Environmental policy for innovations [1]

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Abstract

The instrument theory is reviewed with attention to the effects of policy instrument on technology development. The effects policy instruments on innovations are discussed vis-à-vis the empirical findings. The instrument theory is linked with the innovation theory to assess the conditions that are favourable for environmental innovations. It is argued that innovators must spend a lot of money to demonstrate a new technology and then wait 6 to 8 years until authorities finish the policy preparation and start with the implementation of stricter demands. The innovators are uncertain during the waiting time about the demands and the speed of implementation. The uncertainties reduce the present value of the revenues from sales of technology, thus investments in innovations become unattractive. It is shown that strict environmental demands and type policy instruments, though relevant, have less impact than the duration of and uncertainty about policy preparation and enforcement. The market-based instruments are advantageous in comparison with the direct regulations because they create a larger market for the innovations, but the waiting time can be very long because of resistance to this type of instruments, whereas covenants create less market volume, but entail a shorter waiting time, so they be effective in combination with liabilities, penalties, bonds etc. The conditions for innovations are: short preparation period of environmental demands with clear aims for emission reduction and assurance about enforcement of the demands, based on the policy instruments that provide freedom to anticipate the demands.

Introduction

The question is how policy maker can prepare and enforce environmental demands in such a way that companies can innovate? The answer that is given in the handbooks on environmental economics and management is that policy makers should prepare so strict demands that new technology is necessary and enforce the demands in such a way that companies have freedom to comply in the best possible manner. This way, the policies enable companies to find the least cost solutions. If the companies can not comply with the demands because technology is still not available then the polluters innovate, or they pay for technology development. The debate in the theory is what type of instrument is the most effective to invoke innovations; is it a direct regulations by permits, a market-based one by policy charges, subsidies and trade, or is it a social regulation by covenants (e.g. Pearce and Turner, 1990:61-119, Tietenberg, 1994:211-277, Perman et.al., 1996:216-250, Reijnders, 1996:15-24). The instrument theory assumes that innovations are induced by policy making. However, validity of the instrument theory holds only under the assumption that the policy makers can prepare and enforce so strict demands that the new technologies must be developed and that the technologies can flexibly be adapted to all demands. The assumptions are neither realistic, nor theoretically valuable starting points.

The view that policy makers can implement the standards that invoke technology development is not realistic, because the ALARA principle (As Low As Reasonably Achievable) in environmental policy presumes availability of technologies that are not excessively costly at emission sources (Best Available Technologies or BAT). The demands to implement the technologies beyond the BAT hold only for the so called 'technology forcing standards'. The technology forcing standards are introduced in a few scarce cases, such as the Zero Automotive Emission standard in the state of California in the United States that prescribes so low exhaust emissions for cars that only electric or hybrid fuel-electric cars can attain it, or the Verpackungsverordnung in Germany that prescribes 80% to 90% recycling of all packaging without considerations about availability of recycling technologies. However, most of the policy making is based on the technologies that are available from the past. The assumption in the instrument theory is also a debateable theoretical starting point, because technology forcing standards are not enforceable. So if a suitable technology for environmental demands is not available then policy makers must tolerate disobedience that undermines their legitimacy. This is risky. Moreover, the risk is perceived so high that it is seldom used. The risk is real; note that the technology forcing standards are abandoned in both examples precisely because of lacking technologies.

The second assumption in the instrument theory is that the environmental technologies can flexibly be adapted to the stricter demands. This is irrealistic. It is shown that process characteristics of emission sources largely determine the costs and effects of environmental technologies, so the supply of environmental technologies for various sources is deficient (Krozer, 2002). Hence, companies can not always comply with the demanded emission reduction. It is more realistic to assume that the new environmental technologies are only developed if the innovators expect sufficient sales to make a profit and the users of innovation expect to generate benefit during use. In general, the possibilities to reduce emissions at a reasonable cost determine the environmental demands.

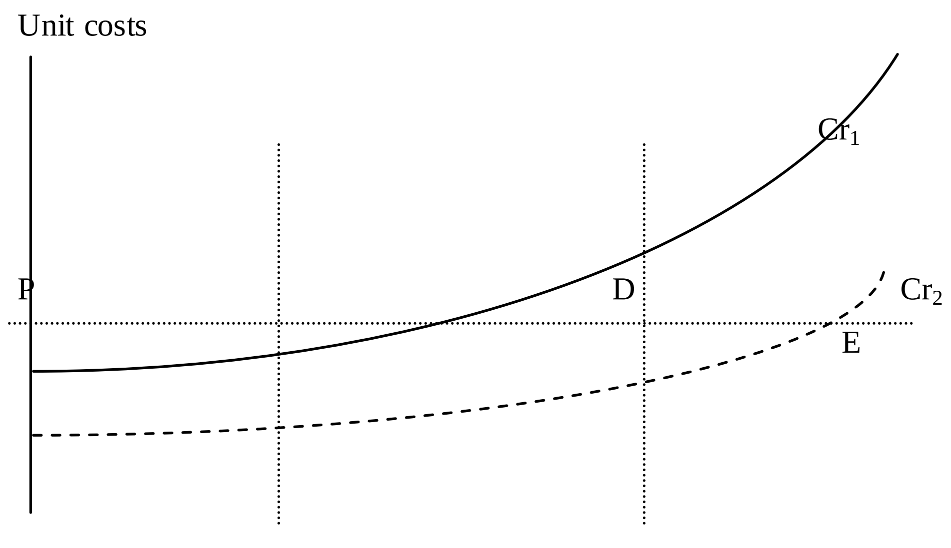
Another view is that innovations enable preparation and enforcement of stricter environmental demands, not another way around, so the rate of technological progress determines how strict demands can be implemented. We use the mainstream innovation theory to discuss this view. In the mainstream innovation theory, it is assumed that the fundamental research provides inputs to the applied research that in turn is used for development of a commercial result. The commercial result of the research and development (R&D) is patent. The patent gives rights to the owner to develop products or sell this right of development as a license (invention). Thereafter, the patent can be use to make products that are demonstrated and finally, manufactured for sales. A manufactured product is called innovation. The sales of the new technology that is often called diffusion, must cover the costs and the risks of all expenditures that are done in the past. So right at the start of the development, the innovators have to decide based on the calculation of all expenditures that are needed to cover the costs from R&D up to the manufacturing. All these costs are considered to be an investment, because the expenditures are fixed during some years independently on the volume of manufacturing and sales. The investment should be profitable, but the profit is uncertain, because the investment can be insufficient, whereas the sales can only be attained some time after the investment. Hence, the revenues are discounted at an interest rate that reflects risks of the investment; a higher interest rate is used for risky investments. The sales are attained if buyers of innovations expect to generate benefits. The present value of the sales must exceed the investment to generate profit and the users must attain a positive present value of savings in comparison with the available technologies (or benefits). The sum of the expected profits and benefits or savings is called the innovation-rent. All innovation-rents that are generated during diffusion of innovation can be called a surplus of innovation-rents (Stoneman, 1983). The view of the mainstream innovation theory is widely accepted, albeit scholars underline that the processes are not linear from research, via patent (invention) to product (innovation) and sales (diffusion), but entail interactions due to generated knowledge and market values. In addition, much know-how that is used in the innovation processes, is not formalised in R&D and that innovations are often a result of entrepreneurial and engineering capacities that are generated in the past and deposited as know-how and cultural tradition (called tacit knowledge).

In this paper, we link the innovation theory with the instrument theory to explain the effects of environmental policies on innovation. We postulate that the profitability is mainly influenced by the lead-time and uncertainty in the environmental policy.

Instrument theories and technological development

In the instrument theory, the basic choice is between the direct regulation (command and control) that is based on emission standards in permit and the market-based regulations with economic instruments, such as the emission charge (Downing and White, 1986; Nentjes and Wiersma, 1987). The assumption is that companies implement additional technologies as long as they reduce the costs (at the margin). It is argued that the market-based regulation gives a stronger incentive for innovations than the direct regulations, because residual emission has a price, whereas the emission standards lack incentives to reduce emission beyond the standard. The argumentation is presented in Figure 6.1. The the unit costs of emission reduction are shown vertically, emission reduction percentage horizontally. If a company must comply with demand for emission reduction that is depicted by a shift from Er_1 to Er_2 then it can use available technologies at the unit costs Cr_1, or apply innovations that reduces the unit costs to Cr_2. For a given demand, the field ABCD shows saving due to the innovations under direct regulation, whereas the field ABED shows the savings under market-based regulation by an emission price P. The extra incentive to innovate by under market-based regulation is equivalent of the field CDE.

Figure 6.1 Theory on the effects of direct and market-based regulations on environmental innovations



A C

B

Er_1 Er_2 emission reduction percentage

Several studies analysed the effect of policy instruments on R&D expenditures for profit and for environment. It is argued that the effects depend on the substitution-elasticity between the R&D options. If the substitution is elastic (elasticity above 1) then the charges stimulate stronger the R&D for environmental technologies than the emission standard. However, in case of inelastic substitution the permits stimulate R&D for environmental technology stronger than chargers (Magat, 1978). The argument in support of the inelastic substitution, hence in favour of direct regulation by permits as a more effective instrument for environmental innovations, is that environmental policies are uncertain so it is not attractive to invest R&D in environmental technology (Mendelsohn, 1984). The inelastic substitution is also expected in case of costly technology development and in case of small scale emissions like small companies (Becker et al., 1993). It is also argued that the combinations of permits with economic instruments are most effective, whereas the comparison of a single instrument like subsidies, charges and tradeable permits is inconclusive because depends on policy specifications (Milliman en Prince, 1989). The arguments derived from the evolutionary theory that distinguish between the add-on and process integrated ('cleaner') technology support the view that combinations of instruments are needed. It is argued that the market-based instruments provide more flexibility to companies, so it is easier to develop and implement cleaner technologies (Verbruggen, 1991; Kemp, 1995). The studies from the institutional perspective suggest that the policy framework depends on policy goals, so the instruments can cause contradicting effects, e.g. the goal to generate income instead of emission reduction (Bohm en Russel, 1985). The point is also made that the theory often assumes stricter demands for emission reduction, but less strict demands strongly decrease the positive effects of economic instruments on technology development, because R&D expenditures on environmental technology become uncertain. The incentive to reduce cost remains under the permit (Heyes en Liston-Heyes, 1997). It is also shown that the specifications of economic instruments have different effects on technologies (Opschoor en Vos, 1991; Kip en Krozer, 1991, Barde, 1999).

Although the comments do not abolish the fundaments of the instrument theory on technology development, there are so many nuances that the policy instruments should be specified with respect to the conditions that favour innovations. The emission standard in permit that is tuned to the source, that is the differentiated emission standards, is used as a reference to compare the effects of instruments on development of environmental technologies.

Policy instruments

Emission standards

In the theory, emission standards in permits are usually analyzed, whereas the technology standards in permits are widely used in practice. The technology standards specify the technological means, like maximum pressure in boilers for the safety reasons or concrete floor at gasoline stations to protect soil. The performance of technology is usually prescribed in detail, sometimes the type of manufactured equipment, or even the manufacturer. The emission standards specify the concentration of emission at the source, but in practice the handbooks for enforcement specify the BAT technologies for every type of emission source. Hence, the suppliers of the BAT can get a dominant position on the market and hold it during many years until a new BAT list is approved. This impedes the innovations.

Contrary to the technology standards that are usually uniform at many different sources, the emission standards are often tuned to various sources. Although the standards are usually based on (inter)national directives, the translation into the regional policies and the way of enforcement of the standards is often adapted to tune to the specific regional and sector situations. The enforcement is increasingly a negotiation process about the minimum standard in the short-term and the progressing emission reduction in the longer term (Doelman et.al., 1991; Kemp, 1998; Kloppenburg, 2000). In result, the emission standards differentiate. The differentiation reduces effectiveness, because less strict demands are enforced at some sources that potentially can reduce more emission, but tuning of the standards to companies' situations increase efficiency. The case studies into the costs of reduction heavy metals to water (Klink et.al. 1991) and biodegradable matter to water (McConnel en Schwartz, 1993) indicate that the differentiated standards are comparably efficient to the charges (static efficiency is similar).

Charges

Studies show that high charges on emission sources are effective (Bressers, 1983; Schuurman, 1988). It is often assumed in the instrument theory that the charges regulate emission (regulatory chanrges), but the charges are usually purposed to finance public policy, for example construction of public water treatment (financing charges). The effects of both can be similar if companies can reduce emission at the source but usually the financing charges are put is such a way that the regulatory effect is avoided. It can be expected that the effects of the financing charges without the regulatory effects on technology development are low, because the charges divert expenditures from emission reduction at the sources to public finances.

A regulatory charge has two positive effects in comparison with the differentiated emission standard. Firstly, the total market volume for environmental technology is larger because the residual emission is charged. Secondly, the use of environmental technology depends only on the costs at the source, not on other policy objectives, which reduces uncertainty about R&D expenditures. However, there are also negative side-effects of the regulatory charges on innovations. It is found that the high administrative charges for tests and precautionary measures for medicines and pesticides in Sweden cause unintentionally a barrier of entry for the environmentally sound substitutes of products and technologies (Fleischner, 1998). High administrative charges on landfills in the densely populated areas in the United States limit landfill in these areas, but cause more waste is transported to the less populated areas with less controlled landfill. The basis of the charge largely determines effect on environmental technologies. For example, if the user charge on waste is set per household then it hardly influences waste prevention because there is no incentive to reduce waste, whereas the user charges per volume of waste triggers waste prevention because it provides savings (Kip and Krozer 1991).

Subsidies

The development of environmental technologies is heavily subsidized, usually to strengthen the local industries. There are three types of subsidies for environmental innovations: subsidies for the developers (innovators), subsidies for the procurement and subsidies for emission reduction. The discussion is necessarily rather basic because each type of subsidy entails many variants.

The subsidy for the technology developer (innovator) is purposed to realize a new technology. The objective can be to strengthen technology suppliers and to enable industries to comply with future, stricter, emission standards at low costs. The later type is not purposed for technology development as such, but to support the policy making that aims to enforce a stricter emission standard. We discuss only this type. The effects of the subsidies on environmental innovations are analyzed based on a model of a developer that can take decision to develop a more effective technology in view of policy making (Nentjes, 1988). In the model, stricter standards enlarge the market, but the chance of the enforcement of stricter standards decreases. The model shows that the subsidy has two positive effects: it reduces the costs of technology development and it increases the chance that the emission standard is tune to the subsidized new technology.

The subsidies for the procurement of new environmental technologies are mainly purposed to reduce the investment costs at the source. The argumentation in favour of this type of subsidies is that the lower investment costs stimulate procurement of cleaner technologies. Hence, the sales of cleaner technologies increase, that in turn encourage technology development. The empirical finding based on the allowance of fast depreciation of cleaner investments in the Netherlands (VAMIL) revealed that the administrative imperfections disort the positive effects of procurement subsidies on innovations. For example the list of cleaner technologies lags way beyond the availability of new technologies (Nentjes and Scholten, 1989). The clarification of the list with new technologies is administratively complex, because various interests press for status quo. Hence, the list is hardly changed in ten years, even after legal renewal of this regulation (VAMIL-list from 1998 is similar to the list of the WIR-premium from 1988). The consequence is that the procurement of available technologies is supported, whereas the sales of new ones are reduced. This hinders innovations.

The subsidies for emission reduction can be per unit emission or per unit emission reduction costs. The first type is introduced within the framework of Kyoto agreement on reduction of the greenhouse gas emissions by the so called Joint Implementation and Clean Development Mechanism. It means that the countries that ratified the agreement, can get financial support for equivalent CO_2 reduction. It is also advocated to entrench this type of subsidies to support the costs of emission reduction as well, on the argument that the subsidy instead of a charge can prevent the negative effects of emission reduction on international competition. The argument is that subsidies have a similar effect on emission reduction as the charges if information about costs and effects is available. An obvious critique is that an imperfect information causes unfair competition, because some sources can receive too little and other too much subsidy in comparison with the untreated emission. This argument is counteracted by advocating a premium for public information that should increase at the lower emission per output, because it becomes more costly to reduce emission (Carraro and Sinicalco, 1992), but it is doubtful how to verify the reliability of the information that is provided to public. There are also several other arguments against subsidization per emission or per unit cost. The administration is troublesome and causes inefficiencies, because emission reduction is difficult to monitor, let alone the unit costs of emission reduction. The subsidies also cause price distortion because they benefit the growth of polluting production by reducing the production costs, thereby causing unnecessary extra growth of emissions (Kanazawa, 1994; Pieters, 1997) and it can be argued that the largest sources receive most subsidies, thus distort the scale effects. Therefore, it is advocated to combine the charges with the subsidies for procurement of technology, which is a variant of the deposit-refund system (Carraro en Siniscalco, 1994; Sigman, 1995; Palmer en Sigman, 1997). It can be effective, but it is costly to administer, because charges and subsidies must be registered. This instrument is applied for disseminate three-way catalyst in cars in the Netherlands with moderate success, but there is no experience with technology development.

Tradeable emission rights

The instrument of tradeable right is based on the assumption that the rights for environmental qualities can be divided among private interests and that the negotiations can balance the interests of polluters and those who are harmed. The instrument is firstly presented as a right of inhabitants to posses and buy environmental qualities (amenity rights). The proposal is made to strengthen the rights of harmed groups vis-à-vis the polluters (Mishan, 1993). The instrument is used in management of nature, for example management of national parks by environmental organisations, but it is hardly developed as a general instrument. The system of tradeable emission rights is more often used in policy making. The system of tradeable emission rights means that policy makers set an emission maximum in a region or sector (emission ceiling), divide allowed emission volume between polluters as a right and allow trade between the emission sources (transactions with the rights). Positive effects of the tradeable emission rights on technological development are expected, because polluters must buy equivalents of emission reduction to produce for growth or to compensate the emission growth by progress in environmental technologies (Dales, 1972; Tietenberg, 1984).

The tradeable emission rights are introduced in 1995 in the United States on SO_2 emissions in electric power sector. In this case, the emission ceiling is set for a number of years and the rights are divided between the power plants in such a way that the rights equal the total emission under the ceiling. The sector and external organizations can buy and sell the rights. The companies that have not used the rights to cover their emission, can store the rights at the bank. The positive effects of tradeable emission rights on development of environmental technologies are disputed on the argument that the technologies are not divisible, that companies make high transaction costs at the expense of technology development and that the companies can trade with the rights between each other to inhibit the entry of more innovative companies (Malueg, 1989; Marin, 1991). The empirical findings do not confirm these objections. The costs of SO_2 emission reduction in electric power sector in 1995 are reduced in comparison with the costs in 1990, mainly due to the substitution of the high-sulphur coal by low-sulphur coal (about 40% of the total cost decrease), by less transport of coal (about 50% of the total cost decrease) and by better mixing of coal. The costs of treatment are also reduced by better capacity utilization. Thus, there are efficiency advantages in comparison with the emission standards, albeit little technological development is found, so far (Ellerman et.al., 1997:44; Klaassen and Nentjes, 1997:399).

Covenants

Covenants are voluntary private agreements between authorities and industries on emission reduction. The covenants started in the mid eighties in the Netherlands. They became a cornerstone of the Dutch policy with 80 covenants in the early nineties (van de Meer, 1997) and recently, the covenants became a major policy instrument in the EU; the number have grown from 23 agreements in the period 1982-1986 to 123 in the period 1992-1996 (Karamanos, 2001). The main advantage of the covenants for the companies is that they can negotiate less strict agreements, thus postpone the more strict direct regulation (Wagner, 1991). This advantage is also suggested by the study into the international covenant on 50% CFC reduction (Montreal Protocol). The goal for the CFC reduction is attained in a few years at low costs, because the companies in the countries that have ratified the covenant could reduce the emissions even before signing up to the agreement due to available substitutes for many CFC's (Murdoch and Sandler, 1997). The main reason for the authorities to introduce the covenants is to shorten the lead-time in policy making, because the preparation of a covenant is less laborious in comparison with regulations. In reality, the evaluation of eight covenants in the Netherlands that were signed in the eighties showed that the preparation time strongly varies from 0,5 to 7,5 years. The average is about of 6 years. The compliance is high in four out of eight cases (Klok, 1989), which is confirmed by the study into six covenants in European Union (EEA, 1997). A study that looked into the regulation and covenant on production of VOC-free paints by the paint industry and prevention of Cadmium in products in the Netherlands suggests that both are not fully complied with. The covenant is less complied than the regulation because only 60% of companies have implemented the agreement and only a small minority did it fully. It is also found that the technological and economic feasibility of environmental technologies determine the compliance and that compliance is improved if the low-cost technologies are available (Van Peppel, 1995). The effectiveness of covenants in comparison with the emission standards is also disputed because a large part of the compliance is not done voluntarily, but enforced by permits (Wit et.al., 1999).

The effects of covenants on technological development are controversial. Some authors expect that covenants provide a main policy instrument on technological development, because the choice is left to the companies (Wallace, 1995). An opposite view is that covenants do not foster technological development, because of delay and piecemeal compliance (Sunnevåg, 1998). The experiences with the waivers for compliance with environmental regulations in the United States in the seventies, confirm the latter. The waivers did not stimulate innovations, because it was possible to delay compliance with agreements (Ashford en Heaton 1979; Ashford et al., 1985). Similar is argued in the study into various policy instruments that are based on negotiations instead of regulation in the United States, such as provision of information, to public and authorities, provision of technology reviews by authorities to companies and agreement about companies' plans. It is concluded that these policy instruments hardly stimulate innovations (Ashford, 1996). A study into six cases of permits based on companies' plans for emission reduction instead of emission standards argued that no technology has been developed. The agreements about flexibility in the permit did not stimulate innovations, but in some cases they provided opportunities to restart negotiations about regulations (van de Woerd, 1997). Opinions confirm the finding. The opinions of fourteen companies and of six external experts about the effects of covenants on technology development in three branch-wise covenants (printing industry, dairies and metal product industry) are strikingly different; the experts value the effects of covenants on technology much higher (average 7) than the companies (average 2). It is also found that the enforced technology agreements help. For example in the covenant with printing industry, it is agreed to define the new technologies in manuals every four years. The result was that the selected, new technologies are immediately recorded in 30% of the companies' manuals and in 50% of the companies with some delay (Hofman and Schrama, 1999). The studies suggest that there are hardly any positive effects of covenants on innovations, the effects are less positive than the differentiated emission standards.

Policy cycle and technology development

The instrument theory partially explains the dissemination of the available technologies from the past with possible adaptations because the specific policy instruments influence the market volume for the technologies. In this respect, the charges and tradeable emission rights can be advantageous. However, the instrument theory does not explain innovations and first stages of diffusion, because it does not consider high costs of R&D that must be made to generate revenues of sales some years later. The key factor is the expectations of innovators about the possibilities to develop a new technology and cover the costs by sales. This is addressed by the innovation theory. To develop and sell environmental technologies, the innovators must consider the process of policy making that is often called a policy cycle.

Signaling period

The start of a policy cycle is usually the signal of degradation of environmental qualities by pollution such as the negative effects of emissions on safety and health. It takes much time to trigger the policy preparation. The period between the signalling and the start of policy preparation usually takes more than a decade. For example, the negative effects of pesticides on environment and health are signaled in 1946, but during more than next thirty years research is done to underpin necessity of the policy in this field, whereas the policy preparation started in the beginning of the seventies. This signaling period was above 30 years (Sheail, 1991). The signaling period of ozone depletion was about fifteen years, which is rather short in environmental policies; the ozone depletion by CFC's is signaled by scientists in 1972, whereas the policy preparation for CFC emission reduction started mid-eighties. During the signaling period, the innovators develop new technologies. Indeed, the anticipation of regulations is the main motive of the environmental innovators; more that two-third of the innovators ask subsidy for this purpose (Arentsen and Hofman, 1996). Although the development of environmental technologies also takes time, sometimes even more than ten years, the development period is usually much shorter than the signaling period.

Preparation period

The policy preparation starts as the signal is incorporated by administration and politics. The process of policy preparation is described based on cases on acidification (Van der Straaten, 1994, pag. 131-145) and on heavy metals to water (Klink, et al., 1991, pag. 70-80). The preparation usually starts with inventory of the emission sources and the demonstration of technologies that can be used to tackle the signalled problem, i.e. preparation of the emissions standards based on performance of technologies that are available at that moment. The R&D

investment in the signaling period enable to demonstrate the new technology for approval among the Best Aavailable Technologies (BAT). The technologies must be available at the start of policy preparation, because the costs and effects must be demonstrated at some emission sources and performance must be verified by some experts. Thereafter, the BAT are approved in expert groups with representatives of authorities, industries and scientific institutions. The demonstrations and approval of BAT take 3 to 4 years, but it is often longer because the environmental impacts are disputed or there is disagreements about performance of technologies. After the approval, the policy documents are drafted, the administrative procedure starts with formalization of the emission standards and finally the politics decides about the enforcement. The procedure takes 5 to 8 years or even more, because many issue must be considered, such as opinions and interests at various departments, lobbies of interest groups, budget constrains for policy making, industries' investment from the past, diversity of emission sources, cost of emission reduction and so on. The preparation of emission standards takes 7 to 12 years. The period can be shortened if politicians sense high urgency, but it is more often longer becuase some interests are able to negotiate delays. The process of policy preparation ends with the announcement of a directive that covers the enforcement of emission standards. The covenants are prepared in a similar way, but it takes less time because it is an agreement between interests that can be enforced without political debates. The preparation of the economic instruments takes longer time than the preparation of the emission standards, because the economic instruments are usually opposed by various interests and because they must be incorporated in the countries' fiscal policy, which entail co-ordination between departments. To avoid the later, one finds private arrangements about funds based on fees, for example for packaging waste, batteries and cars. The subsidies are usually well-accepted by interests, so the preparation phase is shorter.

Enforcement

The enforcement of emission standards after the policy preparation, entails implementation of environmental technologies at emission sources until all sources that are addressed during policy preparation are covered. During enforcement, the innovators can sell the technologies that are prescribed in permits. The sales of technologies remain uncertain during the enforcement, because it is often not the best performing technologies that are enforced, but the technologies that are acceptable for vested interests. In addition, the administrative capacity and legal procedures determine the speed of enforcement, thus rate of diffusion of technologies. The period of enforcement can take 10 to 15 years. The enforcement period can be even longer because of delays of negotiations, exemptions like depreciation of installed equipment in the past, or complex administrative changes. For example, the Water Directive of the European Union that is announced in the year 2001 entails enforcement within 17 years, but pressures are to postpone it with a few years. Companies are also permitted to postpone the implementation, because of other priorities, so the sales of technologies are initially very low and grow only gradually. In other cases, the regulation is enforced rapidly to solve an urgent problem or to create a competitive advantage for domestic industries so the rate of diffusion of new technologies is high. The latter type of enforcement, so called "strategic marketing", is widely disputed as non-tariff barriers in trade, like regulations on pesticide residues in foods, toxic dyes in cloths, equipment for oil losses on ships and so on.

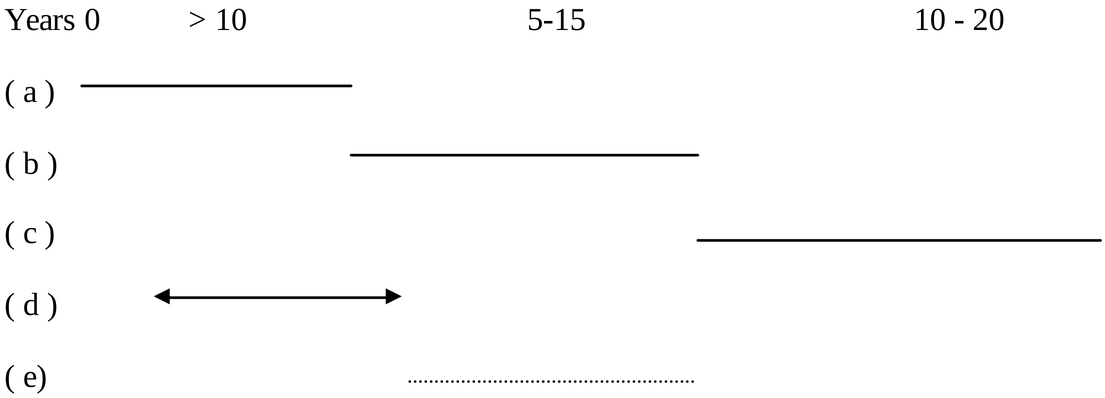
Evaluation

The policy cycle ends with evaluation of the results and eventual preparation of new regulations to accommodate with growth of pollution or changes in opinions about environmental problems. Only a few environmental problems that covered by policy preparation in the seventies, passed the policy cycle

Uncertainty, Waiting time and Enforcement

During the policy cycle, the innovators are uncertain about the perspective of technology sales. It is observed that the considerations of vested interests usually cause higher costs of implementation in comparison with the least cost solutions; so called X-inefficiencies (Rose-Ackerman, 1977; Nentjes, 1988). Thus, the sales of environmental innovations during enforcement are less certain than it can be expected on the basis of demonstrated performance during policy preparation. The policy cycle causes that innovators must be ready to demonstrate their technology in an early phase of policy preparation. Then, the innovators must wait several years until enforcement. During the waiting time, the innovators can not sell their technologies because emission sources have no spontaneous interest in environmental technologies; the sales are possible during the enforcement. The waiting time between the demonstration of the new technology and the political decision to enforce an emission standard is minimum 6 to 8 years. The waiting time can be shortened by publicity and other pressures, but the innovators must often wait even longer before the policy makers start with the enforcement and new technology can be sold. The environmental innovators must wait minimum 6 to 8 years during policy preparation and accept enforcement of minimum 10 years. In Scheme 5.1. the phases in the process are shown.

Scheme 5.1 Phases in environmental policy cycle



a. The signaling phase is the period between an observation of an environmental problem and the decision to start preparation of regulations.
b. The preparation phase covers the administrative preparation of the regulations that are the standards, policy instruments and the political decision to start with enforcement.
c. The enforcement phase is that period in which policy makers enforce the regulations and companies implement environmental technologies.
d. Technology development is the period between the investment in R&D and sales of the first product, presented by the arrow.
e. The waiting time is the period between demonstration of a new technology during preparation and the enforcement, i.e. the possibility to sell the technology, presented by a dotted line.

Model for environmental innovations

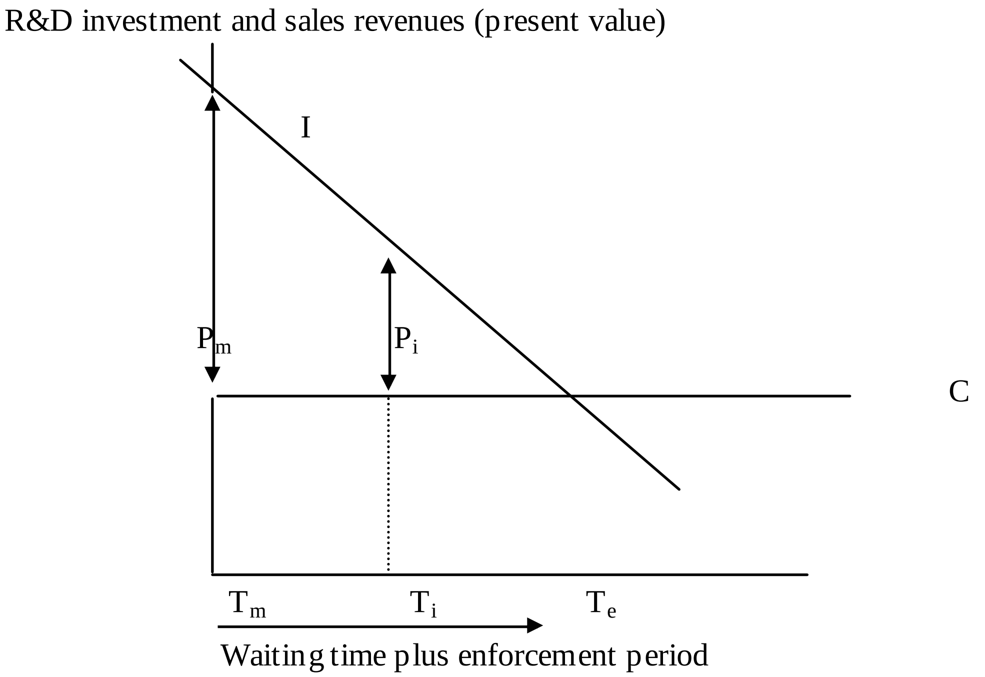
The uncertainty about policy making, the waiting time in the policy preparation and enforcement are relevant factors for environmental innovations. The model enables to assess the main factors that influence profitability of investments in environmental R&D. We take the position of the innovators who anticipates the regulations by technology development before policy preparation. The innovator decides rationally with help of the Net Present Value (NPV). The future revenues of sales of the new technology are discounted at an interest rate that reflects the uncertainties in policy preparation and in enforcement, that is: more uncertainty of sales causes a higher interest rate. The question is: what are the factors that determine the profitability of the investment in innovations. The model for is presented in Figure 5.2. Aside of the sales volume and investment, the factors are:

a. The waiting time, that is the period between the end of a successful demonstration of the innovation and the start of enforcement;

b. The enforcement period, that is the period between the start of enforcement and the final sales of the technology, because all relevant emission sources have complied with the demand;

c. The uncertainty about the consequences of policy preparation and enforcement for the sales of innovation in the future that is reflected in the interest rate for discounting the revenues.

Figure 5.2 Effects of waiting time and enforcement on expected revenues and profit



Vertically, the investment in innovation C and the revenues of the sales I are presented. Horizontally, the years between the realization and sales of the innovation are presented that are the waiting time plus the enforcement period. The discounted sales must cover the investment. The investment in R&D that is the present value of the investment cost, is done before the waiting time, so it is presented as a horizontal line independent of the duration of policy making. Strict environmental demand can require a higher investment, because more advanced technologies must be developed, i.e. the line C can shift up or down depending on the demand. The present value of sales, presented as a decreasing function of time, are influenced by the interest rate, i.e. a steeper line, I, at a higher interest rate. If there is no waiting time, so the sales start directly after the announcement of the demands, then the innovators can expect revenues at the moment T_m, and realize profit that equals P_m. If the innovators must wait until the moment T_i, then they can realize profit P_i and if the waiting time is longer until T_e then there is net loss because the present value of the revenues is lower than the investment. Thus, the longer waiting time or higher interest rates cause less profitable investment. If the innovators expect a long waiting time or an uncertain enforcement then they withdraw from investments in technology development. The model also helps to analyse the effects of policy instruments on innovations:

- A shorter waiting time (e.g. covenant) or enforcement period (e.g. tradeable emissions) shifts the revenues function to the left and increases profitability of the investment in innovation;
- Uncertain preparation (e.g. emission charge) causes higher interest rate and steeper sales line, hence a smaller profit in a discounting period;
- Lower investments in R&D (e.g. subsidy) shift the cost line downward from C_0 to C_1 and increase profitability of the investment.
-

The model is used to simulate the effects of the policy instruments on profitability of investments in innovations taking into consideration the waiting time during policy preparation and different types of enforcement. The indicator of the profitability is the innovation-rent, that is the expected profit of innovators plus the cost savings of the users due to sales of new technology. For convenience of the accounts, we assume that the innovators accrue all the savings, i.e. sell on the margin of costs saving. It is formally:

$$I = \left(\sum_{t=1}^{n} (V_t - C_t) / (1+r)^t - \right) - Ci$$

$t = t_w + t_0$

V_t is revenue from sales of innovations; C_t are operational costs, i.e. the production costs of the new technology; r is the interest rate; C_i is investment; I is the surplus of innovation-rents (i_t), r is interest, t is time and tw is waiting time.

To illustrate the effects of policy instruments on the innovation-rent, we draft scenario's for policy preparation and enforcement. The following numerical values are used. The market volume is 1500 units in all scenario's (V_{total} = 1500). The operational costs are assumed 50% of the sales ($C_t = 0.5 * V_t$). The present value of the investment is 150 (C_t = 150). The interest rates, r, are 0%, 5%, 10% en 15%. The enforcement period is 15 years and the waiting time, tw, is 0, 4 to 8 years, so the lead-time of innovation and diffusion is 15 years for 0 years waiting time, 19 years for 4 years waiting time and 23 years for 8 years waiting time. Three types of enforcement are simulated:

- Reference enforcement that illustrates application of emission standards, with sales of 100 units per year during 15 years (100 units x 15 years = 1500 units).
- Slow enforcement (low diffusion rate) that illustrates a covenant or a subsidy, starting with the sales of 2 units in the first year, growing up to 500 units in the last year and linear interpolation in-between.
- Fast enforcement (high diffusion rate) that illustrates emission charge or tradeable permit that is a reversed version of the slow enforcement: sales of 500 units in the first year and 2 units in the last year with linear interpolation in-between.

The calculations can be found in Appendix 6. Table 6.1 presents the results of simulations. The results are the indexed. The index is based on surplus of the innovation-rent that is the sum of the innovation-rents during the enforcement period. The reference (100 units) is the surplus without waiting time and no discounting. The results show the surplus without investment in innovations due to the subsidy for technology development and with the investment of 150 units.

Table 6.1 Simulation of the effects of interest rates and waiting time on the surplus of innovation-rent in the policy cycle

	Gradual enforcement			Slow enforcement			Fast enforcement		
	0 years	4 years	8 years	0 years	4 years	8 years	0 years	4 years	8 years
No investment in innovations that is 100% subsidy for technology development									
0%	100	100	100	100	100	100	100	100	100
5%	70	57	47	53	44	36	87	72	59
10%	54	35	24	30	20	14	77	53	36
15%	40	22	13	17	10	6	69	39	23
Investment in innovation of 150 units that is 10% of the total market volume									
0%	100	100	100	100	100	100	100	100	100

5%	62	46	34	42	30	20	84	64	49
10%	39	18	5	12	0	-8	71	41	20
15%	25	3	-9	-3	-13	-18	61	24	3

This way, the consequences of the waiting time and the enforcement period on the profitability can be indicated for various instruments; the results of subsidized investments are put between brackets:

- If we assume 10% interest rate for an investment in innovation, 8 years waiting time and a gradual enforcement, in case of emission standards then the innovation-rent after 15 years of enforcement is only 5% of the reference (24% with the subsidy). The innovation-rent is 34% of the reference in case of 5% interest rate. The uncertaunty about enforcement of emission standards strongly influences the profitability of R&D investment, hence innovation spurt.
- At 10% interest rate, only 4 years waiting time but slow enforcement, like it can be in case of the covenants, the surplus is 0% of the reference (20% with the subsidy). However, if the compliance with the coventant is assured so the interest rate is only 5%, for example by liability for non-compliance, then 30% of the reference value can be reached despite of slow enforcement. So a convenant with liability can invoke innovations.
- At 10% interest rate, 8 years waiting time and fast enforcement, like it can be with economic instruments; the surplus is 20% of the reference value (36% with the subsidy). However, the uncertainty about preparation and enforcement of the economic instruments, hence 15% interest rate, can deplore the surplus down to only 3% of the reference. It is even negative in case of a longer waiting time than 8 years.

The results indicate that there is no 'best' policy instrument from the innovators' point of view, but much depends on the balance between uncertainty and duration of policy preparation and enforcement. In general, an uncertain policy making and the waiting time longer than 8 years is usually unprofitable for innovations, albeit the waiting time in policy preparation can be compensated by fast enforcement. In comparison with emission standards, one can argue that fast enforcement of the policies due to economic instruments can counteract the negative effects of the waiting time on the profitability of innovations. The economic instruments are attractive for innovations, but much resistance of polluters causes uncertain enforcement. The present coventants have a detrimental effect on the profitability of innovations, but it is not necessarily the case. A short waiting time in preparation of covenants can be attractive for innovations despite of slow enforcement and smaller market volume in comparison with emission standards if the agreements include liabilities for non-compliance. In addition, note that the waiting time and uncertainty are interlinked, so a shorter waiting time reduces uncertainty. In addition, it is simulated whether the subsidies contribute to the innovation-rent. The first type of subsidy is to support R&D as it is mentioned above, the second one is to support production of new technology, for example financing of manufacturing facilities. The simulations show that both types of subsidies have little positive effects on the innovation-rent.

Conclusions

The question was how to foster environmental innovations. The view that the technology forcing demands are imposed by policy makers trigger innovations is disputable, because the policy makers aim to be assured that companies can comply with the demands at reasonable costs. It is shown that the perspectives of the policy makers and innovators differ. The instrument-theory that takes the view of policy makers, suggests that the economic instruments, like charges and tradeable permits are effective and efficient because polluting companies have to pay for residual emission. Based on the innovation theory it can be argued that the innovators must decide to invest despite of uncertain future sales, so reducing uncertainty about enforcement of environmental demands is the main factor that contributes to environmental innovations.

In practice, the uncertainty about sales of environmental innovations is the decisive factor. It takes twenty five and more years to prepare and enforce a stricter environmental standard at the most of relevant emission sources. The innovator must invest to develop and demonstrate a new technology, then wait 6 to 8 years until the standard is set and the enforcement starts. During the enforcement, the innovations can be sold. The innovators are uncertain if, when and how the standards are going to be approved by politics and enforced. The lead-time in the policy making with uncertain outcomes is a major cause that high investments in environmental innovations are risky and unattractive.

The argument that the economic instruments provide a stronger incentive to innovate in comparison with the emission standards is valid but conditionally. The advantage of the economic instruments is that a larger market volume for the sales is created because polluters pay for residual emission. In addition, economic instruments entails fast enforcement, because the polluters alone decide about procurement based on their calculations, whereas the enforcement of emission standards entails time-consuming negotiations between authorities and polluters. However, the waiting time of economic instrument during policy preparation can be very long, because polluters resist to the instruments. So the environmental policy must be strong enough to impose demands with economic instruments. If the policy makers opt for the covenants, for example because they have not so strong position vis-à-vis other interests, then less market volume can be expected in comparison with the emission standards and economic instruments and slow enforcement, but the waiting time during policy preparation is short. So the loss of innovation-rents by the time-consuming enforcement can be somewhat compensated by the fast preparation. The simulation of the surplus of innovations rents and scenario with empirical data suggest that more than 8 years waiting time and uncertain enforcement deplores investments in innovations. There is no perfect instrument but policy makers can create favourable conditions. The favourable conditions for innovations are short preparation period of environmental demands with clear demands, reasonable assurance of enforcement and freedom of action to the companies. The instruments foster innovations that shorten the waiting time, speed-up enforcement and reduce uncertainty, because these three factors determine the profitability of investment in technology development.

Literature

Arentsen M.J., P.S. Hofman, *Technologie: Schone motor van economie*, Universiteit Twente, CSTM, 1996, p. 26-33.

Ashford, N.A., G.R. Heaton, 'The effects of Health and Environmental Regulation on Technological Change in the Chemical Industry: Theory and Evidence', in T. Hill (ed.), *Federal Regulation and Chemical Innovation, American Chemical Society*, Washington DC, 1979, p. 45-66.

Ashford, N.A., C. Ayers, R.F. Stone, 'Using Regulation to change the market for innovation', *The Harvard Environmental Law Review*, Vol. 9, No. 49, 1985, p. 419-466.

Ashford, N., 'The influence of information-based initiatives and negotiated Environmental Agreements on Technological Changes', in C. Carraro, F. Lévêque, *Voluntary Approaches in Environmental Policy*, Kluwer Academic Publishers, Dordrecht, 1996, p. 137-150.

Barde, J-P, *Economic Instruments for Pollution Control and Natural Resources, Management in OECD countries: A Survey*, Organisation for Economic Co-operation and Development, 1999.

Baumol, W.J., W.F. Oates, *The theory of environmental policy*, Prentice-Hall, Englewood Cliffs, 1975, p. 14-55.

Becker, N., M.G. Baron, M. Shechter, 'Economic Instruments for Emission Abatement under Appreciable Technological Indivisibilities', *Environmental and Resource Economics*, No. 3, 1993, p. 263-284.

Bohm P., C.S. Russel, 'Comparative analysis of alternative policy instruments', in A.V. Kneese, J.L. Sweeney (eds), *Handbook of Natural Resources and Energy Economics*, Vol. 1, Elsevier, 1985, p. 375-460.

Bressers, J.Th.A., *Beleidseffectiviteit en waterkwaliteitsbeleid - een bestuurskundig onderzoek*, TH Twente, Enschede, 1983.

Carrao C., D. Sinicalco, 'Environmental Innovation Policy and International Competition', *Environmental and Resource Economics*, Vol. 2, No. 193-200, 1992.

Carraro, C., D. Siniscalco, 'Environmental policy reconsidered: The role of technological innovation', *European Economic Review*, No. 39, 1994, p. 545-554.

Dales, J.H. (1968), 'Land, Water and Ownership', reprint in R. Dorfman en N.S. Dorfman (eds), *Economics of the Environment*, selected readings, W.W. Norton & Company, New York, 1972, p. 229-245.

Doelman P., J. Krozer, J. Schot, *Een verkenning van de mogelijkheden voor preventie in de milieuvergunningen*, Tebodin Consulting Engineers, Den Haag, 1991.

Downing P.B., L.J. White, 'Innovation in Pollution Control', *Journal of Environmental Economics and Management*, No. 13, 1986, p. 18-29.

Ellerman, A.D., R. Schmalensee, P.L. Jaskow, J.P. Montero, E.M. Bailey, *Emission Trading Under The U.S. Acid Rain Programme*, MIT Centre for Energy and Environmental Policy Research, Cambridge/Massachusetts, 1997.

European Environmental Agency (EEA), *Environmental Agreements, case studies*, Copenhagen, 1997.

Grand, L. le, R. Robinson, *The Economics of Social Problems*, McMillan Press, London, 1976.

Heyes, A., C. Liston-Heyes, 'Regulatory "balancing" and the Efficiency of Green R&D', *Environmental and Resources Economics* No. 9, 1997, p. 493-507.

Hofman, P.S., G.J.I. Schrama, *Innovations in the Dutch environmental policy for the industry target group*, paper for the eighth Greening of Industry Network Conference, Chapel Hill USA, 15-18 November 1999.

Kanazawa, M.T., 'Water Subsidies, Water Transfers and Economic Efficiency', *Contemporary Economic Policy*, Vol XII, April, 1994, p. 112-121.

Karamanos, P., 'Voluntary Environmental Aggreements: Evolution and Definition of a New Environmental Policy Approach', *Journal of Environmental Planning and Management*, Vol. 44, No. 1, 2001, p. 67-84.

Kemp, R., *Environmental Policy and Technical Change*, MERIT, Universiteit van Maastricht, 1995.

Kemp, R., 'Environmental Regulation and Innovation Key Issues and Questions for Research', in F. Leone, J. Hemmelskamp (eds), *The Impact of EU – Regulation on Innovation of European Industry*, Expert meeting on Regulation and Innovation, Sevilla, 18-19 January 1998.

Kip P., J. Krozer, *Financiële instrumenten in het afvalstoffenbeleid, ervaringen en mogelijkheden*, Tebodin Consulting Engineers, juli 1990.

Klaassen, G.A.J., A. Nentjes, 'Macro-economische gevolgen van een intensieve bestrijding van zure regen', *Economische Statistische Berichten*, 12 december 1986, p. 165-169.

Klaassen, G.A.J., J.B. Opschoor, 'Economics of sustainability or the sustainability of economics: different paradigms', *Ecological Economics*, No. 4, 1991, p. 93-115.

Klink, J., J. Krozer, A. Nentjes, *Technologische ontwikkeling en economische instrumenten in het milieubeleid*, Nederlandse Organisatie voor Technologisch Aspectenonderzoek, Den Haag, januari 1991, p. 42-45.

Klok, P-J., *Convenanten als instrument van milieubeleid*, proefschrift, Faculteit der Bestuurskunde, Universiteit Twente, Enschede, 1989.

Kloppenburg, G-J., *Vergunningverlening en het stimuleren van milieu-innovaties*, provincie Friesland, Leeuwarden, januari 2000.

Kremers, G.J., H.S. Buijtenhek, C. van Driel, J. Krozer, *Financieel instrumentarium voor regulering van verf met organische oplosmiddelen*, Tauw, Deventer, juli 1991.

Krozer, Y., *Milieu en Innovatie*, Rijksuniversiteit Groningen, 2002.

Magat, A., 'Pollution Control and Technological Advance: A Dynamic Model of the Firm', *Journal of Environmental Economics and Management*, No. 5, 1978, p. 1-25.

Malueg, D.A., ‘Emission Credit Trading and the Incentive to Adopt New Pollution Abatement Technology’, *Journal of Environmental Economics and Management*, No. 16, 1989, p. 52-57.

Marin, A., ‘Firm Incentive to Promote Technological Change in Pollution Control: Comment’, *Journal of Environmental Economics and Management*, No. 21, 1991, 297-300.

McConnel, V.D., G.E. Schwarz, ‘The Supply and Demand for Pollution Control: Evidence from Wastewater Treatment’, *Journal of Environmental Economics and Management*, No. 23, 1993, p. 54-77.

Meer, J. van der, ‘Soepele afspraken zonder ambities’, *Intermediair*, jrg. 33, nr. 47, 20 november 1997, p. 23-25.

Mendelsohn, R., ‘Endogenous Technical Change and Environmental Regulation’, *Journal of Environmental Economics and Management*, No. 1, 1984, p. 202-207.

Milliman, S.R., R. Prince, ‘Firm Incentives to Promote Technological change in Pollution Control’, *Journal of Environmental Economics and Management*, No. 17, 1989, p. 247-265.

Mishan, E.J., (1967), *The Cost of Economic Growth*, Weidenfeld and Nicholson, London, 1993, p. 30-46.

Murdoch, J.C., T. Sandler, ‘The voluntary provision of a pure public good: The case of reduced CFC emissions and the Montreal Protocol’, *Journal of Public Economics*, No. 63, 1997, p. 331-349.

Nentjes, A., D. Wiersma, ‘Innovation and pollution control’, *International Journal of Social Economics*, Vol. 15, No. ¾, 1987.

Nentjes, A., *An Economic Model of Innovation in Pollution Control Technology*, paper presented at the Annual Meeting at AAERE, New York, 28-30 December 1988.

Nentjes, A., ‘Marktconform milieubeleid’, *Economische Statistische Berichten*, 27 april 1988, p. 401-405.

Nentjes, A., Scholten, H., ‘Een financiële impuls voor het milieu?, kanttekeningen bij het initiatief-wetsvoorstel Vermeend-Melkert’, *Tijdschrift voor Politieke Economie*, jrg. 12, nr. 1, april 1989, p. 17-27.

Opschoor, J.B., H.B. Vos, *Economic instruments for environmental protection*, Organisation for Economic Co-Operation and Development, Paris, 1989.

Palmer, K., H. Sigman, ‘The Cost of Reducing Municipal Solid Waste’, *Journal of Environmental Economics and Management*, No. 33, 1997, p. 128-150.

Pearce, D.W., R. Kerry Turner, *Economics of Natural Resources and the Environment*, Harvester Wheatsheaf, London, 1990.

Peppel, R.A. van, *Naleving van milieurecht; Toepassing van beleidsinstrumenten op de Nederlandse verfindustrie*, Kluwer, Deventer, 1995.

Persson, M., ‘Dankzij moderne techniek kan traditioneel vliegtuig overboord’, *Polytechnisch Weekblad*, 15 december 1999.

Perman, R., Yue, M., J. McGilvray, *Natural Resources & Environmental Economics*, Longman, Lonmdon&New York, 1996.

Pieters, J.H.M., *Subsidies and the Environment: on how subsidies and tax incentives may affect production decision and the environment*, paper for the UN Fourth Expert Group Meeting on Financial Issues of Agenda 21, Santiago, Chile, 8-10 January 1997.

Reijnders, L., *Environmentally Improved Production Processes and Products*, Kluwer Academic Publishers, Dordrecht/Boston/London, 1996.

Rose-Ackerman, S., (1977) ‘Market models for Water Pollution Control’, reprint in O’Riodan, R. Kerry Turner (eds), *Annotated Reader in Environmental Planning and Management*, Pergamon Press, UK, 1983, p. 63-86.

Schuurman, J., *De prijs van water - een onderzoek naar de aard van de regulerende nevenwerking van de verontreinigingsheffing oppervlaktewater*, Gouda Quint BV, Arnhem, 1988.

Sheail, J., ‘The regulation of Pesticides Use: An Historical Perspective’, in L. Roberts, A. Weale (eds), *Innovation and Environmental Risks*, Belhaven Press, London, 1991, p. 38-46.

Siebert, H., A.B. Antal, *The Political Economy of Environmental Protection*, JAI Press, Greenwich, Connecticut, 1979

Sigman, H.A., ‘A comparison of public policies for lead recycling’, *Rand Journal of Economics*, Vol. 26, No. 3, Autumn 1995, p. 452-478.

Sunnevåg, K., *Voluntary Agreements and the incentives for innovation*, paper for the CAVA workshop, 26-27 November 1998.

Stoneman, P., *The Economic Analysis of Technological Change*, Oxford University Press, Oxford, 1983.

Straaten van der, J., “Het Nederlands Milieubeleid” in F. Dietz, W. Hafkamp, J. van der Straaten (eds.), *Basisboek Milieu-economie*, Boom, Amsterdam-Meppel, 1994.

Tietenberg, T.H., *Marketable Emission Permits in Principle and Practices*, paper at the Conference Economics of Energy and Environmental Policies: State of Art and Research Priorities, Yxtaholm, Sweden, 6-10 August 1984.

Tietenberg, T., *Environmental Economics and Policy*, HarperCollins College Publishers, 1994.

Verbruggen, H., ‘Milieutechnologie: de gestuurde deus ex machina’, in J.W.A. van Dijk, L.G. Soete (red.), *Technologie in een open economie*, Samson, Bedrijfsinformatie, Alphen aan den Rijn/Zaventem, 1992.

Wagner, G.R., ‘Entrepreneurship and Innovation from an Environmental Risk Perspective’, in L. Roberts, A. Weale, *Innovation and Environmental Risk*, Belhave Press, London, 1991, p. 138-148.

Wallace, D., *Environmental Policy and Industrial Innovation*, Strategies in Europe, the US and Japan, Earthscan, London, 1995.

Wit, R.C.N., B.A. Leurs, G. de Wit, *Kosten en baten van milieuconvenanten in vergelijking met marktconforme instrumenten*, Centrum voor Energiebesparing en Schone Technologie, 1999.

Woerd, F. van der, *Self-regulation in corporate environmental management: changing interactions between corporations and authorities*, proefschrift Vrije Universiteit, 1997.

Appendix

The Table is divided into three parts, each one shows one type of enforcement. In each part, one finds the undiscounted sales and the discounted innovation-rent for the waiting-time of 0 years, 4 years and 8 years and 15 years of enforcement.

Sales (undiscounted) and innovation rent (discounted), three types of enforcement, waiting time 0 years, 4 years and 8 years, interest rate 10% and no investment in R&D																		
Year	Gradual enforcement						Slow enforcement						Fast enforcement					
	Sales			rent			Sales			rent			Sales			rent		
	0	4	8	0	4	8	0	4	8	0	4	8	0	4	8	0	4	8
1	100			73			2			1			500			227		
2	100			41			3			1			334			138		
3	100			38			4			1			223			84		
4	100			34			6			2			149			51		
5	100	100		31	31		9	2		3	1		99	500		31	155	
6	100	100		28	28		13	3		4	1		66	334		19	94	
7	100	100		26	26		20	4		5	1		44	223		11	57	
8	100	100		23	23		29	6		7	1		29	149		7	35	
9	100	100	100	21	21	21	44	9	2	9	2	0	20	99	500	4	21	106
10	100	100	100	19	19	19	66	13	3	13	3	1	13	66	334	3	13	64
11	100	100	100	18	18	18	99	20	4	17	3	1	9	44	223	2	8	39
12	100	100	100	16	16	16	149	29	6	24	5	1	6	29	149	1	5	24
13	100	100	100	14	14	14	223	44	9	32	6	1	4	20	99	1	3	14
14	100	100	100	13	13	13	334	66	13	44	9	2	3	13	66	0	2	9
15	100	100	100	12	12	12	500	99	20	60	12	2	2	9	44	0	1	5
16		100	100		11	11		149	29		16	3		6	29		1	3
17		100	100		10	10		223	44		22	4		4	20		0	2
18		100	100		9	9		334	66		30	6		3	13		0	1
19		100	100		8	8		500	99		41	8		2	9		0	1
20			100			7			149			11			6			0
21			100			7			223			15			4			0
22			100			6			334			20			3			0
23			100			6			500			28			2			0
Total	1500	1500	1500	408	260	177	1500	1500	1500	223	152	104	1500	1500	1500	578	394	269