>
<td>-0.13</td>
<td>+0.14</td>
<td>+0.04</td>
</tr>
<tr>
<td>IncPr</td>
<td>2.39</td>
<td>-0.62**</td>
<td>-0.00</td>
<td>-0.31</td>
<td>+0.02</td>
<td>-0.10</td>
<td>+0.51***</td>
<td>+0.16</td>
</tr>
<tr>
<td>DecPr</td>
<td>2.06</td>
<td>+0.65**</td>
<td>+0.10</td>
<td>-0.44</td>
<td>-0.18</td>
<td>+0.44</td>
<td>-0.16</td>
<td>-0.34</td>
</tr>
<tr>
<td>Migr</td>
<td>2.60</td>
<td>+0.58</td>
<td>-0.60</td>
<td>-0.03</td>
<td>-0.60</td>
<td>+1.40***</td>
<td>+0.23</td>
<td>-0.55*</td>
</tr>
</tbody>
</table>

*/**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in OLS regression.

VARIABLE DESCRIPTOINS
AltEn Employ other sources of energy;
Shut Shutting down;
DevET Own development of energy-efficient technologies;
ImpET Introduce energy-efficient technologies;
Price Increase prices of final products;
PrMix Start producing a less energy intensive product mix;
Nothing No reaction and incur the loss;
IncPr Increase production;
DecPr Decrease production;
Migr Move (parts of) firm to foreign country.
understood from the lack of external competitors (see Table 7.1 and Table 7.4b).  

The results in Table 7.4b reveal that the responsiveness to an increase in energy taxes is particularly high in competitive industries. The threats from competitors clearly force firms in these industries to react, and the more so the stronger the international orientation. It is interesting to note that more profitable firms have a low tendency to move abroad. This may be explained from the fact that this (probably more drastic) response is not considered necessary when a firm is currently profitable. A related reason could be that current profitability could partly be explained from a relatively favourable current location, where a firm, for instance, benefits from a successful exploitation of local comparative advantages (labour markets, accessibility, and so forth).

Finally, it is noteworthy that that especially firms with a relatively strong international orientation are hesitant to simply shift the burden from the national energy tax to their customers. This is also conform our prior expectation.

7.5 Attitudes towards environmental policy

When barriers exist and restrain firms from investing, there is a potential role for the government. The barriers found in our survey may provide a justification for the active role the Dutch government has recently played in coping with environmental problems, and the type of actions undertaken. Acceptability and support for the various policy measures are a prerequisite for their success. We have therefore asked firms on their opinion about various types of environmental policy. Figure 7.5 summarises the main findings. As one would expect, subsidies are preferred to taxes. Voluntary agreements are also appreciated, in contrast to standards. These results reveal that firms want to maximise the freedom in deciding how to cope with the desire of the government to increase the quality of the environment (see also Chapter 5). Obviously, the acceptance of energy taxes strongly increases if measures are

69 It is interesting to confront the sectoral dependency of the migration-response with the study by van Beers and van den Bergh (1997). They show that the reduction in exports as a consequence of stricter environmental policies is stronger in non-resource based industries than in resource based industries. The fact that the firms that argue to likely react by migrating are industries with many foreign competitors may be seen as evidence that these firms are not primarily based in the Netherlands for reasons of resource availability and may thus be seen as an explanation for the fact that especially these firms argue to react by migrating.

70 Results on the responsiveness to international increases in energy prices, national energy taxes with rebates, and the imposition of stricter standards are also available.
Table 7.4b Reactions on introduction of energy tax on national level with no rebatement: firms’ characteristics, simple ordered probit.

<table>
<thead>
<tr>
<th>REACTIONS</th>
<th>Sample average</th>
<th>Energy quote</th>
<th>Investment quote</th>
<th>Profit quote</th>
<th>Size</th>
<th>Competition</th>
<th>International orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AltEn</td>
<td>2.47</td>
<td>+0.15</td>
<td>-0.48</td>
<td>+0.76</td>
<td>-0.04</td>
<td>+0.07</td>
<td>-0.06</td>
</tr>
<tr>
<td>Shut</td>
<td>2.14</td>
<td>+0.29</td>
<td>-0.11</td>
<td>-0.02</td>
<td>+0.03</td>
<td>+0.28</td>
<td>+0.10</td>
</tr>
<tr>
<td>DevET</td>
<td>2.64</td>
<td>+0.02</td>
<td>+0.36</td>
<td>+0.07</td>
<td>-0.03</td>
<td>+0.10</td>
<td>+0.08</td>
</tr>
<tr>
<td>ImpET</td>
<td>3.49</td>
<td>-0.15</td>
<td>+0.56</td>
<td>+0.19</td>
<td>-0.02</td>
<td>+0.04</td>
<td>-0.08</td>
</tr>
<tr>
<td>Price</td>
<td>3.19</td>
<td>-1.90</td>
<td>-0.56</td>
<td>+0.11</td>
<td>-0.05</td>
<td>-0.09</td>
<td>-0.23***</td>
</tr>
<tr>
<td>PrMix</td>
<td>2.55</td>
<td>+0.19</td>
<td>-0.06</td>
<td>+0.09</td>
<td>-0.01</td>
<td>+0.05</td>
<td>-0.05</td>
</tr>
<tr>
<td>Nothing</td>
<td>1.56</td>
<td>+0.53</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>IncPr</td>
<td>2.39</td>
<td>+0.59</td>
<td>+0.81</td>
<td>-0.13</td>
<td>-0.15***</td>
<td>-0.17</td>
<td>-0.10</td>
</tr>
<tr>
<td>DecPr</td>
<td>2.06</td>
<td>+0.31</td>
<td>-0.03</td>
<td>-0.03</td>
<td>+0.10***</td>
<td>+0.37***</td>
<td>+0.15*</td>
</tr>
<tr>
<td>Migr</td>
<td>2.60</td>
<td>+0.37</td>
<td>-0.60</td>
<td>-2.94**</td>
<td>+0.21**</td>
<td>+0.38**</td>
<td>+0.30***</td>
</tr>
</tbody>
</table>

*//**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in simple ordered probit regression; Bold estimates indicate that the sign of a significant parameter in simple regression is ‘robust’: no significant parameter of the opposite sign is found for this variable in multiple regressions.

taken that minimise the adverse effects on the firms’ competitive position and profitability. Examples are energy taxes with direct recycling of the tax revenues through lower labour taxes, and energy taxes on a European level. Clearly, it is not the efficiency or effectiveness of energy taxes per se (the effect on relative input prices) that worries firms most, but much more the distributional effect (the money transfer), inducing adverse effects on the competitive position of the firm.

Another issue in energy policy is whether additional policy measures to reduce energy use are acceptable for firms, or only so under certain conditions. The majority of firms indicated to accept government interference, especially when this is taking place in an international setting. This again points at the importance of taking into account and sustaining the competitive position of firms when judging energy policies.

Finally, we return to the question whether the acceptability of energy policies in general and policy measures in particular did vary between sectors and with firm characteristics. The results are summarised in Tables 7.5a, 7.5b, 7.6a, and 7.6b.
Figure 7.5 Opinion on environmental policies (score 1 is ‘very bad’, score 5 is ‘very good’).

We may conclude from Tables 7.5a and 7.6a that the acceptability of policy measures is relatively high in the chemical sector and the sector producing basic metals. It is evident from Tables 7.5b and 7.6b that this result is likely to
Table 7.5a Acceptation of energy policies in general: sectors, OLS.

<table>
<thead>
<tr>
<th>VARIABLE DESCRIPTION</th>
<th>CHEM</th>
<th>BASE MET</th>
<th>MET</th>
<th>FOOD</th>
<th>PAPE R</th>
<th>HORT</th>
<th>REST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acc</td>
<td>2.95</td>
<td>-0.05</td>
<td>+0.13</td>
<td>+0.26</td>
<td>+0.36</td>
<td>+0.05</td>
<td>-0.32</td>
</tr>
<tr>
<td>AccForm</td>
<td>3.29</td>
<td>+0.36</td>
<td>+0.28</td>
<td>+0.21</td>
<td>+0.31</td>
<td>-0.15</td>
<td>-0.29</td>
</tr>
<tr>
<td>DaccF</td>
<td>0.48</td>
<td>+0.40</td>
<td>+0.24</td>
<td>-0.35</td>
<td>-0.18</td>
<td>-0.33</td>
<td>+0.00</td>
</tr>
<tr>
<td>DaccSec</td>
<td>3.55</td>
<td>+0.40*</td>
<td>+0.31</td>
<td>-0.17</td>
<td>+0.45</td>
<td>-0.17</td>
<td>-0.20</td>
</tr>
<tr>
<td>DaccS</td>
<td>0.69</td>
<td>+0.44</td>
<td>+0.31</td>
<td>-0.69*</td>
<td>-0.02</td>
<td>-0.44</td>
<td>+0.11</td>
</tr>
<tr>
<td>AccAbr</td>
<td>3.74</td>
<td>+0.26</td>
<td>+0.12</td>
<td>-0.18</td>
<td>+0.17</td>
<td>-0.11</td>
<td>+0.01</td>
</tr>
<tr>
<td>DaccA</td>
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<td>+0.06</td>
<td>-0.61</td>
<td>-0.24</td>
<td>-0.44</td>
<td>+0.24</td>
</tr>
</tbody>
</table>

*/*/**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in OLS regression

From our investigation, we may conclude that energy-efficiency improvement increasingly becomes an integrated and normal part of the business operation of Dutch firms. The economic potential for cost savings is
Table 7.6a Acceptation of specific types of energy policies: sectors, OLS.

<table>
<thead>
<tr>
<th>VARIABLE DESCRIPTION</th>
<th>TAXNL</th>
<th>TAXNLR</th>
<th>DTAxNL</th>
<th>TAXEU</th>
<th>DTAxEU</th>
<th>STANTEC</th>
<th>STANUSE</th>
<th>INVSUB</th>
<th>RDSUB</th>
<th>VOLAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptability of energy tax in Netherlands</td>
<td>2.02</td>
<td>3.01</td>
<td>1.03</td>
<td>2.90</td>
<td>0.89</td>
<td>2.22</td>
<td>2.31</td>
<td>3.43</td>
<td>3.49</td>
<td>3.20</td>
</tr>
<tr>
<td>Acceptability of energy tax in Netherlands with rebatement of tax revenues</td>
<td>-0.16</td>
<td>-0.10</td>
<td>+0.12</td>
<td>+0.02</td>
<td>+0.20</td>
<td>-0.04</td>
<td>-0.12</td>
<td>+0.21</td>
<td>+0.38</td>
<td>+0.27</td>
</tr>
<tr>
<td>Difference in acceptability between energy tax in Netherlands with and without rebatement</td>
<td>+0.28</td>
<td>-0.01</td>
<td>-0.33</td>
<td>+0.03</td>
<td>-0.27</td>
<td>+0.24</td>
<td>-0.24</td>
<td>+0.03</td>
<td>-0.03</td>
<td>+0.30</td>
</tr>
<tr>
<td>Acceptability of technology standards</td>
<td>+0.11</td>
<td>+0.13</td>
<td>-0.03</td>
<td>+0.17</td>
<td>+0.04</td>
<td>+0.15</td>
<td>+0.16</td>
<td>+0.21</td>
<td>+0.15</td>
<td>+0.08</td>
</tr>
<tr>
<td>Acceptability of emission standards</td>
<td>+0.08</td>
<td>+0.13</td>
<td>-0.24</td>
<td>+0.21</td>
<td>+0.17</td>
<td>+0.11</td>
<td>+0.24</td>
<td>+0.08</td>
<td>-0.15</td>
<td>-0.28</td>
</tr>
<tr>
<td>Acceptability of investment subsidies</td>
<td>+0.15</td>
<td>+0.13</td>
<td>-0.24</td>
<td>+0.16</td>
<td>+0.03</td>
<td>+0.11</td>
<td>+0.16</td>
<td>+0.20</td>
<td>-0.08</td>
<td>-0.20</td>
</tr>
<tr>
<td>Acceptability of R&amp;D subsidies</td>
<td>+0.27</td>
<td>+0.08</td>
<td>+0.03</td>
<td>+0.08</td>
<td>+0.30</td>
<td>+0.17</td>
<td>+0.15</td>
<td>+0.20</td>
<td>-0.20</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

*/**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in OLS regression

the most important driving force behind investment decisions. The existence of other, more attractive, investment opportunities and the incomplete depreciation of the existing capital stock are important impediments for not (yet) investing in energy-efficient technologies. A more strict environmental policy is acceptable for most firms, provided that this measure will not negatively affect profitability and the competitive position of firms. Taxes, especially with tax-recycling schemes and carried out in a wider international context, are even preferred to detailed policy guidelines on how to achieve policy goals. To conclude, we found strong evidence for considering sector- and firm-specific factors in explaining investment behaviour and responsiveness to and acceptability of policy measures. The latter result is of importance for environmental policy making since it constrains the applicability and desirability of generic policies. Especially firm size, energy intensity and competitive position were found to be important distinguishing factors in explaining differences in behaviour and attitude towards policy.
Table 7.5b  Acceptation of energy policies in general: firms’ characteristics, simple ordered probit.

<table>
<thead>
<tr>
<th>ACCEPTATION</th>
<th>Sample average</th>
<th>Energy quote</th>
<th>Investment quote</th>
<th>Profit quote</th>
<th>Size</th>
<th>Competition</th>
<th>International orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acc</td>
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<td>-0.25</td>
<td>-0.78</td>
<td>-0.03</td>
<td>+0.06</td>
<td>+0.14</td>
<td>-0.05</td>
</tr>
<tr>
<td>AccForm</td>
<td>3.29</td>
<td>+0.10</td>
<td>-0.51</td>
<td>-0.09</td>
<td>+0.14***</td>
<td>+0.33*</td>
<td>-0.02</td>
</tr>
<tr>
<td>DaccF</td>
<td>0.48</td>
<td>+0.33</td>
<td>+0.20</td>
<td>-0.07</td>
<td>+0.12***</td>
<td>+0.32*</td>
<td>+0.09</td>
</tr>
<tr>
<td>AccSec</td>
<td>3.55</td>
<td>+0.18</td>
<td>-0.51</td>
<td>-0.06</td>
<td>+0.16***</td>
<td>+0.28</td>
<td>+0.01</td>
</tr>
<tr>
<td>DaccS</td>
<td>0.69</td>
<td>+0.38</td>
<td>+0.34</td>
<td>-0.06</td>
<td>+0.14***</td>
<td>+0.41**</td>
<td>+0.12</td>
</tr>
<tr>
<td>AccAbr</td>
<td>3.74</td>
<td>+0.01</td>
<td>-0.24</td>
<td>-2.44*</td>
<td>+0.17***</td>
<td>+0.51***</td>
<td>+0.18**</td>
</tr>
<tr>
<td>DaccA</td>
<td>0.94</td>
<td>+0.23</td>
<td>+0.17</td>
<td>-0.03</td>
<td>+0.14***</td>
<td>+0.52***</td>
<td>+0.24**</td>
</tr>
</tbody>
</table>

*/**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in simple ordered probit regression;
Bold estimates indicate that sign of a significant parameter in simple regression is ‘robust’: no significant parameter of the opposite sign is found for this variable in multiple regressions.

Table 7.6b  Acceptation of specific types of energy policies: firms’ characteristics, simple ordered probit.

<table>
<thead>
<tr>
<th>ACCEPTATION</th>
<th>Sample average</th>
<th>Energy quote</th>
<th>Investment quote</th>
<th>Profit quote</th>
<th>Size</th>
<th>Competition</th>
<th>International orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>TaxNL</td>
<td>2.02</td>
<td>-0.39</td>
<td>-0.18</td>
<td>+0.01</td>
<td>-0.11*</td>
<td>-0.15</td>
<td>-0.15</td>
</tr>
<tr>
<td>TaxNLR</td>
<td>3.01</td>
<td>-0.09</td>
<td>+0.48</td>
<td>+0.01</td>
<td>-0.06</td>
<td>-0.18</td>
<td>-0.09</td>
</tr>
<tr>
<td>DtaxNLR</td>
<td>1.03</td>
<td>+0.27</td>
<td>+0.55</td>
<td>-0.01</td>
<td>+0.04</td>
<td>-0.06</td>
<td>+0.03</td>
</tr>
<tr>
<td>TaxEU</td>
<td>2.90</td>
<td>-0.46</td>
<td>+0.66</td>
<td>+0.07</td>
<td>-0.03</td>
<td>-0.02</td>
<td>-0.02</td>
</tr>
<tr>
<td>DtaxEU</td>
<td>0.89</td>
<td>-0.19</td>
<td>+0.69</td>
<td>+0.08</td>
<td>+0.08*</td>
<td>+0.14</td>
<td>+0.12</td>
</tr>
<tr>
<td>StanTec</td>
<td>2.22</td>
<td>+0.45</td>
<td>-0.13</td>
<td>-0.15</td>
<td>+0.09*</td>
<td>-0.06</td>
<td>+0.11</td>
</tr>
<tr>
<td>StanUse</td>
<td>2.31</td>
<td>+0.17</td>
<td>+0.41</td>
<td>+0.02</td>
<td>+0.09*</td>
<td>+0.15</td>
<td>+0.06</td>
</tr>
<tr>
<td>InvSub</td>
<td>3.43</td>
<td>+0.08</td>
<td>-0.36</td>
<td>-2.47***</td>
<td>+0.09*</td>
<td>-0.09</td>
<td>+0.01</td>
</tr>
<tr>
<td>RDSub</td>
<td>3.49</td>
<td>+0.50</td>
<td>-0.56</td>
<td>-0.12</td>
<td>+0.18*</td>
<td>+0.05</td>
<td>+0.13</td>
</tr>
<tr>
<td>Volag</td>
<td>3.20</td>
<td>+0.37</td>
<td>-0.11</td>
<td>-3.67***</td>
<td>+0.26***</td>
<td>+0.02</td>
<td>+0.15**</td>
</tr>
</tbody>
</table>

*/**/*** indicates significance at the 0.1/0.05/0.01 level (two-sided t-test) in simple ordered probit regression;
Bold estimates indicate that sign of a significant parameter in simple regression is ‘robust’: no significant parameter of the opposite sign is found for this variable in multiple regressions.
8 POLICY INSTRUMENTS FOR TECHNOLOGY ADOPTION: A MODEL FOR ANALYSING THE DIFFUSION OF ENERGY-EFFICIENT TECHNOLOGIES

8.1 Introduction

As we saw in previous Chapters, analysing the effectiveness of policy instruments in achieving improvements in energy-efficiency is a difficult task. It requires a careful analysis and description and a deep understanding of decision-making processes at the firm level and at the same time a careful analysis of general-equilibrium mechanisms that are especially relevant for understanding the economy-wide effects, including rebound-effects, etc.

Existing policy models do not simultaneously satisfy these requirements. Some of them take a bottom-up perspective focusing on technologies and their characteristics, largely neglecting general equilibrium mechanisms. A good example of such a model is SAVE (developed at ECN, the Netherlands Energy Research Foundation; see, for example, Boonekamp, 1994, and Van Dril et al., 1994). It aims at analysing developments of energy use and future energy-saving options for end users. Other models take a more top-down perspective and model technological progress in a highly aggregate way, but focus more explicitly on general equilibrium mechanisms. A good example is NEMO (developed at the CPB; see Koopmans et al., 1999, and Koopmans and Te Velde, 2001). It aims at relating energy use to energy prices and economic growth in order to analyse policies aimed at fostering energy saving and reductions of greenhouse gas emissions. Both types of models have in common that they focus on economic policy instruments and take rational behaviour of economic agents for granted. At the other extreme are models that do not

72 This chapter was written by Henri de Groot, Jan Ros, Robert Engelen (both affiliated to RIVM/LAE, Bilthoven), Martijn Rietbergen and Esther Luiten. This chapter builds on a series of meetings in the context of the NOP project on Policy Instruments for Energy Efficiency Improvement and of RIVM/LAE’s interest to develop a model for the effect of policy instruments on industrial energy-use. Jakomijn van Wijk, Bart Wesselink, Hans Elzinga, Hilbert Booij, Mark van Oorschot and Remko Roodseelaar (all affiliated to RIVM/LAE, Bilthoven), Peter Mulder (VU, Amsterdam) and Erik Alsema (Department of Science, Technology and Society, Utrecht University) are gratefully acknowledged for their contributions to these meetings.

73 For a discussion, comparison and classification of existing policy models, we refer to Mulder et al. (1999).
heavily rely on economic rationality, but instead rely on more quantitative mechanisms along which policy instruments affect behaviour (such as information dissemination, responsiveness to strictness of monitoring, etc.). These models are thereby able to consider the effects of a much wider array of economic policy instruments. An example is MEI (Model Effectiveness of (Policy) Instruments, developed at RIVM; see Booij et al., 1999).

The aim of this chapter is not to develop a model that combines all the attractive features of the before-mentioned models and simultaneously cures all their problems. Integrating top-down and bottom-up approaches has proven an extremely difficult task and is beyond the scope of this book. Instead, we describe a model that acknowledges the relevance of economic factors in steering adoption behaviour, but at the same time also considers other factors that are relevant for understanding the diffusion of technologies, but that do not neatly fit in traditional economic models.

This chapter proceeds in a straightforward manner. Section 8.2 describes the basis-diffusion curve that is at the heart of the policy model MEI-energy\(^\text{74}\). Section 8.3 subsequently elaborates on the incorporation of the ‘non-economic’ factors in the model. Some preliminary policy analyses with the model are discussed in Section 8.4. Section 8.5 concludes.

8.2 The basis-diffusion curve

The aim of this section is to introduce the essence of the MEI-energy model in a non-technical way. Interested readers are referred to background material in which technical details of the model are presented and discussed (RIVM, 2001; Van Wijk et al., 2001; Roodselaar, 2001). At the heart of the MEI-energy model is the basis diffusion curve. This curve describes the way technologies diffuse through sectors over time.\(^\text{75}\) It is called the basis diffusion curve since only standard economic factors affecting the cost-benefit analyses made by firms enter into the determination of the location of the basis diffusion curve.

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\(^{74}\) The model builds on the previously developed MEI model. For a discussion of similarities and differences between MEI and MEI-energy, we refer to RIVM (2000).

\(^{75}\) Calculations are performed for individual economic sectors. The sectoral classification coincides with the classification in the technology database ICARUS which forms the major source of empirical information used to quantify key-parameters in the model and identify potential future energy-efficiency improvements.
8.2.1 A three-phase diffusion model

Figure 8.1 depicts in a very stylised way the form of the basis-diffusion curve. It essentially consists of three parts. Part I is called the preparation phase. The length of this phase \((t_v)\) is mainly determined by technical factors: time elapses between the moment a new technology is ready for the market and the moment at which a technology is installed and can effectively be employed in existing production processes. In addition, diffusion of information about the new technology can be an important determinant of the length of the preparation phase.

![Figure 8.1 The three-phase diffusion curve: Preparation (t_v), acceleration (S_p) and stabilisation (at P_t).](image)

The second phase is the acceleration phase \((S_p)\). Upon arrival, an attractive technology is not immediately and fully incorporated in all existing production processes by existing firms. For instance, existing capital first needs to be depreciated before new technologies start to be considered. The speed at which the diffusion of technologies takes place essentially depends on three key factors, which are taken into account in the model (see Chapter 2 for a more
extensive discussion of the various existing diffusion models). First, it depends on the age distribution of the existing capital stock and its average (economic) lifetime. The relevance of this is easiest seen by confronting a replacement technology with an add-on technology. The former requires the replacement of the economic lifetime is $T$ years, $1/T$ of the existing capital stock will be replaced with new capital. The longer the average economic lifetime of existing capital and the younger the age of the existing capital, the longer the diffusion of new capital will take.

The third phase is the stabilisation phase at which diffusion no longer continues. The level of stabilisation is determined by the share of firms that will ultimately decide to adopt the new technology. In the basis diffusion curve, this share is determined on the basis of a standard Net Present Value calculation and builds on the theoretical work as was discussed form a theoretical point of view in Chapter 2 and from an empirical point of view in Chapter 3. As was discussed in Chapter 2, an important reason for incomplete adoption of technologies is the existence of heterogeneity among potential adopters. This heterogeneity can be related to access to capital markets, firm size, solvability, dynamic evolution of the sector, specific energy prices, etc. In the model, we account for the relevance of heterogeneity in two ways. First, we make a distinction between small and large firms. This distinction builds on the
empirical studies discussed in Chapter 2 and revealing its relevance. Second, we introduce a distribution of critical Pay-Back Periods among firms. This distribution reflects the fact that within the groups of large and small firms, there may still be heterogeneities which are not accounted for, but which are still relevant. Building on this assumption, what results is a share of firms for which the critical Pay-Back Period is sufficiently low such that they will adopt the technology and a share for which the critical Pay-Back Period is so high that they will not adopt the technology. This is illustrated in Figure 8.2.

![Figure 8.2](image.png)

*Figure 8.2 The distribution of the critical discount rate over firms and the fraction of firms that will adopt a technology with a given rate of return r. The shaded area equals the fraction of firms that will adopt a technology with rate of return r ($P_{\text{max}}$).*

### 8.2.2 Quantifying the basis diffusion curve

In order to quantify the model, we employ various sources of information. The first source is the ICARUS-database, which contains information on available energy-efficient technologies. The database contains information on the date of availability of technologies, the costs and associated energy savings, type of technology (add-on versus replacement), etc. The second source
provides information on the distribution of Pay-Back Periods. This information was derived from the reported Pay-Back Periods in the survey which was discussed and used in Chapter 3. Finally, information was required on the level of critical Pay-Back periods used by firms to evaluate the profitability of technologies. Here, we leave open various possibilities to use the model. One is to use Pay-Back periods as derived from the survey discussed in Chapter 3. The other is to take the market rate of interest as the basis for Net-Present Value calculations. A third is to use intermediate approaches in which a mark-up is put on the market rate of interest. This mark-up may, among others, reflect the effect of uncertainty on adoption behaviour (see Chapter 2). In the currently available version, all possibilities are left open and depending on the background of the user, he can chose the option which fits most closely with his background.

8.3 A description of the full-fledged model

8.3.1 Accounting for ‘other’ factors: incorporating driving forces

The analysis so far essentially described a standard economic perspective on technology diffusion. As we emphasised in the introduction, policies affect diffusion in a wide variety of ways. The MEI-energy model tries to incorporate the role of these factors in a stylised way. This is done by introducing the concept of driving forces. These driving forces are complex combinations of factors that are relevant for understanding diffusion patterns but difficult to operationalise in a standard Net-Present Value framework. We have used various sources of information and insights on which the quantification of the driving forces in the model is built. On the one hand recent studies (Gillissen et al., 1995; De Groot et al. 1999; Velthuijsen, 1995) show a wide range of determinants of investment in energy conservation. The most relevant determinants are used and reflected in MEI-energy. On the other hand the concept of MEI already existed (RIVM, 1999). The concept has been improved over the last years by combining the knowledge and effort of several scientists.

77 The advantage of this approach is that one is certain that the discount rate does not incorporate other factors that affect adoption behaviour such as lack of knowledge, differences in access to capital markets, differences in firm size, etc. which are already accounted for in other parts of the model. See especially section 8.3 for a discussion on these other factors.
of different disciplines. The driving forces that we distinguish in the model can be classified in seven groups.

1. Complexity. This measures the extent to which the complexity of an energy-saving measure restricts a successful implementation. There are three important characteristics that determine the complexity of a technique:
   - Is the measure an ‘off-the-shelf-technique’ or a complex ‘tailor-made technique’?
   - Is the measure part of the core production process or not?;
   - Can the technique be implemented during the production or maintenance or only during a shut down?

2. Financial economical position of the industrial sector. This measures:
   - The extent to which the sector has financial possibilities to invest;
   - The extent to which negative social-economic consequences can occur due to the adoption of the technology;
   This driving force is to be distinguished from the NPV-analysis underlying the basis diffusion curve that just measures straightforward profitability.

3. Opportunities and threats in operational management by implementing a certain technique (market pressure). This driving force is based on:
   - The degree to which the techniques creates or limits market opportunities: e.g. energy saving measures can also be beneficial to product quality;
   - The extent to which additional product policies influence market opportunities.

4. Level of (technological) knowledge. This reflects the amount of knowledge the sector possesses about energy-efficient technological options. This driving force is characterised by:
   - The structure of the sector, which is reflected by the number of companies in the sector and the energy intensity of the sector;
   - The degree to which knowledge has been institutionalised and the degree to which policy measures can increase the level of knowledge;
   - The role of Information and Communication Technologies in increasing knowledge.
5. Political pressure. Industrial sectors are stimulated or forced to save energy by various policy instruments. The MEI-model incorporates the following types of policy instruments for energy conservation: Benchmarking, Long-term Agreements, Environmental Permits, taxes and subsidies. This driving force is determined by the mix of the policy instruments and the specific characteristics of the policy instrument such as the level of ambition, level of enforcement and financial support. It is important to emphasise that various policy instruments also affect the other driving forces. For example, a voluntary agreement has a positive impact on the attitude of a sector, but lowers the political pressure in comparison with legislation.

6. Public pressure. This captures the extent to which non-market actors put pressure on industrial companies (sectors) to improve the energy performance. This is determined by:
   - The degree to which the government provides information and knowledge on the problem of climate change;
   - General public opinion regarding climate change.

7. Attitude of (sub-)sector towards environmental issues. The attitude towards environmental issues is reflected by:
   - The willingness of a sector to take care for the environment and climate;
   - The expected impact of policy instruments on the attitude of sectors towards energy and environmental issues.
8.3.2 Quantifying driving forces

The previous section has shown that driving forces are complex combinations of determinants such as measure characteristics, characteristics of policy instruments, sectoral specific data and environmental characteristics (see also Figure 8.4). These determinants are for a large part based on qualitative expert judgements. The next step is to quantify the driving forces. For a more detailed description of the rules for calculating driving forces including the way of weighting mutual relations between determinants, we refer to RIVM (2001). As an example Box 8.1 shows how the driving force ‘complexity’ is calculated. Each driving force gives a score on a 0-10 scale (0 = affects adoption in a negative way; 10 = affects adoption in a positive way).

Box 8.1 Calculating the driving force ‘complexity’

The driving force (DF) Complexity determines the extent to which the complexity of an energy-saving measure restricts a successful implementation. The formula for calculating this driving force is:

\[
DF \text{ (Compl)} = 3 - C - S - I
\]

Where

- C: The measure is part of the core process or not: yes \(\rightarrow C = 1\), no \(\rightarrow C = 0\)
- S: The measure is a standard ‘off the shelf’ technique or a non-standard complex ‘tailor-made’ technique: standard \(\rightarrow S = 0\), not-standard \(\rightarrow S = 1\)
- I: The technique can be implemented during the production, maintenance, or during a shut down: during the production \(\rightarrow I = 0\), during maintenance \(\rightarrow I = ½\), during shut down \(\rightarrow I = 1\)

The value for the complexity of a technique can vary between 0 and 3. To calculate the driving force, the value for complexity is translated to a scale from 0 to 10.
8.3.3 The impact of driving forces on the basis diffusion curve

In the model, the driving forces essentially yield corrections on the basis diffusion curve. More specifically, the driving forces affect each phase of the diffusion curve (with varying weights) for each measure. By using a weighting scheme, the extent to which a driving force is important for a specific phase is allowed to vary. In the preparation phase, complexity, market and political pressure are assumed to be the most important driving forces. Market pressure is the main factor in the acceleration phase. Finally, the combination of ‘financial-economic position, market pressure, policy pressure and attitude’ has a major impact on the maximum diffusion. It must be mentioned that the model distinguishes three different types of techniques: new, retrofit and good housekeeping. These techniques require different model parameters and thus different weighting schemes.

Just to give an example of how driving forces impact on the penetration of a technology, consider policies aimed at information dissemination. These can, for example, shorten the preparation phase and speed up the diffusion process. This is graphically illustrated in Figure 8.3.
8.3.4 Summary of the MEI-energy model

Figure 8.4 schematically summarises the model set-up as it has been discussed so far. At the heart of the model is the basis diffusion curve, which is represented in the upper-part of the scheme. Based on technological information from ICARUS, information on the development of energy prices which is key to energy-saving possibilities in monetary terms, and policy information on subsidies and savings, the profitability of a technology is determined. This profitability is confronted with behavioural information regarding the critical profitability required by firms. The confrontation of these two pieces of information yields the percentage of firms that will - on the basis of a rational cost-benefit analysis - decide to adopt the technology. The driving forces are represented in the center of the scheme. They are made up of information about the technologies (such as their complexity), policy characteristics such as monitoring intensity and environmental characteristics. The combination of 'corrections' of the driving forces on the basis diffusion curve and the basis diffusion curve itself results in a description of the penetration of technologies. Technological information regarding energy savings and macroeconomic information regarding growth and sectoral composition then ultimately results in measures for energy-saving and future energy use.

The model is currently operational. For the moment, it is a research model rather than a validated model that can be used for evaluating or forecasting the effect of policy instruments on investment in energy efficiency. The determinants that describe the driving forces, the weighing scheme and the way the driving forces affect the basis-diffusion curve are mainly based on expert judgement. As such, the current MEI-energy model is a formal representation on what is known about investment behaviour of firms in energy-efficient technologies.

Figure 8.5 shows the energy savings in the various policy scenarios for paper industries in the Netherlands. The scenarios do not take into account physical growth.
Table 8.1 Policy scenarios.

<table>
<thead>
<tr>
<th>Scenario’s</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 BAU</td>
<td>-</td>
</tr>
<tr>
<td>2 VA 0</td>
<td>Voluntary agreement with a moderate level of enforcement and control</td>
</tr>
<tr>
<td>3 VA 0 + subsidy</td>
<td>Voluntary agreement with moderate level of enforcement and control in combination with a subsidy 25%.</td>
</tr>
<tr>
<td>4 Subsidy</td>
<td>An investment subsidy of 25%</td>
</tr>
<tr>
<td>5 Tax</td>
<td>Energy tax on electricity for large firms: 25%. Energy tax on electricity for small firms: 7.5%. Energy tax on natural gas for large firms: 10%. Energy tax on natural gas for small firms: 3%. These percentages are based on a levy of fl 0.5 / GJ.</td>
</tr>
<tr>
<td>7 Subsidy + tax</td>
<td>Scenario 4 in combination with Scenario 5</td>
</tr>
<tr>
<td>8 EP 0</td>
<td>Environmental permit with moderate level of enforcement and control</td>
</tr>
<tr>
<td>9 EP 1</td>
<td>Environmental permit with a high level of enforcement and control</td>
</tr>
</tbody>
</table>
**Figure 8.4** Summary of the MEI-energy model. The model's calculation steps are depicted in dark boxes, whereas the inputs are in light boxes (Roodselaar, 2001).
8.4 Some first analyses

The aim of the MEI-energy model is to simulate the effect of various policy instruments on investment behaviour of firms. Although various choices in the model structure need further refinement and the quantification of mechanisms and driving forces requires further testing, it is interesting to present some preliminary results of various policy scenario’s derived with a demo-version of the model. These analyses are not meant to give reliable predictions on energy-saving possibilities or the effectiveness of policy instruments, but are merely intended to give an impression of the kind of exercises that will be possible when using MEI-energy. They also provide information on how to continue with using MEI-energy in modelling the effect of policy instruments on the adoption of energy-efficient technologies.

We run some policy scenarios from 1995 till 2010 (see Table 8.1). All policy instruments were implemented in 1995 and affected investment decisions from that moment onwards. Other parameters than the ones scored for the various policy scenarios were kept constant.

Figure 8.5 Energy savings (PJ) in the policy scenarios 1 to 9 (see Table 8.1) for the paper and board industry.
If one looks at the results in Figure 8.5 and compares these with insights provided in the earlier chapters, the following observations can be made:

- Environmental permits (Scenario 8 and 9) lead to higher energy savings compared to the scenarios with economic instruments (regardless of the level of enforcement and control). The environmental permit includes strict standards on energy conservation; firms should implement all energy conservation measures with a pay-back period of 3-5 years (depending on the type of measure). If full compliance is assumed to occur, this scenario leads to considerable energy savings in the sector. The results in Chapter 4 on standards do not give a complete empirical account on the way standards affect the implementation of energy-efficiency measures (in what time frame do firms comply, what measures do they take, etc.). Thus, it would be interesting to study the impact of the level enforcement and control on the compliance of firms in more detail amongst others to validate and improve the model.

- Voluntary agreements (Scenario 2) lead to energy savings comparable with the environmental permits (Scenario 8). The effect of combining voluntary agreements with an investment subsidy (Scenario 3) is modest. This is strange since Chapter 5 shows that the voluntary agreement is typically a mix of policy instruments (energy covenant, subsidies and communication services). The combination of the instruments is effective. However, the results in Figure 8.5 show that the agreement itself (i.e. the energy covenant) appears to have a dominating impact on the energy savings. Taking into account the results of Chapter 5, this does not seem to be realistic.

- In the case of the paper industry, taxes (scenarios 5 and 6) do not have large additional effects compared to the BAU Scenario 1. The type of measures included in the ICARUS database likely explains this. The tax levels are based on a levy of 0.5 GJ (primary energy). This tax level is currently being used in Denmark for firms that do not have a voluntary agreement. Firms with an agreement pay lower taxes.

- The effect of investment subsidies (Scenario 4) is higher than the effect of taxes. The investment subsidies used in the scenario calculations are a bit high (25%) compared to the level that are currently being used in large subsidy schemes such as EIA and EINP (16-18%) (see Chapter 3). It is remarkable that voluntary agreements (also without subsidies!) do have a large effect on energy savings.
These preliminary policy scenario analyses using the MEI-energy model illustrate the potential possibilities of such a model. They also illustrate that further development and validation of the model is absolutely needed if one aims at developing a sound and valuable expert supporting system. Important points for improving the model are:

- The data used and the model as such need to be separated. If one develops scenarios for a specific sector, the required data can be included (such as the ICARUS data and sector specific data). This increases the flexibility and transparency of the model. The model also becomes more robust (each time the same data are used).
- In reality, there is no business-as-usual without policy intervention. From an analytic point of view, it would be valuable to be able to run a scenario without any policy instrument included (as a basis for comparison).
- It would be interesting to add the cost-effectiveness of policy instruments. To do this data are needed on the costs of various policy instruments and the energy-efficiency improvements achieved (due to that instrument).
- Not only various policy instruments (environmental permits and voluntary agreements), but also some driving forces (such as political pressure and public pressure) need some further thought and testing to come to a model representation that is more realistic.
- It would be interesting to gain a better insight (at the output side of the model) into the various steps in which the diffusion curve is calculated. It would also be interesting to have a better insight into the mechanisms along which various driving forces affect the investment behaviour of firms. This is clearly a matter of communication and transparency, but it may be important for a further improvement of the model.
- Finally, some technologies in the ICARUS database exclude each other. This needs to be included in a next version of the MEI-energy model.

If agreement can be reached regarding the formula of the various driving forces and the scores in the weighing scheme and if the MEI-energy model is better validated it may become an interesting tool for evaluating the effect of various policy instruments.

### 8.5 Conclusions

This chapter has described the basic structure of a modelling tool aimed at assessing the effectiveness of energy policies aimed at fostering the adoption of energy-efficient technologies. The model differs from existing models in that it
explicitly allows for effects of policy measures that are acknowledged to be relevant, but at the same time are difficult to operationalize in 'standard' economically oriented policy models.

The addition of the driving forces to a more standard economic perspective on technology diffusion is an appealing step in coming to a formal representation of the factors influencing the investment behaviour of firms in energy-efficient technology. Various policy instruments may affect various driving forces. Recent theoretical insights as described in Chapter 2 were thoroughly discussed and included as data availability allowed a quantitative representation in the model. As such, the current MEI-energy model is a formal representation on what is known about investment behaviour of firms in energy-efficient technologies.

Some first policy analyses were discussed that are intended to illustrate the type of instruments that can in principle be analysed with the model. Future research is needed to further develop, improve and validate the model. The analysis will focus on further exploiting existing empirical insights in quantifying the mechanisms, developing measures for cost effectiveness of policy instruments that enable the user to compare different policy instruments on a uniform measure (total costs of the instrument per ton emission avoided), validation of the model, comparison of model outcomes with outcomes derived from other policy models such as NEMO and SAVE, etc.
CHAPTER 9

9 CONCLUSIONS

Energy-efficiency improvement – defined as the reduction of the energy use per unit of human activity – is an important option for the reduction of greenhouse gas emissions. Much was already known now about the techno-economic potentials for energy-efficiency improvement in industrialised societies. The question in this book was how government can actually stimulate energy-efficiency improvement.

The focus of this research has been on policy instruments for energy-efficiency improvement in firms. Specific attention was paid to some important characteristics of policy instruments: effectiveness and cost-effectiveness. We also studied the mechanisms along which various policy instruments affected investment behaviour of firms.

9.1 The adoption and development of energy-efficient technologies in firms

From techno-economic studies it is concluded that many technologies for energy-efficiency improvement are cost-effective. We analysed why the adoption of such technologies is slower than could be expected from straightforward cost-benefit analysis.

One set of causes is that there are additional costs on top of the direct investment costs such as, for example, transaction costs associated with the investment and additional annual costs. Or the savings associated with the new technology may not be perceived as such, due to, for example, the low share of energy costs in the total costs.

However, there is a set of other factors that may cause firms to refrain from adopting new technologies (see Chapter 2). One of them is lack of information: firms may not know about new technologies. Second, there is a lack of capital that is necessary to invest in new technologies. Third, the fact that most investments are to a large extent irreversible creates an ‘option value of waiting’: if market conditions are uncertain it may be attractive for firms to postpone investments. Fourth, firms may not always strive for profit maximisation, but instead may strive for satisfactory profits. Fifth, there may exist so-called network externalities: it may be unattractive for firms to invest in a technology if other firms (also) refrain from investing. Related to this is the observation that initial costs of a technology are higher than the costs after
some penetration; also this provides an incentive to wait. Finally, there are agency problems: the firm that invests may not receive the benefits of the investment.

All these factors together can to a large extent explain why firms are not adopting energy efficient technology, the so-called energy-efficiency paradox. A next step would be to translate these explanations into quantitative models.

In a survey among firms we found that the following reasons for not investing in energy efficient technology were mentioned most often (see Chapter 7):

- other investments are more important
- technology can only be implemented after existing technology has been replaced
- energy costs are not sufficiently important
- energy efficiency has a low priority.

If we look at firms’ decision-making processes, there is no intrinsic difference between investment decisions in normal technologies and energy-efficient technologies.

We did not only study the investment behaviour of firms with regard to existing technology, but also the investment behaviour of actors in developing new, innovative energy-efficient technology (see Chapter 6). The latter is important to attain long-term climate policy goals. Four case studies were carried out – two in the paper and board industry and two in the iron and steel industry - to obtain a better understanding of the way technological development in these sectors occurs.

Development of industrial energy-efficient technologies turns out to be a slow process. It is striking that the principles of all four technologies were known long before a network of industries started to work on the technologies. Only if the new technologies are recognised as the 'next-step-to-take', actual development takes of. Still then, the road towards commercialisation is long: it may take ten to twenty years - even if the momentum is sufficiently high for commercialisation to occur. It was also found that technological development is heavily constrained by existing production processes.

Firms’ decision-making on R&D regarding energy-efficient technologies that affect the core of the manufacturing process was driven by other considerations than energy efficiency: ‘other’ cost advantages were far more important than reduced energy costs. Energy-efficiency improvement is not an important reason to develop so-called energy-efficient technologies. In addition
to the gradual materialisation of the technology, the claims of success, improvements to the conventional manufacturing process and changes in the industry’s business affect the time frame of subsequent up-scaling.

Networks around technologies differ, which is relevant for the choice of actors that government intervention should focus on. For instance, in the paper and board industry there are only a few paper machine manufacturers that drive the entire development. In the iron and steel industry, more groups of companies are involved and the role of the iron and steel companies themselves is central. The target group of firms (and other actors) that can be addressed for developing innovative process technologies is highly international and relatively small (compared to the total number of manufacturing firms).

9.2 Policy instruments – applicability and effectiveness

Governments can try to stimulate energy-efficiency improvement by applying policy instruments like taxes, subsidies, agreements and standards.

The main aim of the research project that is summarised here was to study the applicability (to what extent and how can policy instruments be applied in specific situations?) and effectiveness (do policy instruments lead to actual energy-efficiency improvement?) of some potentially major policy instruments directed at energy-efficiency improvement in firms. We have studied both economic instruments (subsidies), voluntary agreements and energy-efficiency standards.

One general finding is that the performance of policy instruments depends heavily on the way these are designed, implemented, enforced and monitored. In many cases the question which policy instrument is chosen may be less important than the question how it is applied.

Economic instruments: subsidies

Subsidies – or fiscal incentives with comparable effect – have been widely used, both for stimulating the adoption of energy-efficient technology and for stimulating R&D into energy-efficient technologies. Investment subsidies have always been an important instrument for stimulating investment in energy-efficient technology, in many countries, and also in the Netherlands. By carrying out a survey among companies and non-profit organisations that made use of two subsidy schemes in the Netherlands, we investigated the degree to which the subsidy schemes led to additional investments (see Chapter 3).
Through the subsidies, government contributes 15 to 20 percent to the investment. We found that half to two-thirds of the subsidy receivers are free riders: they would have done the investment also in case when no subsidy scheme would have been in place and without a delay. The costs for the government are estimated to be 20 - 50 $ per tonne of CO₂ avoided. For specific technologies, these costs may well be a factor ten higher or lower. The costs for implementing the scheme make up only a small part (1 - 7%) of the subsidies provided.

We also examined the effect of government subsidies for research and development through an analysis of the decision making process in firms for the four technology cases in the iron and steel industry and the paper and board industry. We found that in two of the cases the momentum of the technological development was too high for government intervention to be effective. If subsidies were provided in these cases, they did not accelerate the rate of development. In the other two cases, government subsidies enhanced the rate of development. However, in both cases the development did not (yet) lead to the commercialisation of the technologies.

Despite the free-rider effects, subsidies can be effective instruments: both energy-investment activities and R&D activities were beyond what they would have been without these instruments (in the case of R&D this does not necessarily lead to conserved energy). In both cases, the government costs per unit of effect can be decreased if the subsidy schemes are made more specific. In the case of investment subsidies, this can be achieved by excluding technologies that are already profitable without the subsidy. In the case of research and development subsidies, governments should first investigate which companies are active in technology development; what type of actors are most important and what the momentum of the development is. Subsequently, governments can decide whether to subsidise and what the appropriate target groups are.

So, improvement of the cost-effectiveness of subsidy schemes seems to be possible, but at a cost: it requires that the government has a more detailed knowledge about the characteristics of energy-efficient technologies and the actors involved.
Voluntary agreements

Voluntary agreements (see Chapter 5), also called negotiated agreements, have become a popular policy instrument for improving industrial energy efficiency in many countries. They can be considered as one of the major innovations in energy policy in the last decade.

Communication turns out to be one of the key mechanisms that help negotiated agreements work. The issue of energy efficiency was actively brought to the attention of the firms involved. The agreements have clearly extended and structured communication flows and knowledge transfer within industrial sectors. Due to sharing of information and knowledge an increase of investments in energy-efficient measures can be observed.

We investigated the effectiveness of the long-term agreements in the Netherlands. Long-term agreements have been established with 30 sectors, involving 1350 companies. The agreements generally aimed at a reduction of the specific energy consumption by 20% in the period 1989 - 2000. This target was not reached across industry, mainly due to non-participation of sectors or parts of sectors. Within the participating sectors, on average the targets were reached.

We investigated the degree to which the energy-efficiency improvement was stimulated by the long-term agreements both by using expert judgements and by a survey among companies involved in the long-term agreements. We conclude that a quarter to half of the energy-efficiency improvement achieved in the period is the result of the long-term agreements. The remainder of the energy-efficiency improvement actions would have been undertaken anyway. The long-term agreements in the Netherlands were fairly costly. Nevertheless, there is evidence that the specific costs for the government (10 - 15 $/tonne CO₂ avoided) are lower than those of investment subsidies.

We conclude that voluntary agreements are effective policy instruments for energy-efficiency improvement if accompanied by ambitious target setting, which requires a good government negotiation position; a transparent description of the targets; continuous government support, e.g. through additional policy measures; reliable monitoring procedures; and independent verification. Voluntary agreements tend to be less successful for sectors with a low energy intensity and a large number of companies involved.
Energy-efficiency standards

Direct regulation (‘command-and-control’) belongs to the oldest instruments in environmental policy. Also in the energy sector such instruments have been applied: energy-efficiency standards have shown to be effective for very specific equipment, like cars and household appliances, e.g. in the USA. However, standard setting is much easier for these fairly homogeneous product categories than for the wide variety of energy-using equipment in many industrial and service sectors.

We investigated (see Chapter 4) how general guiding principles like the requirement to apply 'best-available-techniques-not-entailing-excessive-costs' can be translated into practical guidelines. We found that private sector profitability criteria are not a very good choice. National economic criteria (e.g. $/tonne of CO₂) seem more appropriate, except for energy-intensive firms. Setting a maximum to the costs of energy improvement measures as a share of total costs (e.g. 0.2 - 0.5%) may be more suitable for the energy-intensive sectors; using the same criteria, fairly far-reaching energy-efficiency improvement measures can be asked from firms that are not energy-intensive.

In order to obtain a better idea of the practical applicability of energy-efficiency standards, a newly introduced 'general administrative order' on energy-efficiency for small and medium enterprises (e.g. hotels and catering) was examined. A survey was carried out among the agencies responsible for implementing the regulation, i.e. the municipalities. We found that in the overwhelming majority of the cases, the municipalities are not very active in enforcing compliance: the knowledge about energy conservation in firms is limited and the priority given to the issue is low.

It is recommended that in the design of energy-efficiency regulation the issue of how the regulating agencies will implement the regulation is taken into account. It must be noted that it is difficult anyway to design effective policy instruments for small and medium sized enterprises.

From a survey among firms we concluded that energy-efficiency standards are considered less acceptable than energy and carbon taxes. Subsidies and voluntary agreements are preferred most.

We conclude that – although energy-efficiency standards could be applied in practice – the experience so far is not encouraging; much better policy designs are necessary to make normative instruments for firms effective.
Conclusions on the effectiveness and efficiency of policy instruments

The results of this study have improved the understanding of the way policy instruments influence the behaviour of firms regarding the adoption and development of energy-efficient technologies. It turned out that there is no generic answer to the question which policy instrument is the best; the effectiveness of a policy instruments depends on the design, the actual implementation and the enforcement (or monitoring). In terms of effectiveness, design, implementation and enforcement of policy instruments may be more important than the selection of a specific policy instrument as such. Regarding this, much can be learned from the experience with existing policies.

Based on the Dutch experience, we can conclude that both investment subsidy schemes and voluntary agreements have increased the adoption rate of energy-efficient technologies in the Netherlands and therefore have shown to be effective. However, effectiveness should also be judged in comparison with the effort required. In both cases we found that substantial effort from the government is needed. Comparing both instruments, we found that voluntary agreements (that include subsidies) seem to be more cost-effective from the government point of view than pure subsidies. However, in both cases, there is still room for improvement of the cost-effectiveness. Energy-efficiency standards for firms have not turned out to be effective, but this may be due to improper design of the instrument.

9.3 Further work

In spite of the conclusions drawn, there is still more empirical (quantitative) research needed to look for relationships between policy instruments and the investment behaviour of heterogeneous firms in the wide variety of energy-efficient technologies. We identified a number of areas for further research.

1. We have a fairly good knowledge of the range of critical discount rates used by firms. However, there is a need for a quantitative explanation of the difference between these critical discount rates and market discount rates, next to the qualitative explanation provided in Chapter 2. This may also help explaining differences in critical discount rates between firms and its development in time. Also, it is relevant to investigate investment behaviour of the large number of firms that does not apply formal investment decision criteria at all. One may suggest all kinds of assumptions on which type of firms
do (or do not) deploy critical discount rates – one may for instance assume that more capital-intensive firms tend to apply a critical discount rate more strictly - though empirical grounding of such plausible assumptions is still lacking.

2. Lack of knowledge on energy-efficiency options is clearly identified as one of the barriers to energy-efficiency improvement. In this regard, it is interesting to note that the empirical results in Chapter 7 indicate that 20% of the firms have only limited knowledge about technologies that currently are being used by other firms. The question clearly is whether 20% is much or little. One has to take into account that there is no strict definition of having ‘knowledge of’; it can vary of having ‘heard of’ via ‘fairly good knowledge’ to a precise insight what the technology will cost and deliver for the specific firm. It is important to get a better understanding of the effect that lack of knowledge has on, e.g., the delay of investing in technology and how knowledge diffuses.

3. Our research suggests that differences among firms within sectors can be more important for technology adoption than the differences between sectors. More should be known about heterogeneity of firms, both in physical terms and in terms of behaviour, and how heterogeneity influences adoption rates. In Chapter 2 it was already indicated that the simple net-present value framework is static and therefore cannot explain the most prevalent stylised fact in adoption, namely the S-shaped diffusion over time. Thus far, we can indicate four explanations:

- physical heterogeneity (for instance differences in specific products);
- differences in firms’ attitude;
- firms’ typical regular major upgrading of production facilities;
- firm external factors (like policy instruments).

With regard to these four explanations - that go one step beyond suggesting heterogeneity as the explanation - we must say that these are plausible insights rather than that they are based on extensive empirical testing, let alone that we have a quantitative indication of the effects.

4. We also learned that the present way of characterisation of technologies in techno-economic information systems need improvement. Energy-efficient technologies are typically characterised as retrofit or replacement option. There is little empirical information on firms and their behaviour in replacing technologies. Are technologies replaced when the technology is depreciated or are they used until they are technically worn out? One typically uses time frames of 15 to 30 years, but there is hardly any empirical insight into the typical economic / technical life-times of energy-efficient technologies in various manufacturing industries. How often do firms invest in a major
upgrading of their facilities? There is no empirical insight into the difference between replacement and retrofit. The distinction may not be the way to continue in order to get a better understanding of firms’ investment behaviour. Anecdotal empirical evidence suggests that industrial production processes are continuously improved; the distinction between retrofit and replacement is however fuzzier than often assumed. The value of the distinction between retrofit and replacement has to be studied for various categories of technologies and for various manufacturing industries.

5. We have learned about the effectiveness of a range of policy instruments in specific situations. A next step is to learn more about how the effectiveness depends, e.g., on the design of the policy instrument; on the level of ambition; and on the accompanying measures. Still, insight into the effect of various policy instruments on various mechanisms remains highly qualitative. It is neither clear whether similarly designed policy instruments affect the same mechanisms in all contexts. In addition, the extrapolation of the effectiveness of specific policy instruments to other contexts and the flexibility in the ambitions of instruments and the final energy savings achieved are under-researched. We do not know whether the Dutch energy covenants would have had the same success when the ambitions were for instance 30% instead of 20% energy-efficiency improvement (against the same costs). It is still difficult to compare various policy instruments (for instance on cost-effectiveness). More knowledge is needed about the effectiveness of policy instruments in various contexts. There is no definitive answer on all the firm-, sector- and technology characteristics that affect the effectiveness of various policy instruments. Furthermore, it is important to perform more evaluation studies in order to enlarge the pool of data available on the cost-effectiveness and efficiency of policy instrument and to better understand which design characteristics of policy instruments may improve the efficiency of government intervention.

It is sometimes assumed that when it becomes clear that as soon as an industrial sector complies with the goal formulated in an energy covenant, the incentive to invest in energy-efficient technologies will reduce. There is no empirical insight into the response of firms to specific policy goals. In what kind of energy-efficient technologies do they invest and does this indeed vary over time? There is only limited insight into the direct link between a policy incentive and the type of energy-efficiency measures taken.

To be able to answer such questions, the range of methodologies needs to be expanded. It is especially recommended to do in-depth research by monitoring
a number of firms regarding their investment behaviour and the way they are influenced by policy instruments. Secondly we suggest to do micro-panel data analysis. This type of analysis makes it possible to analyse the energy conservation behaviour of firms on the basis of a large number of firm characteristics.

From the point-of-view of the government, a continuous effort of policy evaluation is important to monitor effectiveness and cost consequences of various policy instruments. It is recommended to design policy instruments in such a way that (ex post) evaluation is well possible. Too often, evaluation of policy instruments is hampered by the design of policy instruments. The recommendation can be extended one step further: ideally, policy design should be based on an (assumed) understanding of decision mechanisms in firms; this understanding should be tested and improved in the evaluation process, leading to an improved design of future policy instruments.
REFERENCES


REFERENCES


REFERENCES


REFERENCES


Infomil (1998-1999): Informatiebladen, Horeca (R01), Sport (R02), Gebouwen (RE03), Recreatie (R03), Zwembaden (R04), Algemeen (R05), School- en Opleidingsgebouwen (R06), Kantoorgebouwen (R07), Zorgsector (R08), Inspectie en onderhoud van stookinstallaties (R09), Detailhandel en ambachtsbedrijven met winkel (R10), informatiecentrum Milieuvergunningen, Casparie, Den Haag.


REFERENCES


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APPENDIX I.

Net Present Value and Payback period (Chapter 2)

In the literature on adoption of energy-efficient technologies, two indicators of profitability of technologies are used. These are the Pay-Back Period (PBP) and the internal discount rate. The aim of this Appendix is to show that the two concepts are very closely connected. To show this, note that the PBP is the number of periods required for the accumulated (net) benefits to exceed the (initial) investment costs, so PBP = I/B, where I is the initial investment cost and B the annual benefit net of operation and maintenance costs, etc. The Internal Discount Rate is defined as the discount rate for which the Net-Present-Value of a technology equals zero. This discount rate is thus derived as r from the equality

\[ I = B \sum_{t=1}^{N} \frac{1}{(1 + r)^t} \]  

(A.1)

Confronting the two, it is evident that for the PBP and the Internal Discount Rate to be internally consistent for a given investment project, the following equality should hold:

\[ PBP = \sum_{t=1}^{N} \frac{1}{(1 + r)^t} \]  

(A.2)

Relationship (A.2) illustrates that for a given critical pay-back period (PBP), the internal discount rate (r) that yields the same outcome for the evaluation of an investment project increases with the lifetime (N) of the investment project.
APPENDIX II.

Description of Variables (Chapter 7)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>Energy policies acceptable in any case</td>
</tr>
<tr>
<td>ACCABR</td>
<td>Energy policies acceptable provided it also applies abroad</td>
</tr>
<tr>
<td>ACCFORM</td>
<td>Energy policies acceptable provided it is in a particular (unspecified) format</td>
</tr>
<tr>
<td>ACCSEC</td>
<td>Energy policy acceptable provided it applies to all sectors</td>
</tr>
<tr>
<td>AFTRE</td>
<td>No adoption because technology can only be implemented after existing technology has been replaced</td>
</tr>
<tr>
<td>ALTEN</td>
<td>React on energy tax by employing other sources of energy</td>
</tr>
<tr>
<td>BASEMET</td>
<td>Basic metals industry</td>
</tr>
<tr>
<td>CHEAP</td>
<td>No adoption because technology will become cheaper</td>
</tr>
<tr>
<td>CHEM</td>
<td>Chemical industry</td>
</tr>
<tr>
<td>COMP</td>
<td>Degree of competition on sales market (1=limited, 2=average, and 3=strong)</td>
</tr>
<tr>
<td>COMPIN</td>
<td>Location of competitors (1=mainly in Netherlands, 2=less than 50% abroad, 3=more than 50% abroad, 4=virtually all abroad)</td>
</tr>
<tr>
<td>CUREF</td>
<td>No adoption because current installations are sufficiently efficient</td>
</tr>
<tr>
<td>DACCA</td>
<td>Difference between acceptability of policy applied abroad and acceptability in any case</td>
</tr>
<tr>
<td>DACCF</td>
<td>Difference between acceptability of policy in particular format and acceptability in any case</td>
</tr>
<tr>
<td>DACCS</td>
<td>Difference between acceptability of policy applied in all sectors and acceptability in any case</td>
</tr>
<tr>
<td>DECPPR</td>
<td>React on energy tax by decreasing production</td>
</tr>
<tr>
<td>DEVET</td>
<td>React on energy tax by own development of energy-efficient technologies</td>
</tr>
<tr>
<td>DTAXEU</td>
<td>Difference in acceptability between energy tax in Europe and in Netherlands</td>
</tr>
<tr>
<td>DTAXNLR</td>
<td>Difference in acceptability between energy tax in Netherlands with and without rebatement</td>
</tr>
<tr>
<td>ENCO</td>
<td>Energy costs are not sufficiently important</td>
</tr>
<tr>
<td>ENQ</td>
<td>Energy intensity (expenditures on energy as fraction of sales)</td>
</tr>
<tr>
<td>EXTBU</td>
<td>Problems with external financing</td>
</tr>
<tr>
<td>FOOD</td>
<td>Food industry</td>
</tr>
<tr>
<td>HORT</td>
<td>Horticulture</td>
</tr>
<tr>
<td>IMPET</td>
<td>Introduce energy-efficient technologies</td>
</tr>
<tr>
<td>INCR</td>
<td>Increase production</td>
</tr>
<tr>
<td>INQ</td>
<td>Investment ratio in 1997 (total investments as fraction of sales)</td>
</tr>
<tr>
<td>INTBU</td>
<td>Internal constraints on the budget</td>
</tr>
<tr>
<td>INVSUB</td>
<td>Acceptability of investment subsidies</td>
</tr>
<tr>
<td>KNOW_EXIST</td>
<td>Knowledge on already existing technologies that are currently being used by competitors</td>
</tr>
<tr>
<td>KNOW_NEW</td>
<td>Knowledge on new technologies that are not yet being used in practice.</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>LABOUR</td>
<td>Number of employees (sum of full time and part time employees)</td>
</tr>
<tr>
<td>LLABOUR</td>
<td>Log of number of employees</td>
</tr>
<tr>
<td>LOPRIO</td>
<td>Energy efficiency has low priority</td>
</tr>
<tr>
<td>MET</td>
<td>Metal products industry</td>
</tr>
<tr>
<td>MIGR</td>
<td>Move (parts of) firm to foreign country</td>
</tr>
<tr>
<td>NORMS</td>
<td>Maybe new technology will not satisfy future standards</td>
</tr>
<tr>
<td>NOTHING</td>
<td>No reaction and incur the loss</td>
</tr>
<tr>
<td>NOWIM</td>
<td>Currently introducing the specific technology</td>
</tr>
<tr>
<td>OBSERV</td>
<td>Number of observations</td>
</tr>
<tr>
<td>ORGAN</td>
<td>Difficult to implement due to internal organisation</td>
</tr>
<tr>
<td>OTHIM</td>
<td>Other investments more important</td>
</tr>
<tr>
<td>OVERV</td>
<td>No good overview of existing technologies</td>
</tr>
<tr>
<td>PAPER</td>
<td>Paper industry</td>
</tr>
<tr>
<td>PRICE</td>
<td>Increase prices of final products</td>
</tr>
<tr>
<td>PRMIX</td>
<td>Start producing a less energy intensive product mix</td>
</tr>
<tr>
<td>PRQ</td>
<td>Profit ratio (total net profits as fraction of sales)</td>
</tr>
<tr>
<td>RDSUB</td>
<td>Acceptability of R&amp;D subsidies</td>
</tr>
<tr>
<td>REST</td>
<td>Other industries (machinery, construction materials and textiles industry)</td>
</tr>
<tr>
<td>SHUT</td>
<td>Shutting down</td>
</tr>
<tr>
<td>STANTEC</td>
<td>Acceptability of technology standards</td>
</tr>
<tr>
<td>STANUSE</td>
<td>Acceptability of emission standards</td>
</tr>
<tr>
<td>SUB</td>
<td>Better to wait for subsidies</td>
</tr>
<tr>
<td>TAXEU</td>
<td>Acceptability of energy tax on European level</td>
</tr>
<tr>
<td>TAXNL</td>
<td>Acceptability of energy tax in Netherlands</td>
</tr>
<tr>
<td>TAXNLREL</td>
<td>Acceptability of energy tax in Netherlands with rebatement of tax revenues</td>
</tr>
<tr>
<td>UNQUA</td>
<td>Uncertainty regarding the quality</td>
</tr>
<tr>
<td>VOLAG</td>
<td>Acceptability of voluntary agreements</td>
</tr>
<tr>
<td>WAIT</td>
<td>Better to await experience of colleagues</td>
</tr>
</tbody>
</table>