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The Cost Effectiveness of Environmental Policy Instruments in the Presence of Imperfect Compliance[1]

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Abstract

We aim to integrate information, monitoring and enforcement costs into the choice of environmental policy instruments. We use a static partial equilibrium framework to study different combinations of regulatory instruments (taxes, standards…) and enforcement instruments (criminal fine, administrative fine…). The firms' compliance decisions depend on the instrument combination selected by the government. The model is used to compare the welfare effects of different instrument combinations for the textile industry in Flanders. We find that administrative, implementation, enforcement and monitoring costs are important to decide on the necessity of an environmental policy. Moreover, we show that emission taxes are not necessarily the most cost-effective instrument. This result holds even if we include industry heterogeneity. The decision of whether to pursue an environmental policy or not depends crucially on the formulation of an appropriate monitoring and enforcement policy.

Keywords: K32 Environmental Law, K42 Illegal behaviour and enforcement of law, Q28 Government policy

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I. INTRODUCTION

When designing environmental regulation governments face many choices. One of the hardest, without a doubt, is the selection of a suitable environmental policy instrument (Bohm and Russell, 1985). One important consideration is clearly the cost effectiveness of the instruments. Traditionally[2] market-based instruments, such as emission taxes, are assumed to be more cost efficient than command-and-control (CAC) instruments since they equalise marginal abatement costs across firms and industries. The influence of monitoring and enforcement costs on the cost effectiveness of different instruments, however, is often neglected. Recently, monitoring and enforcement costs have been studied extensively in theory and often on a per instrument basis (Cohen, 2000; Heyes, 2001).

In this paper we aim to integrate information, monitoring and enforcement costs into the choice of policy instruments. Malik (1992) already showed that the decision rules for minimising enforcement costs and minimising abatement costs are different. Therefore it is not a priori certain that CAC policies are more expensive than incentive-based policies when enforcement is taken into account. Enforcement and monitoring costs are highly non-linear and depend on the legal system. Therefore we use a simple partial equilibrium model and apply it to one industrial sector, i.e. the textile industry in Flanders. The simple model we use includes abatement decisions and costly monitoring and enforcement. The case study uses individual firm data to simulate the differences in abatement costs and compliance decisions between firms. For the problem of water pollution in the Flemish textile industry we compare combinations of regulatory instruments (emission taxes, emission standards and technology standards) and enforcement instruments (criminal fines, administrative fines and transaction offers). We show that the inclusion of information, monitoring and enforcement costs alters indeed the relative cost efficiency of the different instruments[3].

In the following section we describe the theoretical framework. Next we focus on the assumptions underlying the case study. In the fourth section we construct the welfare function for the different instrument combinations and discuss the results of the case study.

II. THEORETICAL FRAMEWORK

Using a static partial equilibrium framework we define the behaviour of three types of agents in the economy: firms, households and government. Each agent has a specific objective function. The environmental regulation and the associated enforcement policy determine the feasible options. The problem is one of asymmetric information since the abatement costs are known to the firms but not to the regulator.

For the regulator there are three stages in selecting an environmental policy: the rule-making stage, the implementation stage and the enforcement stage (see table 1). This succession of stages is called the regulatory chain. In the rule-making stage the regulator chooses how to tackle the pollution problem. Discussions with administrations and interest groups are held to decide on the environmental goals and on the instruments used to attain those goals. Costs linked to this stage are called rule-making costs (RC). In the implementation stage the environmental regulation is in force and in order to ensure its correct implementation some extra regulation is needed. Costs linked to this stage are abatement costs (AC) and administrative implementation costs (IC). In the enforcement stage compliance with the

[2] See, for example, Kolstad (2000).
[3] We do not consider liability rules in this paper.

regulation is ensured. A monitoring and enforcement policy is developed. Costs linked to this stage are the enforcement costs (EC). For a more detailed study of the legal and administrative process we refer to Billiet (2001).

	Description	**List of Instruments**
Stage 1 - **Rule making stage**	The regulator chooses the instrument to tackle pollution. Discussions with administrations and interest groups are held. Costs linked to this stage are called rule-making costs **(RC).**	Emission tax
		Emission standard Emission standard included in a license system Emission standard combined with an authorising notification duty
		Technology standard Technology standard included in a license system Technology standard combined with authorising notification duty
Stage 2 - **Implementation stage**	The environmental regulation is in force and in order to ensure its correct application some extra regulation is needed. Costs linked to this stage are abatement costs **(AC)** and administrative implementation costs **(IC)**.	Documentation duty Notification duty Inspection and maintenance duty
Stage 3 - **Enforcement stage**	The compliance with the regulation needs to be ensured. A monitoring and enforcement policy is needed. Costs linked to this stage are the enforcement costs **(EC).**	Criminal fine Administrative fine Transaction offer

Table 1

In each stage an instrument has to be selected. A list of these instruments can be found in table 1. In our model we include the following rule making instruments: an emission tax, an emission standard and a technology standard. Moreover we discuss three different versions of the emission and technology standard: firstly we look purely at the instrument itself, secondly we include the instrument in a license system and thirdly we combine the instrument with an authorising notification duty[4]. In the implementation stage the policy maker can choose among three instruments: a documentation duty[5], a

[4] In an 'authorising notification duty' system the agent has to report some information to the administration, for example, that they have installed a particular filter. This report then automatically allows ('empowers') them to, for example, continue their business.

[5] A documentation duty asks the firm to have documentation about, for example, its emissions. Nothing has to be done with the documents; firms just need to have them.

notification duty[6] and an inspection and maintenance duty[7]. Finally we also distinguish three enforcement instruments: a criminal fine, an administrative fine and a transaction offer[8].

We now describe the behaviour and objectives of the production sector, the households and the government. An overview of the used notation can be found in appendix A.

1. Production sector

In order to concentrate on the choice of instruments and the role of monitoring and enforcement we assume that the output of firms is fixed[9]. We therefore assume that firms cannot go out of business. Once the environmental regulation is implemented firms have to make at most two decisions. First they have to decide whether to comply or not with the regulation. Next firms have to decide what technology to use. Firms fix automatically the amount of emissions they emit when they decide about abatement. In the case of an emission tax, the firm also decides how many emissions they report to the administration.

Firms take their decisions after the government has fixed the environmental policy and has decided on the monitoring and enforcement policy it will follow. We assume that the government can commit to these policy choices.

We successively discuss three different rule-making instruments: emission standard, emission tax and technology standard.

1.1 Emission standard

Firm *i* minimises the expected costs associated with the regulation in force. These costs include abatement costs *(AC_i)*, rule-making costs *(RC_f)*, administrative implementation costs *(IC_f)*, expected enforcement costs *($E(EC_f)$)* and the expected sanction *($p_i.F_i$)*. Some of these costs are identical for all firms and are marked with the index *f*.

Formally the firm *i* faces the following optimisation problem[10]:

$$\begin{aligned} \min_{y_{ij_i}} \exp TC_i &= AC_i + p_i F_i + RC_f + IC_f + p_i \left(\overline{EC}_f + y_{F_i} EC_f \right) \\ s.t. \quad E_i &= E_i^o - EA_i \leq \overline{E} \end{aligned} \tag{1}$$

[6] A notification duty asks the firm to communicate certain information to the administration; e.g. in order to pay taxes a firm has to notify the administration of its emissions.

[7] An inspection and maintenance duty asks firms to maintain and test its installation on a regular basis and often, by means of officially recognised expert.

[8] A transaction offer is a special kind of administrative fine used in Belgium. Administrative costs are very low for this instrument.

[9] Rousseau and Proost (2001a) analysed the general equilibrium effects of enforcement costs on the efficiency of different regulatory instruments.

[10] We assume that firms are risk neutral. This is no innocent assumption when it comes to enforcement.

$$
\begin{aligned}
\textit{with} \quad A_i &= \sum_{j_i} AC_{ij_i} y_{j_i} \\
EA_i &= \sum_{j_i} Eab_{ij_i} y_{j_i} \\
y_{j_i} &= 1 \quad \text{if technology } j \text{ is chosen by firm } i \\
&= 0 \quad \text{otherwise} \\
y_{F_i} &= 1 \quad \text{if } F_i > 0 \\
&= 0 \quad \text{if } F_i = 0
\end{aligned}
$$

The firm emits E_i and is subject to an emission standard $\overline{E}$. When the firm is violating the environmental policy it faces an expected sanction p_iF_i where p_i is the inspection frequency and F_i is the fine. The fine depends on the size of the violation and the penalty parameter π_{es}.

$$
\begin{aligned}
p_i &= \min\left(\overline{p} + \alpha \frac{E_i - \overline{E}}{\overline{E}} \ ; 1 \right) \\
F_i &= \pi_{es} \max\left(E_i - \overline{E} \ ; \ 0 \right)
\end{aligned}
\tag{2}
$$

In section II.4 we look further into the assumptions underlying the monitoring and enforcement policy.

The rule-making, implementation and expected enforcement costs are identical for all firms. These costs include, among others, the costs of the firms' extra administration. Managers need to be informed about their legal obligations and the implications for their company. They may need to apply for a license. Moreover they need to collect information about the technological possibilities to comply with the standard. Some employees may need training. Measurement of emissions is necessary to evaluate the compliance status. The enforcement costs consist of two parts: inspection costs ($\overline{EC_f}$) and sanctioning costs (EC_f). The inspection costs are incurred every time an inspection is performed on the firms' premises. Examples of these costs are the costs of having to follow up the inspection and to perform a second test if necessary. Sanctioning costs are only relevant if a firm is actually fined. Examples are costs of legal representation and court costs. A detailed identification and estimation of these costs is part of the empirical exercise and will be discussed later.

Firms decide which abatement technology to install based on a very simple decision rule: they install technology $\tilde{j}$ if total costs are smaller with that technology than without. If more than one technology or technology combination gives a costs reduction, the technology with the highest cost reduction is chosen. Abatement will lead to a cost reduction for the firm if the expected fines exceeds investment costs. We cannot derive general first-order conditions since our abatement cost functions are step-functions and firm specific. We have:

$$
y_{i\tilde{j}_i} = 1 \qquad \textit{if} \qquad D_{i\tilde{j}_i} = \max\left(D_{ij_i} \right) \text{ and } D_{i\tilde{j}_i} > 0 \tag{3}
$$

$$with \quad D_{i\tilde{j}_i} = \min\left(\bar{p} + \alpha \frac{E_i^o - \bar{E}}{\bar{E}} \;;1\right)\left(\overline{EC}_f + y_{F_{io}} EC_f\right)$$
$$+\min\left(\bar{p} + \alpha \frac{E_i^o - \bar{E}}{\bar{E}} \;;1\right)\pi_{es} \max\left(E_i^o - \bar{E} \;;0\right) - AC_{ij_i}$$
$$-\min\left(\bar{p} + \alpha \frac{E_i^o - EA_{i\tilde{j}_i} - \bar{E}}{\bar{E}} \;;1\right)(\overline{EC}_f + y_{F_{i\tilde{j}}} EC_f)$$
$$-\min\left(\bar{p} + \alpha \frac{E_i^o - EA_{i\tilde{j}_i} - \bar{E}}{\bar{E}} \;;1\right)\pi_{es} \max\left(E_i^o - EA_{i\tilde{j}_i} - \bar{E} \;;0\right)$$

Once the abatement decision is taken, actual emissions are determined and also the degree of firm violation. Notice that due to the indivisibilities in the abatement cost function, firms can overcomply with the regulation. The extra emission reductions benefit society but not the firms.

1.2 Emission tax

For an emission tax τ the firm's problem can be represented as follows:

$$\min_{AC_i;E_i^R} \exp TC_i = A_i + \tau E_i^R + p_i F_i + RC_f + IC_f + p_i(\overline{EC}_f + y_{F_i} EC_f)$$

$$\begin{aligned} with \qquad A_i &= \sum_{j_i} AC_{ij_i} y_{j_i} \\ y_{j_i} &= 1 \quad \text{if technology } j \text{ is chosen by firm } i \\ &= 0 \quad \text{otherwise} \\ y_{F_i} &= 1 \quad \text{if } F_i > 0 \\ &= 0 \quad \text{if } F_i = 0 \end{aligned} \tag{4}$$

Every year firms that are subject to an emission tax, report a certain amount of emissions E_i^R to the government. They pay taxes on these reported emissions. However, if a firm reports less than the actual amount of emissions, it is in violation and faces a penalty. The difference between actual and reported emissions is never negative if the firm behaves rationally. Enforcement is discussed more thoroughly in section II.4.

$$\begin{aligned} p_i &= \min\left(\bar{p} + \alpha \frac{E_i - E_i^R}{E_i} \;;1\right) \\ F_i &= \pi_{et}\, \tau \max\left(E_i - E_i^R \;;0\right) \end{aligned} \tag{5}$$

In analogy to the emission standard the rule-making, implementation and expected enforcement costs are identical for all firms. Firms now not only face information costs but also the costs for the yearly tax report. Data must be collected and reported. Calculations must be made. Moreover, the firm also has to perform measurements to know its actual emissions.

The first-order condition that determine how much emissions (E_i^R) a firm will report is:

$$E_i^R = \min\left(\left(1-\frac{\alpha\left(\overline{EC}_f + y_{Fi}EC_f\right)-\overline{p}\,\tau\,\pi_{et}-\tau}{\left(1-E_i\right)\alpha\,\tau\,\pi_{et}}\right).E_i\ ;\ E_i\right) \tag{6}$$

The actual emissions E_i of firm *i* are equal to the difference $E_i^O - E_i^A$; with E_i^O equal to the firm's initial emissions before abatement technology has been installed and E_i^A equal to the amount of emissions reduced by abatement. Firms will never report more than there actual emissions.

Next firms have to decide which technologies they want to install. A firm will invest in a particular abatement technology if the following condition is fulfilled:

$$y_{i\tilde{j}_i} = 1 \qquad \text{if} \qquad D_{i\tilde{j}_i} = \max\left(D_{ij_i}\right) \text{ and } D_{i\tilde{j}_i} > 0$$
$$\text{with} \qquad D_{i\tilde{j}_i} = TC_i(\text{without techn.}\,\tilde{j}_i) - TC_i(\text{with techn.}\,\tilde{j}_i) \tag{7}$$

Firms will invest in abatement if the costs of doing so are smaller than the corresponding decrease in taxes paid and expected fine.

1.3 Technology standard

A technology standard forces the firm to use a particular abatement technology $\hat{j}$ or production process. The firm's choice space is therefore limited. Either they comply with regulations and install the technology or they are in violation. Abatement costs are fixed for one company but can differ between firms. We allow for firm heterogeneity.

The firm's objective function is:

$$\min_{y_{i\hat{j}}} TC_i = \min_{y_{i\hat{j}}}\left(A_i + RC_f + IC_f + p_i(\overline{EC}_f + y_{F_i}EC_f) + p_iF_i\right)$$
$$\begin{aligned} \textit{with} \qquad A_i &= AC_{i\hat{j}}\,y_{i\hat{j}} \\ y_{i\hat{j}} &= 1 \quad \text{if techn } \hat{j} \text{ is chosen by firm } i \\ &= 0 \quad \text{otherwise} \\ y_{F_i} &= 1 \quad \text{if } F_i > 0 \\ &= 0 \quad \text{if } F_i = 0 \end{aligned} \tag{8}$$

The standard fixes one particular technology for each firm. The implementation of this technology can lead to different costs for each firm. Each firm has two options: either it complies with the standard and installs the technology at cost $AC_{i\hat{j}}$ or it does not install the technology and incurs no costs.

The expressions for the inspection frequency and the fine are:

$$\begin{aligned} p_i &= \min\left(\overline{p} + \alpha\left(1 - y_{i\hat{j}}\right)\ ;\ 1\right) \\ F_i &= \pi_{ts}\left(1 - y_{i\hat{j}}\right) \end{aligned} \tag{9}$$

Again rule-making, implementation and expected enforcement costs are identical for all firms. Cost for information acquisition are limited in size since the regulation already indicates which technology must be used. There is no need to know alternatives or even actual emissions.

For a technology standard the compliance decision is simple. A particular technology will be implemented if costs fulfil the following condition:

$$\begin{aligned} & y_{i\hat{j}} = 1 \qquad if \qquad D_{i\hat{j}} > 0 \\ \text{with} \quad & D_{i\hat{j}} = \min\left(\overline{p}+\alpha;1\right)\left(\overline{EC}_f + y_{F_{io}} EC_f\right) + \min\left(\overline{p}+\alpha;1\right)\pi_{ts} \\ & - \min\left(\overline{p};1\right)\overline{EC}_f - AC_{i\hat{j}} \end{aligned} \tag{10}$$

A firm will comply with the technology standard if it costs less than the expected fine. This expression will lead to a corner solution for the firm.

2. Households

The households are treated as a more or less passive agent. We assume that households maximise utility:

$$\max \text{U} = \max\left(CS - RC_h - IC_h - E(EC_h)\right) \tag{11}$$

We assume that consumer prices are determined on the world market. Therefore local producers and consumers do not influence prices. Consequently the consumer surplus will remain constant in our model.

Rule-making costs for households can include the possibility to object to a permit request. Administrative implementation costs result from investments in lobbying and information acquisition. Expected enforcement costs result from complaining to or warning the appropriate authorities. All these costs are considered as fixed but they vary with the instrument selected by the government.

3. Government

Government maximises social welfare *(*SW) and this is expressed as follows:

$$\max SW = \max \begin{pmatrix} PS + CS + EQ - RC_f - IC_f - \sum_i p_i(\overline{EC}_f + y_{F_i} EC_f) \\ -RC_h - IC_h - E(EC_h) \\ +MCPF \sum_i \left(\tau E_i^R + p_i F_i - RC_g - IC_g - \sum_i p_i(\overline{EC}_g + y_{F_i} EC_g) \right) \end{pmatrix} \tag{12}$$

Social welfare comprises producer *(PS)* and consumer *(CS)* surplus, environmental quality *(EQ)*, regulation costs for firms and households and the governmental budgetary surplus corrected with the marginal cost of public funds *(MCPF)*.

In the global welfare function we include all rule-making, implementation and enforcement costs associated with a particular set of instruments but also subtract environmental benefits. Environmental benefits are subtracted to allow us to deal with the indivisibilities of the abatement costs that make comparisons across instruments more difficult (Oates et al., 1989).

Rule-making costs for the government result from meetings within the administration and with interest groups and experts. Governmental operating costs have to do with, for instance, distributing regulatory information through official publication of laws and statutes. Enforcement costs include inspection and prosecution costs.

4. Monitoring and enforcement

The monitoring and enforcement policy is modelled in a simple way and is similar but not identical to the one used by Harford (1978) and Malik (1992).

The probability of inspection is modelled in the following way:

$$p_i = \overline{p} + \phi(\textit{size of violation}) \qquad \textit{with } 0 \le \phi(.) \le 1 \tag{13}$$

Every firm, whether it is violating the environmental regulation or not, will be inspected with a certain fixed probability $\overline{p}$. A violator, however, faces an extra possibility of being inspected. This probability $\phi(.)$ is proportional to the level of violation. This does not imply that the agency knows the level of violation or even which firms are in violation. It simply represents the practice that every complaint is followed up by the environmental inspection agency. The neighbouring community, environmental pressure groups or civil servants can issue complaints when they notice something suspicious. We assume that complaints are highly correlated with the degree of violation. More specifically we had for our three types of instruments:

$$\begin{aligned}
p_i &= \min\left(\overline{p} + \alpha \frac{E_i - \overline{E}}{\overline{E}} \ ; 1 \right) && \textit{for an emission standard} \\
p_i &= \min\left(\overline{p} + \alpha \frac{E_i - E_i^R}{E_i} \ ; 1 \right) && \textit{for an emission tax} \\
p_i &= \min\left(\overline{p} + \alpha \left(1 - y_{i\hat{j}}\right) \ ; 1 \right) && \textit{for a technology standard}
\end{aligned} \tag{14}$$

We assume that every violation that is detected leads to a sanction for the violator. The three types of sanctions we use are a function of the degree of violation. We recapitulate:

$$\begin{aligned}
F_i &= \pi_{es} \max\left(E_i - \overline{E} \,;\, 0 \right) && \textit{for an emission standard} \\
F_i &= \pi_{et}\, \tau \left(E_i - E_i^R \right) && \textit{for an emission tax} \\
F_i &= \pi_{ts}\, \overline{AC_i} && \textit{for a technology standard}
\end{aligned} \tag{15}$$

Finally we assume that firms, households and government know the relation between the level of violation, the probability of inspection and the sanction.

III. EMPIRICAL ILLUSTRATION

1. Benchmark and description

In order to illustrate our theoretical model we decided to focus on the Flemish textile industry. More specifically we concentrate on the water pollution caused by textile improvement and carpet production. These two subsectors are after all responsible for most of the water pollution in the sector. Several sector studies (PRESTI, 1994-1997; Jacobs et al., 1998; Centexbel, 1996 and OVAM, 1996) provide us with useful information. For reasons of tractability we limit our study to water pollution caused by BOD[11] emissions and we only consider point sources.

In our benchmark scenario there is no environmental regulation in place. We do, however, assume that all necessary legal and economic institutions are already in place; such as the environmental inspection agency, courts, senate…

Finally the marginal cost of public funds equals 1 and the willingness to pay for an improvement in water quality equals € 31 per year for each ton of BOD removed (Rousseau and Proost, 2001b). We will provide a sensitivity analysis of this last estimate.

2. Selection and specification of the regulatory chain

When we combine all possible instruments in the three stages we obtain thirty regulatory chains that could be of interest (Billiet et al., 2002). For each of these combinations we will consider several values for the instruments. By using different values for, for example, the emission tax rate we are able to construct a global welfare function defining the costs and benefits connected with a certain emission reduction (see figure 1).

3. Monitoring and enforcement parameters

We assume that the fixed inspection probability $\overline{p}$ is equal to 0.1[12]. Next we assume that the variable inspection parameter α is equal to 0.5. The probability of inspection is therefore proportional to the size of the violation.

Finally we assume that the penalty parameter π_{et} is equal to 2. In Billiet (2001) we find that in Belgium the penalty for evading an emission tax is typically twice the evaded amount. Since we have no information on the other instruments, we use the same number for the penalty parameter for the emission standard $(\pi_{es} = 2)$. The penalty parameter π_{ts} for a technology standard is also different in dimensions and is assumed to equal 50000 Euro.

In section IV we perform a sensitivity analysis on these parameters.

4. Abatement cost function

Explicitly modelling the firms' heterogeneity is important to capture the advantages of market-based versus command-and-control instruments. Therefore we made use of a firm level survey on abatement costs. We first contacted by mail 106 Flemish companies active in textile improvement and carpet production. Then we conducted a follow-up interview on site. We obtained useful cost estimates from

[11] Biological Oxygen Demand (BOD) is after all the standard measure of pollution (Helland, 1998).

[12] This value is based on a press release from the Ministry of the Flemish Community on 11 June 2001. We read *'… that every class-I-firm is inspected thoroughly not even once every ten year'*. Since we only consider class-I-firms we can assume that every firm regardless of its compliance status has a ten percent probability of being inspected per year.

20 firms. We asked firms to state the costs of presently installed abatement technologies and of planned investments in the next two years. These data were used to estimate abatement cost functions for each company in order to represent firms' heterogeneity. In appendix B we give a summary of the cost estimates we obtained.

The cost estimates take both fixed and variable costs into account. We include initial investment costs, subsidies, personnel, energy and other costs. The life span of an investment is assumed to be 20 years. We assign all costs to only one pollutant, i.e. BOD, and therefore assume that the sole purpose of the investment is to reduce BOD emissions[13]. After calculating the net present value (NPV) of each technology we derive the associated annuities and use these in the model.

An extensive range of technologies was reported including filters, use of different inputs and wastewater treatment. Cost differences of abatement technologies between firms turn out to be large indeed; cost estimates (NPV) for one particular technology ranged from 1 million € in one firm to 4.7 million € in another firm.

5. Rule-making, implementation and enforcement costs

We identify fixed cost factors that result from the legal context and from the instrument itself (see Billiet et al., 2002). The cost factors resulting from the legal context are:

- guarantees required for civil rights;
- guarantees required for criminal pursuits;
- the possibility that an instrument is unavailable for a particular legislator;
- uncertainty about the competency status of an instrument or a variation thereof;
- dysfunctional structure of the instrument due to limitations in the division of competencies among government levels;
- structural susceptibility of the instruments for violations of the equality principle or the discrimination injunction

The cost factors resulting from the instrument itself are:

- administrative sustainability
- technical content (environmental and legal)
- knowability (can an instrument easily be known by the firms, administration and citizens?)
- procedures required in order to implement the rules
- legal formalisation
- time profile in the implementation stage
- rules which require an administration as implementation partner
- flexibility
- clustering

For each of these cost factors we have performed a relative valuation (see table 2) per instrument and per agent; and we haven taken into account the different stages of the regulatory chain. We include a wide variety of costs: the costs of lobbying, of filling in forms, of communicating with the administration, of performing inspections, of internal meetings, of legal counselling…

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[13] In reality investments in abatement technologies often serve multiple purpose and reduce the output of several pollutants. This means that firms can 'overachieve' and do better than legally required. One way to deal with this overachievement problem can be found in Oates et al. (1989). In this paper, we make abstraction of this.

	Government			Households			Firms		
Instrument	RC	IC	EC Incl. $\overline{EC}_g$	RC	IC	EC	RC	IC	EC Incl. $\overline{EC}_f$
Emission standard	105	2+print	2.5	0.5		1	1	15 + lab	3.5
Authorising notification duty	35	0.5	0.5					1	
License system	137	35	3	0.5	0.5	0.5	2.5	26.5	1
Emission tax	133	6+print	5	0.5			1	20	8
Technology standard	75	2+print	2.5	0.25		0.5	1	8.5	1
Documentation duty	17	0.5	1.5					7	
Notification duty 1	15.5	0.5						0.25	
Notification duty 2	18.5+print	4.5+print	1.25					4.25	0.75
Testing duty	15.5								
Criminal fine	33	34			7.75			39	
Civil fine	62.5	65		0.25			0.25	13	
Transaction offer	63.5	2						1.25	

Table 2: Rule-making, implementation and enforcement costs (in man-days)

The enforcement, inspection and information costs were estimated using the same firm survey, by checking court rulings and by interviewing experts in the administration and in the law profession[14]. The results are summarised in Table 2. An example of the cost breakdown for the emission tax can be found in appendix C.

The relative cost differences between the different instruments is what counts in this analysis. We do not want to stress the absolute values of these cost estimates. Therefore we have expressed the costs in man-days rather than in monetary terms. However, in order to calculate welfare effects we will need a monetary estimate of these costs. We have chosen an average gross wage level[15] in the textile industry of 37 €/hour. The average gross wage in the civil sector is assumed to be 50 €/hour. The value of time to the households is assumed to be on average 5 €/hour. The costs of analysing a sample in the lab are assumed to be € 372 on average. The costs of printing the regulatory information are assumed to be € 12395.

These costs are not used as such in the model. We have estimated and taken into account how often a particular instrument is used or changed by government, how often firms are punished for being in violation, etc. Costs associated with an emission tax are incurred each year and are, therefore, taken completely into account. Costs associated with an emission standard, on the contrary, are assumed to occur every four years and we, therefore, use the figure in table 2 divided by five (remember that we look at a time period of 20 years). Costs associated with inspections depend on the number of inspections performed.

[14] We would like to thank especially Carole M. Billiet for the expert help on estimating the different costs.
[15] This amount is based on the answers obtained when we questioned the textile firms.

IV. RESULTS

1. Base scenario

First we plot in Figure 1 the welfare effects and emission levels for one instrument combination, i.e. an emission tax combined with a documentation duty, a notification duty and a civil fine. We consider the effect of implementing different tax rates.

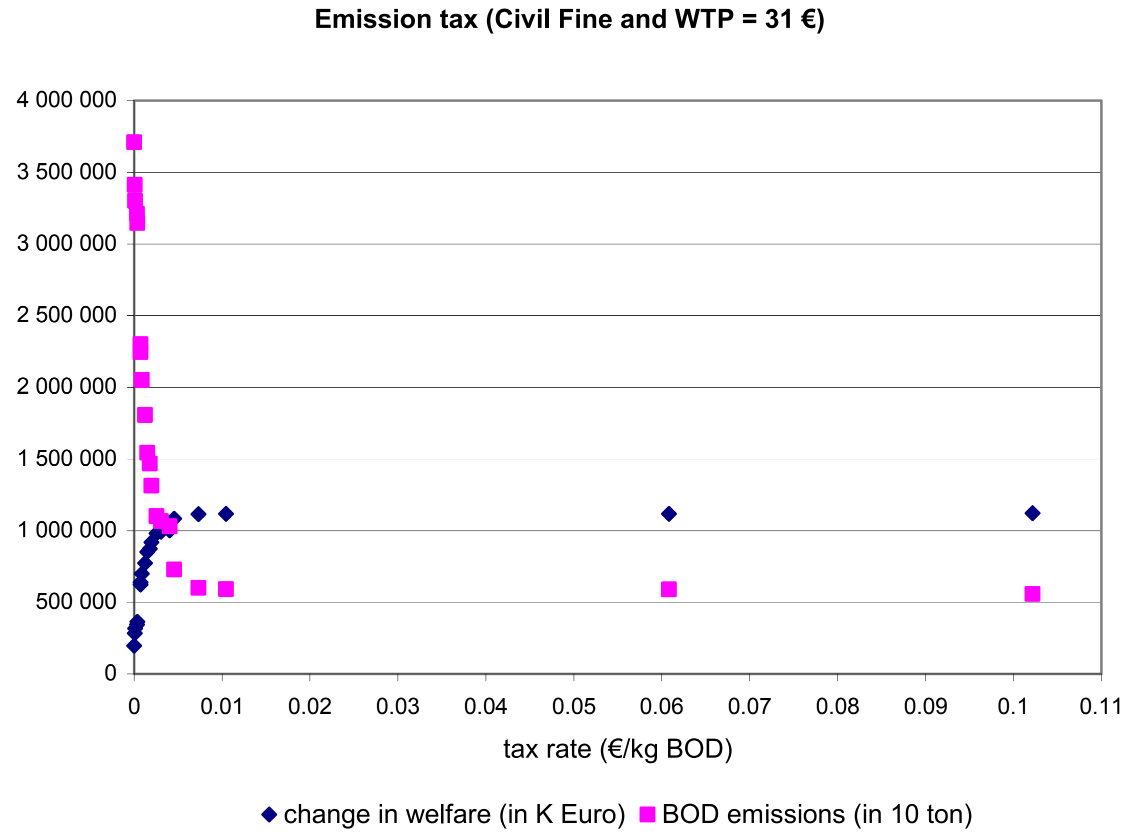

Figure 1

BOD emissions reduce stepwise with an increasing tax rate because of the indivisibilities included via the abatement cost curves (see Figure 1). It is only profitable to invest in a particular abatement technology when the tax rate exceeds a certain level. The abatement cost function is therefore not continuous. Due to the same reason the welfare level changes stepwise. Once the tax rate exceeds a threshold value, the welfare level jumps up only to slowly decline until another threshold is exceeded. This decline is caused by the increase in costs without a compensating decrease in emissions.

In order to provide some insight in the relative impact of the regulatory costs on social welfare[16], we give in Table 3 the rule-making, implementation (including abatement costs) and enforcement costs for the three different agents as a percentage of social welfare. It is clear from this table that the costs are substantial in absolute values but are less important relative to social welfare.

[16] We assume that the instruments are combined with a civil fine.

Instrument	Specification	Emissions (in ton BOD)	Social welfare (in K Euro)	Costs (RC+IC+EC+AC as % of SW)	
Emission tax	0.00074 €/kg BOD	22 461 007	640 033	Firm	1.09888
				Citizen	0.68167
				Government	0.07615
Emission standard	293 mg BOD/l	22 447 726	622 094	Firm	4.38374
				Citizen	0.44630
				Government	0.03038
Technology standard	Heat exchange	22 066 071	659 624	Firm	0.40223
				Citizen	0.28562
				Government	0.00933

Table 3

First of all we notice that costs for firms are higher than costs for citizens or government for all three instruments. Costs for citizens are, in general, relatively high since many households are affected by the regulation. Differences between citizens' costs over the different instruments are due to our assumptions concerning the instruments' durability[17].

Even though the costs of an emission tax for the government is twice that of an emission standard, the emission tax leads to higher welfare. This result is due to the fact that costs for firms are much lower for an emission tax than for an emission standard. This is something we expected since taxes allow firms to equalise marginal costs (and minimise total costs) while standards do not. Moreover this observation may point to one possible reason why standards are preferred by governments. From the government's point of view it is often cheaper to install an emission standard than to use an emission tax to obtain an environmental improvement.

In the base scenario we exclude environmental benefits. A sensitivity analysis will check the influence of environmental benefits on the results. In Figure 2 we plot the welfare effect for all instruments combined with a civil fine. In figure 3 we give a detail of the first emission reductions. In these graphs we measure the emission level on the horizontal axis and the welfare level on the vertical axis. We immediately see that a certain amount of rest emissions (namely 5 563 192 ton BOD) will persist whatever firms or government do. This is due to our assumption that the industry's output remains fixed.

Our results indicate that in most cases emission taxes are the cheapest instrument to use. Only for minor reductions do emission standards outperform taxes. The welfare curves are not continuous due to the step-wise abatement functions. Both instruments can be useful since they can each reach their own specific set of emission reductions. Technology standards prove to be a very limited instrument since they can only reach as many points as there are possible abatement technologies.

[17] We assume that emission taxes are adapted yearly while emission standards are only adapted every four years and technology standards every five years.

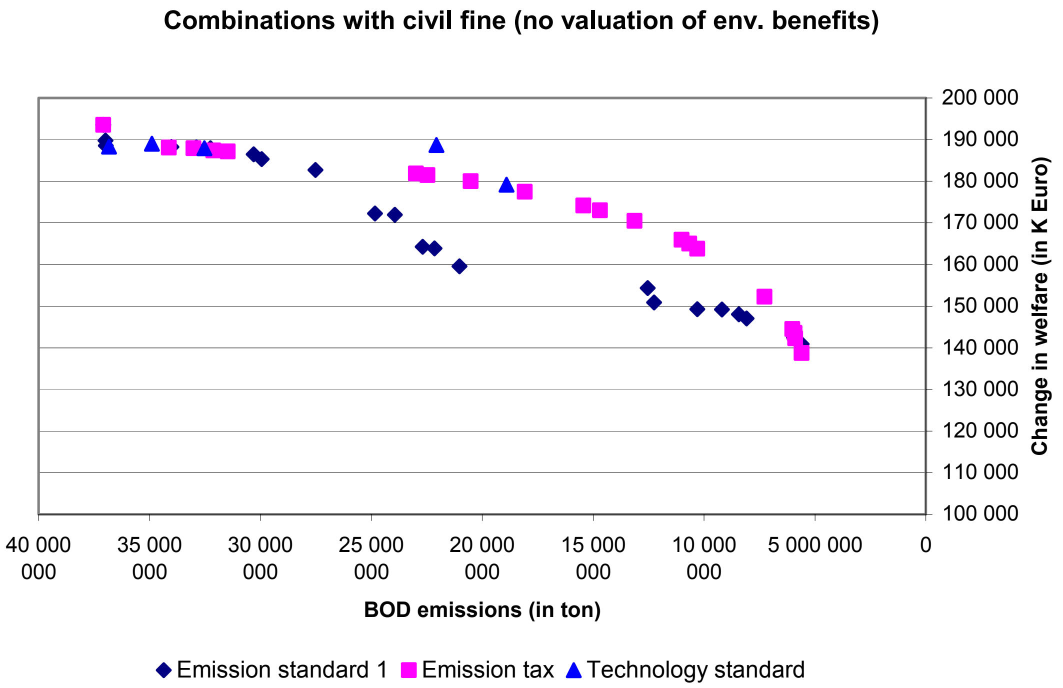

Figure 2[18]

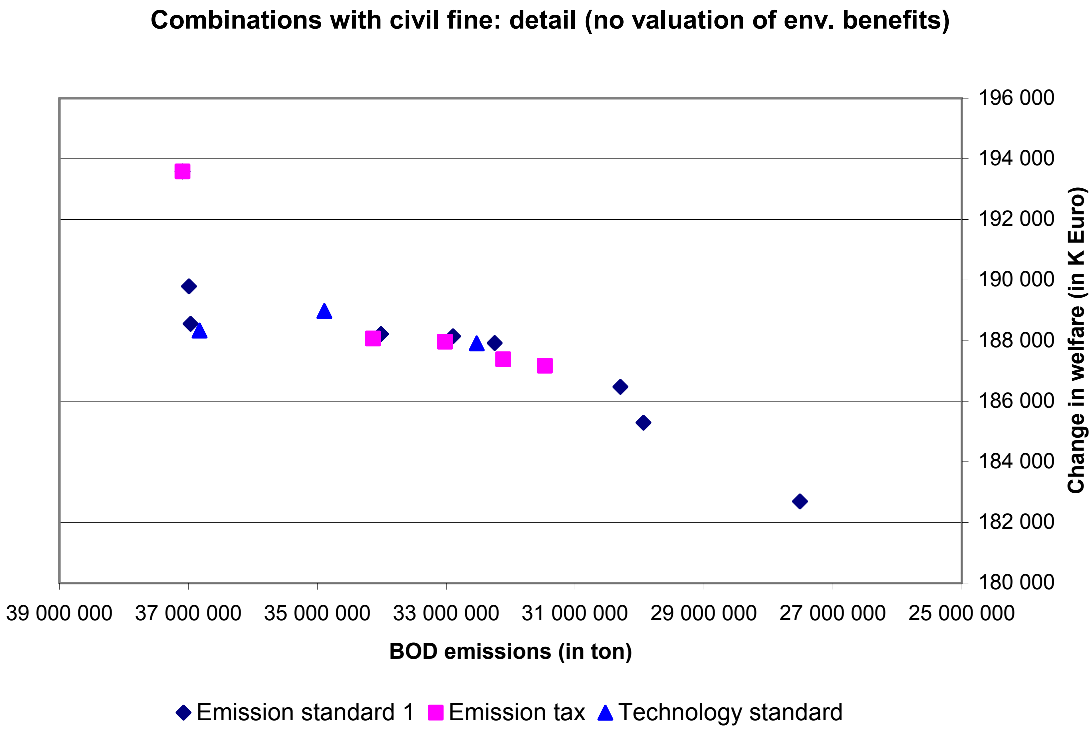

Figure 3

In Figure 4 we compare the different sanctioning instruments for an emission tax. The criminal fine is by far the most expensive instrument to use and, as could be expected, the transaction offer is the cheapest to use. However, in reality these three instruments are often used as complements. For minor

[18] Abbreviations are: emission tax *(Tax)*, emission standard version 1 or 2 *(ES 1/2)* and technology standard *(TS)*.

violations or first time offenders, a transaction offer will often suffice. A criminal fine will be used for serious violations or extremely uncooperative firms. The administrative fine also has its specific use. Using an administrative fine avoids the social stigma associated with criminal fines. Therefore we cannot a priori choose one of the enforcement instruments as being *'the best'*. We need a dynamic model to study the power of this type of strategies more closely. An example of a model that punishes repeat offenders more severely is Harrington (1988).

Emission tax with different sanctioning instruments

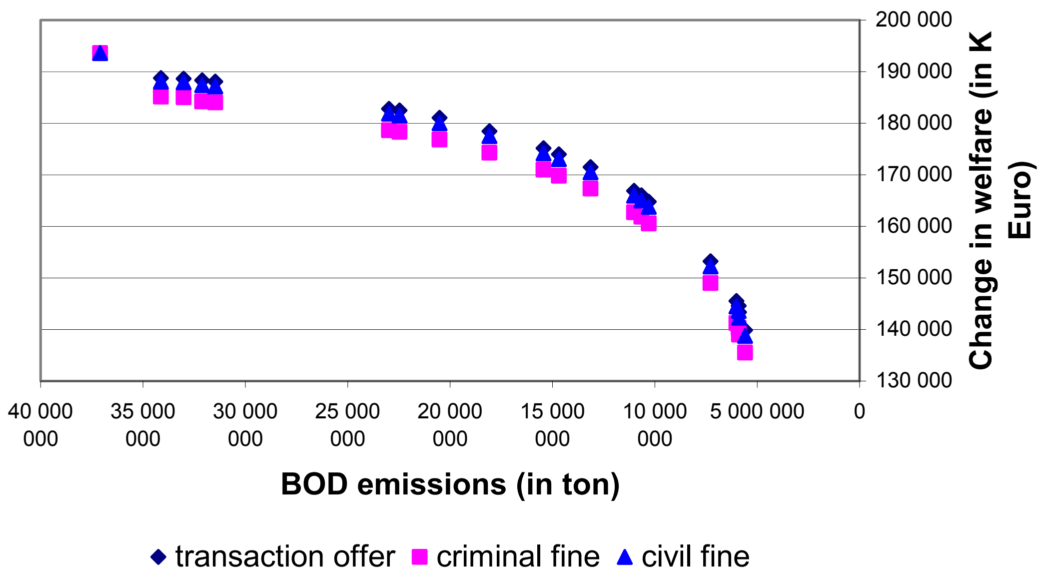

Figure 4

Emission standard in three variations (civil fine)

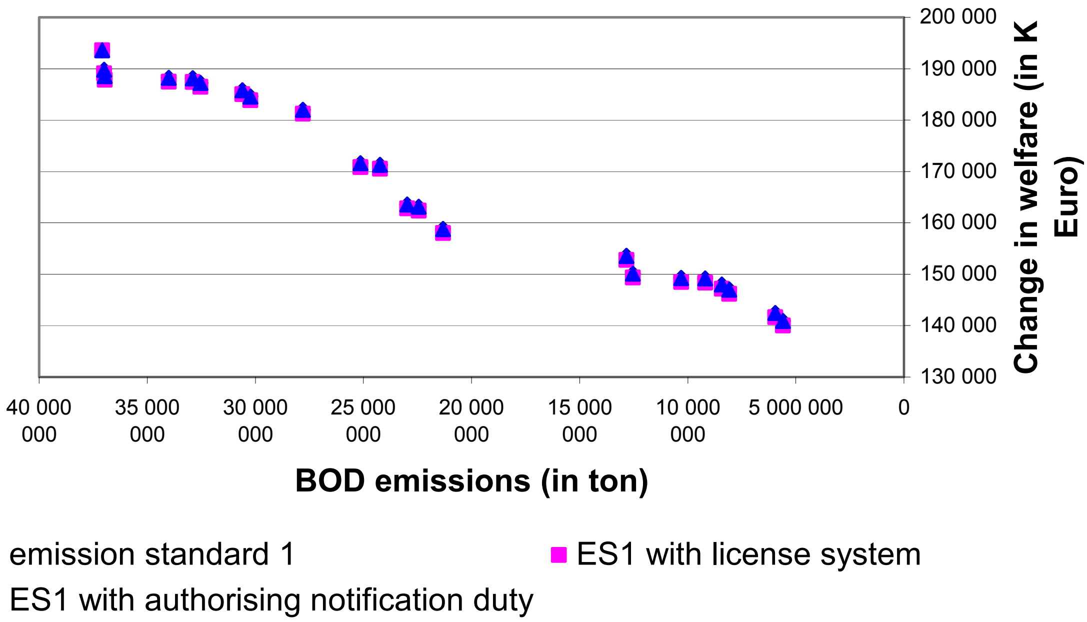

Figure 5

We also compare three different versions of the emission standard in Figure 5. Adding an authorising notification duty to a standard only minimally increases the associated costs. Including the standard in a license system, on the contrary, markedly increases costs. We cannot say as such which combination the regulator should use since other criteria, besides costs, can play a role.

2. Sensitivity analysis

Sensitivity analysis shows that the results are – in certain aspects - highly sensitive to the differences in the willingness to pay (WTP) for water quality improvements. The higher the WTP for the improvement in environmental quality, the more it pays to pursue an environmental policy even if the emissions are only minimally reduced.

See, for example, Figure 6 for the welfare curves associated with three different level of WTP for the emission tax combined with a transaction offer. Remarkable is that the changes in WTP do not influence the relative position of the different instruments. This implies that the result of Oates et al. (1989) do not carry through in our model.

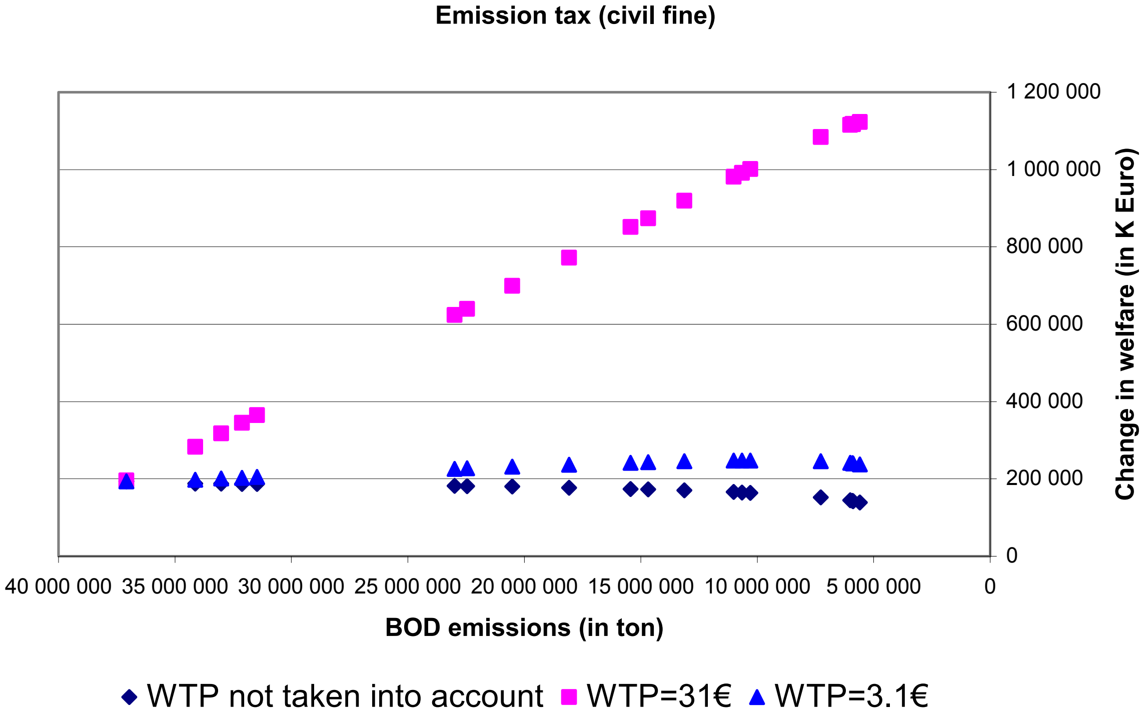

Figure 6

Sensitivity analysis with respect to the enforcement parameters (fixed inspection probability, coefficient of the variable inspection probability and the penalty coefficient) shows their immense importance. When the enforcement parameters are at a suboptimal level, it may be that is more cost effective not to have environmental regulation at all (see figure 9).

In Figure 7 we have plotted the change in welfare and emission reduction for one particular tax rate ($\tau = 0.0012 € / kg\ BOD$) when the fixed inspection frequency $\overline{p}_i$ changes from zero to one. An optimum is reached for a fixed inspection frequency equal to 0.5. Reducing the parameter from 50% to 40% decreases welfare with approximately 615 000 Euros.

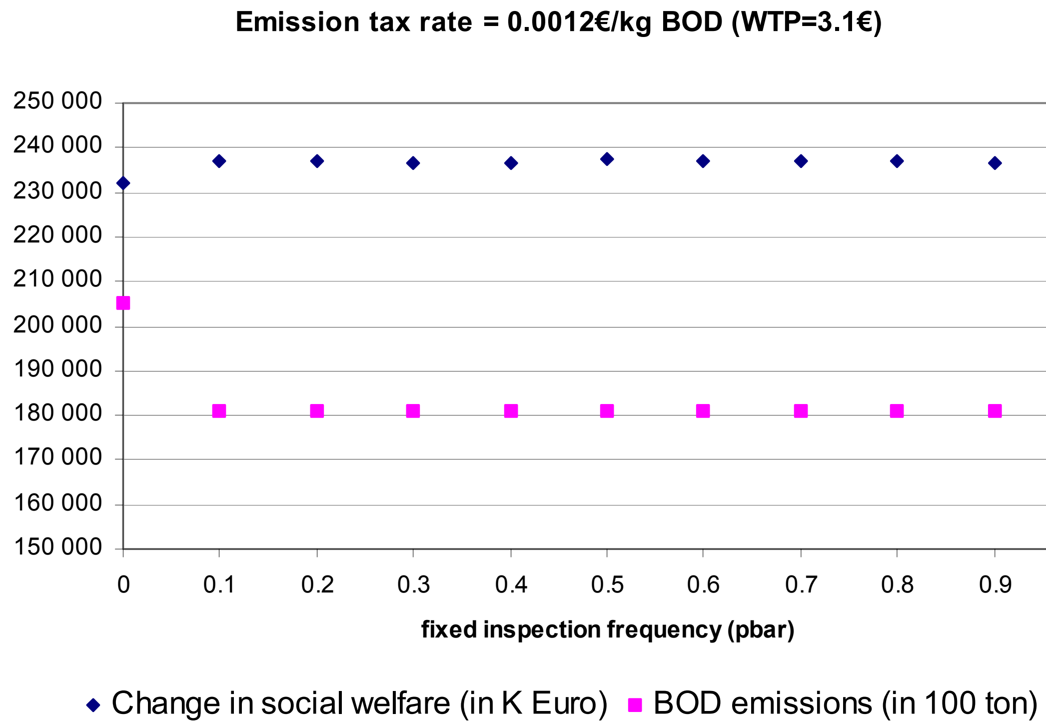

Figure 7

In Figure 8 we perform the same exercise for the variable inspection parameter α. Here the higher α, the higher social welfare will be. However, increasing the variable inspection parameter from 0.4 to 0.5 improves social welfare by 5 million Euro, while increasing α from 0.5 to 1 additionally increases welfare by only 92 000 Euro. We also see that improving the parameter α from 0.1 to 0.2 increases social welfare by approximately 31.5 million Euro.

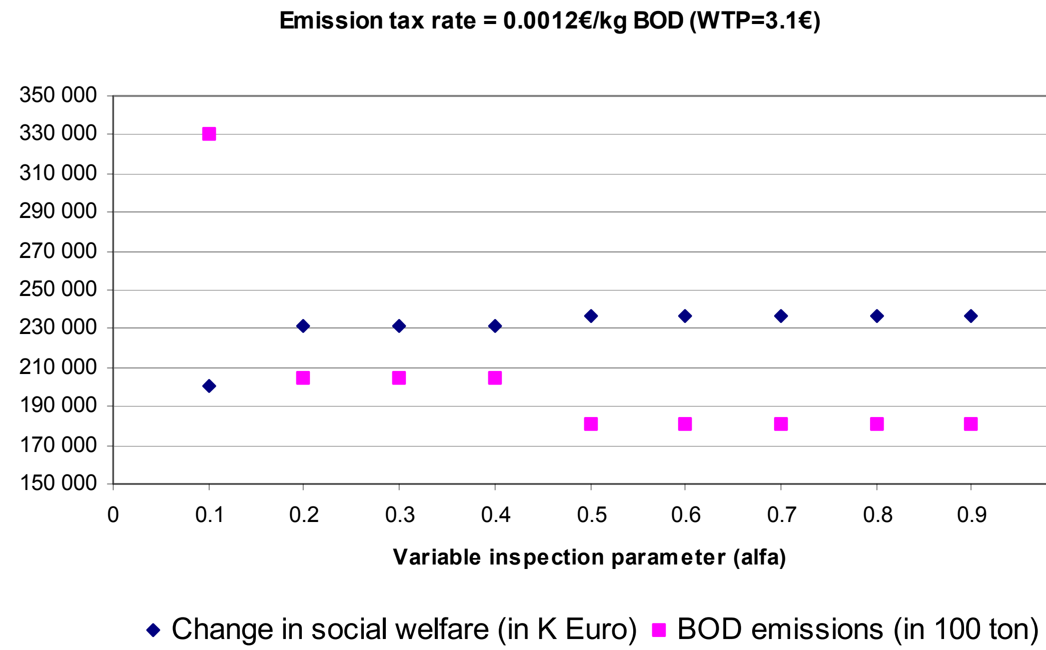

Figure 8

Tests have shown us that both inspection parameters (fixed inspection frequency and variable inspection parameter) influence each other. In order to optimise the inspection policy, government will have to fix both parameters simultaneously. This surely is an exercise worth doing since welfare can increase considerably.

Finally we perform the same exercise for the penalty parameter π_{et}. One immediately sees that the penalty greatly influences the outcome: resulting emissions range from 37,1 million to 18,1 million ton BOD. Welfare levels range form 5 million to 237 million Euro. The penalty can be used as substitute for a higher tax up to a certain point. Manipulating the penalty cannot achieve the same emission reduction as manipulating the tax rate beyond the limit of 18.1 million ton BOD for this specification.

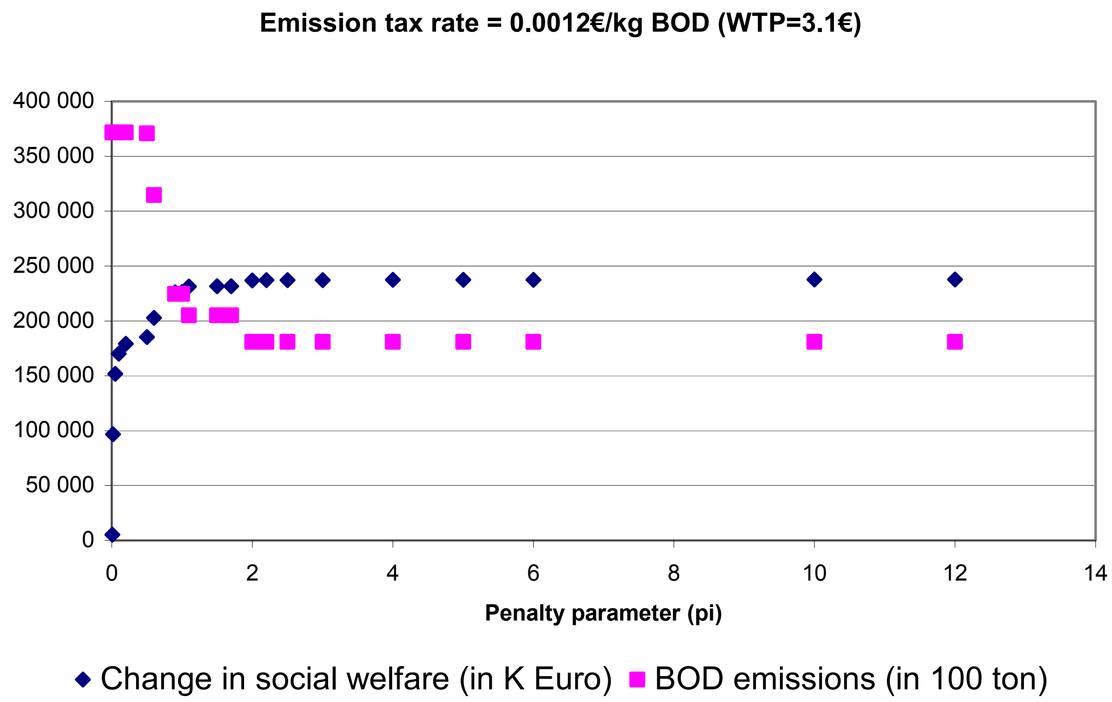

Figure 9

We also find that it does not pay to increase the penalty parameter above 10. Both social welfare and BOD emissions have then reached their optimum and do not change anymore.0

V. CONCLUSION

The global welfare functions associated with each regulatory chain lead us to six key observations.

1. First, the technology standard turns out to be an extremely limited instrument. This instrument can only reach as many levels of emission reductions as there are abatement technologies and the obtained result is highly sensitive to changes in the monitoring and enforcement parameters.
2. Identifying the instrument that leads to the highest welfare level was less clear-cut. The welfare curves for emission standard and emission tax cross each other. We can nevertheless say that an emission tax is less costly than an emission standard for most of the emission reduction levels. Only for minor reductions we find that an emission standard outperforms an emission tax. These

results are also sensitive to changes in the monitoring and enforcement parameters and to the emission tax procedure used in Belgian environmental law.

3. Further we compared three different versions of the emission and technology standard. Adding an authorising notification duty to a standard only minimally increases the associated costs. Including the standard in a license system, on the contrary, markedly increases costs.
4. The criminal fine is by far the most expensive sanctioning instrument to use and, as could be expected, the transaction offer is the cheapest to use. However, in reality these three instruments are often used as complements. For minor violations or first time offenders, a transaction offer will often suffice. A criminal fine will be used for serious violations or extremely uncooperative firms. The administrative fine also has its specific use. Therefore we cannot a priori choose one of the enforcement instruments as being *'the best'*.
5. Sensitivity analysis shows that the results are – in certain aspects - highly sensitive to the differences in the willingness to pay (WTP) for water quality improvements. The higher the WTP for the improvement in environmental quality, the more it pays to pursue an environmental policy even if emissions are only minimally reduced. Remarkably the changes in WTP do not influence the relative position of the different instruments.
6. Sensitivity analysis with respect to the enforcement parameters (fixed inspection probability, coefficient of the variable inspection probability and the penalty coefficient) shows their immense importance. Choosing the optimal level of the parameters is crucial to the decision of the appropriateness of environmental regulation. Changing the level of the parameters can suddenly make a policy worthwhile pursuing.

In conclusion we can say that adding a detailed identification and estimation of information, monitoring and enforcement costs linked to an environmental policy, can greatly change traditional results with respect to the relative efficiency of instruments. Our numerical illustration proves this point by showing how an emission tax can be the most expensive instrument to use in order to obtain a particular level of environmental quality. This result holds even if we include heterogeneity of the industry into our model.

Moreover we have also shown that it is important to use a correct estimate of the willingness to pay for environmental quality improvements but that it is even more important to formulate an appropriate monitoring and enforcement policy. The decision of whether to pursue an environmental policy or not depends on it.

APPENDIX A – Notation

TC_i	Total costs for firm i
AC_{ij}	Costs of implementing technology j for firm i
A_i	Total abatement costs for firm i
$IC_{f/h/g}$	Implementation costs of firms/ households/ government
$EC_{f/h/g}$	Prosecution and sanctioning costs of firms/ households/ government
$\overline{EC}_{f/g}$	Inspection costs for firms/government
$RC_{f/h/g}$	Rule making costs of firms/ households/ government

p_i	Probability of detection of firm i
F_i	Fine of firm i
y_{Fi}	0/1 variable – indicates whether a firm would receive a fine or not
y_{ij}	0/1 variable – indicates whether firm i uses technology j or not
y_{Fio}	0/1 variable – indicates whether firm i would receive a fine if it did not abate
y_{Fij}	0/1 variable – indicates whether firm i would receive a fine if it installed technology j
$\pi_{es/et/ts}$	Penalty parameter associated with emission standard/ emission tax/ technology standard
E_i	Actual emissions of firm i
E_i^R	Reported emissions of firm i
EA_i	Abated emissions of firm i
$\overline{E}$	Emission norm
Eab_{ij}	Potential emission reduction if technology j is used by firm i
E_i^o	Initial emissions by firm i
D_{ij}	Help parameter for making abatement decision
SW	Social welfare
CS	Consumer surplus
PS	Producer surplus
EQ	Environmental quality
WTP	Willingness to pay for an improvement
$MCPF$	Marginal cost of public funds

APPENDIX B – Abatement cost estimates

To guarantee anonymity of the participating firms we did not explicitly name technologies and firms.

Firm	Technology	NPV (in €)	BOD	COD[19]	Other chemicals	Water
A	T1	3 168 402		X	caprolactam	
	T2	354 113				
B	T1	1 051 470	X	X		
	T3	24 789			Latex	
	T4	12 394 676				X

[19] Chemical oxygen demand

	T5	9 916				X
C	T6	191 326				X
D	T7	1 859 201	X	X	N, Zn, Ni, Cr	
	T8	371 840		X	metals, salts, colour	
	T9	421 419		X	metals, salts, colour	
E	T10	49 579				X
	T5	718 891				
	T11	463 395	(X)[20]	(X)		
F	T13	1 983				X
	T12	-111 159	(X)	(X)	Latex	
H	T13	2 220				X
	T14	20 035				
	T15	103 650	X	X		
	T12	133 570	X	X		
	T16	10 018				X
	T17	80 142	(X)	(X)		
	T18	66 785				X
I	T23	339 823			SS	
J	T24	294 459				X
	T13	5 404				X
	T18	49579				X
	T25	3 470 509				X
	T26	1 611 308				X
	T12	594 944	X	X		
	T19	1 363 414	(X)	(X)	(Metals, SS)	
K	T1	4 719 663	X	X	N, Ni	
	T12	*495 787*[21]	(X)	(X)		
L	T1	1 090 393	X	X	SS	
	T21	347 051	(X)	(X)		
M	T3	358 869	X	X	SS, Zn	
	T20	9 916				
	T27	-21 625			SS, Zn	
	T11	*495 787*	X	X	SS, Zn	
	T28	19 794				X
N	T13	4 958				X
	T19	371 840	(X)	(X)	(Metals, SS)	
	T12	88 081	(X)	(X)		
O	T29	123 947			Fibres	
	T3	1 050 737			Fibres, latex	
	T22	366 512			Inputs	X
	T13	992				X
	T23	149 000			Inputs	X
P	T1	2 133 371	X	X	SS, N, F, Metals	
	T18	47 959				X

[20] (.) = estimate, not based on data obtained from that firm but analogue to other companies
[21] ___ = estimate of costs analogue to other companies

	T30	495 787				X
R	T3	1 687 658		X	Zn, Mangaan	
S	T31	12 870			latex	X
T	T32	-75 618	(X)	(X)		
	T33	199 346				
U	T11	37 184	(X)	X		
	T19	1 041 153	X	X	(Metals, SS)	
	T16	195 787				X
V	T34	71 702				

APPENDIX C - Rule-making, implementation and enforcement costs associated with an emission tax.

Emission tax[22]	Firm			Households			Government		
	RC	IC	EC	RC	IC	EC	RC	IC	EC
Technicity	1d participation	8d info realisation, technology	2d contra analysis	1/2d participation			12d state of the art		
Knowability			1d proof						1d[23] control samples
Procedure		3d administration	4d[24] appeal				1d procedure	3d administration	4d appeal
Juridical Formalisation							XXL[25]		
Time profile		5d Self-control	1d accompanying, certified expert					2d inning	
Administrative Partner									
Flexibility		4d info, negotiation, strategy						1d negotiation	

[22] The declaration of the tax is not taken into account. It is captured in the notification duty.
[23] Control and enforcement are difficult to implement since one has to work backward in time (for the past year).
[24] We assume that firms go into appeal once every three years and that this takes them 12 days per appeal.
[25] Less in volume than license system but needs the Flemish parliament more often.

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