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Instant Efficient Pollution Abatement Under Non-Linear Taxation and Asymmetric Information: The Differential Tax Revisited

Summary

This paper analyzes incentives for polluting firms to exchange abatement cost information under the non-linear pollution tax scheme ('differential tax') introduced by Kim and Chang [J. Regul. Econom. 5, 1993, 193-197]. It shows that polluting firms have - under mild conditions - an incentive to join a coalition whose members mutually truthfully exchange information as well as commit themselves with respect to their abatement decisions. As a result, the differential tax triggers instantly - i.e. no abatement adaptation is needed – efficient abatement levels without the regulator knowing marginal abatement costs. Consequently, this paper shows that differential taxation results in lower social costs than traditional non-linear taxation which triggers efficient emissions only after a period of non-efficient abatement.

Keywords: Externalities, Pollution taxes, Coalition formation, Non-linear taxation, Asymmetric information, Co-operative game theory

JEL Classification: C71, D62, D82, Q20

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1 Introduction

To minimize social costs in the presence of environmental pollution, one option a regulator has to internalize externalities is through pollution taxation. To be able to set the correct emission tax, however, this regulator should know (future) abatement costs across industries. Unfortunately, polluters have in general no incentive to reveal their true abatement costs - Kwerel (1977) and Dasgupta et al. (1980) dealt with this issue - or just do not know them yet due to uncertainty about future innovation options available

Non-linear taxation has been suggested as one solution in cases where marginal abatement costs are not known by the regulator (Kim and Chang, 1993; Kaplow and Shavell, 2002). Under non-linear taxation the marginal tax level is a function of aggregated emissions and mimics marginal damages, doing potentially a better job in equalizing marginal abatement and marginal damage costs than standard (linear) taxation with its constant marginal tax level. Unfortunately, the problem has not been solved how potential polluters should resolve the uncertainty with respect to emissions of other firms - emissions that determine the tax level under a non-linear taxation scheme. If abatement decisions involve sunk costs or take time to be implemented this uncertainty will lead to inefficiencies because firms will not or only at high costs be able to pollute instantly at the socially optimal level.

Several attempts were made to guide the polluting firms to the efficient emission level in the presence of non-linear taxation under asymmetric information. These included (*i*) a tax adjustment rule that automatically changes the tax level as a function of actual emissions, resulting - after an unspecified period of time - in the socially efficient emission level[1] (Karp and Livernois, 1994), (*ii*) firm commitment to the reported

[1]Under the condition that firms behave non-strategically. If they behave strategically there is a trade-off between speed of convergence of the tax level and its efficiency in equilibrium.

abatement costs to prevent excessive under-reporting of abatement costs leading to better forecasts of the emission and tax level (Bulckaen, 1997), and (*iii*) abatement based on conjectures about emissions by other firms (McKitrick, 1999). In the latter paper, McKitrick proved that the simple non-linear 'differential tax' suggested by Kim and Chang (1993) triggers the socially optimal level of pollution in the long run, without the regulator knowing marginal abatement costs. 'Long run' refers to the time that it takes for firms to sequentially adapt their abatement decisions - based on conjectures with respect to emissions by other firms - until the socially optimal emission level is reached.

This paper analyzes incentives for firms to form coalitions to exchange information with respect to their abatement behavior under the above-mentioned 'differential tax' and discusses the welfare effects of this coalition formation. In game-theoretic terms: the paper analyzes the welfare effects of a cooperative game with asymmetric information that is the result of the announcement of a differential pollution tax (Allen, 1997). A prominent role in the analysis plays the commitment to announced abatement behavior as was originally suggested by Bulckaen (1997).

Section 2 introduces the model. Section 3 and section 4 present the results on information exchange and coalition formation respectively. Section 5 concludes with a discussion.

2 The model

Total emissions E of an environmental pollutant causes in monetary terms quantifiable damages $D(E)$, with $D'(E) > 0$ and $D''(E) > 0$. Set I represents the set of n polluting firms, and the firms in I have the opportunity to reduce emissions, but face abatement costs $C_i(e_i)$, where e_i is the emission level of firm i, with $C_i(e_i) > 0$ if and only if $0 < e_i < e_{max}$; $C_i'(e_i) < 0$; and $C_i''(e_i) > 0$. Emissions of the polluting firms sum up to

$E = \sum_{i \in I} e_i$. The firms are not flexible with respect to their abatement level in the sense that they cannot - or only at high costs - change emissions immediately and therefore have to decide on the emission abatement level one period before the actual emissions take place.

The regulator does not know the abatement costs of the firms. Firm i does not know the abatement costs of firm j either, but has at least some subjective expectation of the emission which is denoted by $\hat{e}^i_j$.[2]

The regulator's aim is to minimize social costs, i.e. minimize $\sum_{i \in I} C_i(e_i) + D(\sum_{i \in I} e_i)$. The social optimum, therefore, is characterized by the first order conditions:

$$-\frac{\partial C(e_i)}{\partial e_i} = \frac{\partial D(\sum_{i \in I} e_i)}{\partial e_i} \quad \forall i \in I \tag{1}$$

Let $e^*_1, ..., e^*_n$ be the socially efficient emission levels that solve equation system 1 and let $E^* = \sum_{i \in I} e^*_i$. As in McKitrick (1999, p.356) the standard Cournot assumption is employed that firms do not believe their abatement decision will simultaneously change other firms' emission levels.[3]

Following Kim and Chang (1993) and McKitrick (1999) we assume that the regulator announces it will levy a charge of $D(E) - D(E - e_i)$ on firm i's emission e_i. The rationale of this tax is that the marginal emission tax paid by firm i is always equal to

[2]One might consider to specify $\hat{e}^i_j$ properly, for example by introducing explicit stochastics in the model: firm i does not know the vector θ_j, $j \neq i$, that determines the abatement costs firm j. It does know, however, a distribution of stochastic vector θ_j, and developed - based on that knowledge - a subjective expectation of the emissions of firm j denoted by $\hat{e}^i_j$ given a particular policy. In my view this would make the analysis in thus paper unnecessarily complex and less general and would therefore distract from its quintessence.

[3]Because this assumption also underlies the analysis in McKitrick (1999), the results derived in this paper are as general as they are in McKitrick (1999).

marginal damage costs, thereby minimizing social costs.[4]. The announcement of the differential tax scheme is assumed to be made prior to any abatement decision of the firms.

To analyze what will happen after this announcement, we first introduce the *emission reaction commitment contract*. This contract is crucial for the rest of the analysis.

Definition 1 *An 'emission reaction commitment contract' between members of coalition*[5] $S \subseteq I$ *is a contract where firm* $j \in S$ *commits itself to an emission reaction function* $e_j^S(E_j^S)$.

If firm j signed the above mentioned contract we will say 'firm j committed itself to emission reaction curve $e_j^S(\cdot\ )$'. By means of this emission reaction commitment contract each firm in the coalition commits itself to an endogenous abatement effort: by signing the emission reaction commitment contract the firm commits itself to emit $e_j^S(\tilde{E}_j^S)$, where $\tilde{E}_j^S = \tilde{E}^S - \tilde{e}_j^S$ and $\{\tilde{E}^S, \{\tilde{e}_j^S | j \in S\}\}$ is the solution of the equation system

$$e_i^S = e_i^S(E_i^S), \forall i \in S \tag{2}$$

$$E^S = \sum_{i \in S} e_i^S \tag{3}$$

$$E_i^S = E^S - e_i^S \tag{4}$$

From Brouwers fixed point theorem it directly follows that there exists a solution $\{\tilde{e}_j | j \in S\}$ of equations 2-4 as long as emissions are bounded and the functions $e_j^S(\ \cdot\ )$ are continuous.[6] Neither of these assumptions seem to be over-restrictive. Moreover, if

[4]Moreover, the total tax burden for each individual firm is smaller than under linear taxation as was pointed out by McKitrick (1999)

[5]In this section we will - for the time being - assume such a coalition is given. In section 4 we will deal with the question how such a coalition is formed.

[6]Conditions for uniqueness of the solution will be discussed in the context of theorem 4.

the firms in S would found a body that calculates $\tilde{E}^S$ there would be no need for the firms to provide the other firms in S with their reaction curves which might contain strategic information. As a result, these commitments together establish the actual abatement efforts of the firms in S: firm $i \in S$ will emit $\tilde{e}_i^S$. Now two questions can be asked: *i*) What is the best emission reaction function a firm can commit itself to if it would sign such a contract? And *ii*), will it be attractive for a firm to sign the contract? In other words, is it attractive for a firm to join the coalition? The first question is answered in section 3. The second question will be dealt with in section 4.

3 Commitment and information exchange

Let $\hat{E}_j^{\bar{S}}$ be the subjective expectation of firm j with respect to the emissions of firms $i \in \bar{S}$, where $\bar{S} = I \setminus S$ and $i \neq j$. That is, $\hat{E}_j^{\bar{S}}$ is the subjective expectation of firm j with respect to the emissions of the firms outside the coalition.

Theorem 2 *Suppose firms $j \in S$, with $j \neq i$, committed themselves to reaction curves $e_j^S(E_j^S)$ respectively. Then for firm $i \in S$, given subjective emission expectations $\hat{E}_i^{\bar{S}}$, the best reaction function to commit to is*

$$e_i^S(E_i^S) = \arg\min\{C(e_i) + D(\hat{E}_i^{\bar{S}} + E_i^S + e_i) - D(\hat{E}_i^{\bar{S}} + E_i^S)\}.$$

Proof: Theorem 2 follows directly from the definition of the operator *arg min* which generates the emission decision that minimizes the costs of the firm given the tax scheme and the subjective emission expectation.[7]

[7]Here the assumption that firms do not believe their abatement decision will simultaneously change other firms' emission levels is crucial.

Corollary 3 *Suppose firms $j \in I$ with $j \neq i$ committed themselves to reaction curves $e_j^I(E_j^I)$ respectively. Then for firm i there is no better reaction function to commit to then $e_i^I(E_i^I) = \arg\min\{C(e_i) + D(E_i^I + e_i) - D(E_i^I)\}$.*

Corollary 3 follows directly from theorem 2 by selecting $S = I$. Given these reaction curves, there is good reason to believe the firms can find the solution $\{\tilde{e}_j^I | j \in I\}$ of equations 2 and 3: emulating the adjustment rule suggested by McKitrick (1999) meant for *long run adaptation* by means of an algorithm that converges to the fixed point, the firms in I can find $\{\tilde{e}_j^I | j \in I\}$ directly and will behave accordingly. We are now ready to address the welfare consequences of corollary 3, i.e. the welfare aspects of $\{\tilde{e}_j^I | j \in I\}$:

Theorem 4 *If firms $i \in I$ commit to reaction curves $e_i^I(E_i^I) = \arg\min\{C(e_i)+D(E_i^I + e_i) - D(E_i^I)\}$, then $\tilde{e}_i = e_i^*$ for all i, and therefore $\tilde{E}^I = E^*$. That is, all firms will emit at the social optimal level.*

Proof: If $\tilde{E}_i^I$ is the realized total emission level of all firms except i, the emission level firm i committed itself to, $e_i^I(\tilde{E}_i^I) = \arg\min\{C(e_i) + D(\tilde{E}_i^I + e_i) - D(\tilde{E}_i^I)\}$, satisfies the first order conditions in equation 1 by virtue of the *arg min* operator. This of course holds for all $i \in I$. Consequently, it follows from equations 3 and 4 that $\tilde{E}^I - \tilde{e}_i^I = \tilde{E}_i^I$ indeed is the emission level of all firms expect i. Which proves the theorem.[8] By combining corollary 3 and theorem 4 we find that if all firms would sign the most attractive emission reaction commitment contract from their point of view, this would

[8]This theorem is closely related to proposition 3 in McKitrick (1999). Theorem 4 also gives a clue with respect to uniqueness of the solution of equations 2-4: If $S = I$ and if $(e_1^*, ..., e_n^*)$ is unique, then the solution of the equations 2-4 must also be unique. A socially optimal emissions vector $(e_1^*, ..., e_n^*)$ itself is unique under the assumptions with respect to the derivatives of $C(e_i)$ and $D(E)$ as formulated in section 2.

result in the efficient emission level. From the point of view of the regulator it seems to be very attractive if all firms would sign a contract like that. So the question is: do firms have an incentive to sign a contract like that? I.e. under what circumstance will they join the coalition? We will deal with that question in the following section.

4 Coalition formation

With the question whether firms have an incentive to join the coalition we enter the field of cooperative game theory.

4.1 Coalition formation: cooperative games with asymmetric information

In section 3 we implicitly defined a cooperative game with asymmetric information, where the pay-off from joining a coalition is equal to the abatement cost reduction plus the tax burden reduction resulting from mutual information exchange and commitment (e.g. Mas-Colell et al., 1995; Allen, 1997; Schwalbe, 1999).

Though the abatement cost and tax burden reduction resulting from mutual information exchange and commitment can easily be shared among members of a coalition, we will analyze the incentives for firms to join a coalition in the absence of transfers. The reason for that is that the cost and tax burden reductions depend on subjective ex ante emission estimates. As a result, measures of individual contributions to the collective cost reduction effort - like Shapley values - can neither ex-ante nor ex-post be determined unambiguously, which makes agreements with respect to ex-post transfers very unlikely. Consequently, we implicitly interpret the game as a cooperative game with asymmetric information and non-transferable utility (Allen, 1997).

Within the coalition information is shared completely among coalition members. This characteristic of coalition formation within a cooperative game with asymmetric information was first described as *full communication system* in the seminal paper by Wilson (1978, p.807). The fundamental difference with the set-up in Wilson (1978) is that in this paper - as argued above - the assumption is adopted that no transfers can be agreed upon. So only information is shared among coalition members. Due to the special characteristics of the good 'information' compared with traditional goods - information cannot be returned if one is not satisfied, i.e. one cannot be forced to forget (e.g. Hirshlifer and Riley, 1992, section 5.2) - the relevance of concepts like 'core' and 'blocking' seem to be limited in our application: once a firm is in the coalition and found out about the value of the information good there is no way it could leave the coalition and form another coalition.

Unaware of a rigorous and applicable treatment of this special form of game[9], I will take an intuitive approach to analyze the incentives for coalition formation in the following of this section.

4.2 Coalition formation: an intuitive approach

By joining S, firm i gets reliable information on the individual reaction functions and abatement decisions of the members of S and therefore has better information about the future total emission level and the future marginal tax level it will face. As a result, one would expect firm i to do a better job in minimizing the sum of reduction costs and tax payments if it joins the coalition.

Following the same reasoning, one would believe that members of the coalition would always welcome a new member: if firm i joins S, members of the coalition will get reliable information with respect to the abatement decision of firm i, and therefore will

[9] Suggestions will be welcomed by the author.

be better able to anticipate the marginal tax level. Reality, unfortunately, turns out to be slightly more complex.

The following theorem answers the question what exactly makes it attractive or unattractive for a firm to join the coalition:

Lemma 5 *If firms $j \in S \subseteq I$ committed themselves to $e_j^S(E_j^S)$, then firm i joining the coalition - thereby forming the new coalition $S' = S \cup \{i\}$ - would be confronted with two effects on its costs:* 1*) an effect caused by adapting its own abatement decision after receiving correct information on emission decisions of the members of the coalition, and* 2*) an effect caused by changing abatement behavior of the firms in the coalition after they received the correct information on the emission decision by firm i.*

Proof: Let $\hat{e}_i^S$ be the emission decision by firm i if it does not join the coalition, and let $\tilde{e}_i^{S'}$ be the emission decision by firm i when it does:

$$\hat{e}_i^S = \arg\min\{C_i(\hat{e}_i^S) + D(\hat{E}_i^{\bar{S}} + \hat{E}_i^S + \hat{e}_i^S) - D(\hat{E}_i^{\bar{S}} + \hat{E}_i^S)\} \tag{5}$$

$$\tilde{e}_i^{S'} = \arg\min\{C_i(\tilde{e}_i^{S'}) + D(\hat{E}_i^{\bar{S}'} + \tilde{E}_i^{S'} + \tilde{e}_i^{S'}) - D(\hat{E}_i^{\bar{S}'} + \tilde{E}_i^{S'})\} \tag{6}$$

Now let ${}^R E_i^{\bar{S}}$ be the *realized* emissions of the firms in $\bar{S}$ after the tax system has been introduced, and let $K_i^S(\,\cdot\,)$ be the abatement plus tax costs that firm i has to pay if a coalition S was formed. Then if firm i did not join the coalition its costs would be:

$$K_i^S(\hat{e}_i^S) = C_i(\hat{e}_i^S) + D({}^R E_i^{\bar{S}} + \tilde{E}_i^S + \hat{e}_i^S) - D({}^R E_i^{\bar{S}} + \tilde{E}_i^S).$$

If firm i joined the coalition its costs will be:

$$K_i^{S'}(\tilde{e}_i^{S'}) = C_i(\tilde{e}_i^{S'}) + D({}^R E_i^{\bar{S}'} + \tilde{E}_i^{S'} + \tilde{e}_i^{S'}) - D({}^R E_i^{\bar{S}'} + \tilde{E}_i^{S'}).$$

So firm i gains from joining the coalition if $K_i^S(\hat{e}_i^S) - K_i^{S'}(\tilde{e}_i^{S'})$ is positive. This difference can be decomposed into two terms:

$$K_i^S(\hat{e}_i^S) - K_i^{S'}(\tilde{e}_i^{S'}) = K_i^S(\hat{e}_i^S) + [K_i^S(\tilde{e}_i^S) - K_i^S(\tilde{e}_i^S)] - K_i^{S'}(\tilde{e}_i^{S'}) \tag{7}$$

$$= \underbrace{[K_i^S(\hat{e}_i^S) - K_i^S(\tilde{e}_i^S)]}_{\alpha} + \underbrace{[K_i^S(\tilde{e}_i^S) - K_i^{S'}(\tilde{e}_i^{S'})]}_{\beta} \tag{8}$$

Equation 8 reveals two effects:

Effect α This is the cost change resulting from firm i having more information on the emission decisions of the firms in the coalition.

Effect β This is the cost change resulting from an adaptation of the emission decisions by the firms in the coalition.

End of proof.

Under standard second order conditions the cost change caused by Effect α will be positive (i.e. joining the coalition reduces abatement costs plus tax costs) if $\hat{E}_i^{\bar{S}} + \tilde{E}_i^S$ is closer to ${}^R E_i^{\bar{S}} + \tilde{E}_i^S$ than $\hat{E}_i^{\bar{S}} + \hat{E}_i^S$. That is, when joining the coalition leads to a more realistic estimation of total emissions. This will be the case in general, because firm i after joining the coalition will have perfect information with respect to emissions of the firms in S, in stead of its subjective estimate.

The sign of Effect β, however, is ex ante less clear. It will be negative if the firms in the coalition raise their emissions after finding out about the reaction function of firm i, i.e. when they found out - after i joined the coalition - that they over-estimated firm i's emissions. This effect will be close to zero if the errors of the firms in S with respect the emission decision by firm i level each other more or less out.

Under assumption 6 firm i will join the coalition:

Assumption 6 *Firm $i \notin S$ believes the cost reducing Effect α is larger than its (potentially cost raising) Effect β.*

In general one would expect that assumption 6 is satisfied: the larger the summed emissions of the members of S are relative to those of the individual firm i, the larger Effect α will be relative to Effect β. Moreover, the less successful firm i is in suggesting his marginal emission reduction costs will be higher than they actually are, the less positive will Effect β be. In the situation at hand it seems difficult for firm i to deceit structurally, because firms - inside and outside the coalition - expect it to cheat and therefore will for example base their subjective expectations on independently reported data, not on those provided by firm i.

Now we turn to the question in what circumstances individual members of the coalition would gain from firm i joining the coalition.

Lemma 7 *Member j of coalition S is confronted with two effects when firm $i \notin S$ joins the coalition, thereby forming the new coalition $S' = S \cup \{i\}$: 1) an effect through adaptation of the abatement decision of j itself, originating from receiving correct information on abatement behavior of firm i, and 2) an effect through adaptation of the behavior of the other firms due to new information on behavior of firm i.*

Proof: Let us define e_j^* as follows:

$$e_j^* := \arg\min\{C_j(e_j) + D(\hat{E}_j^{\bar{S}} - \hat{e}_i^S + \tilde{e}_i^S + \tilde{E}_j^S + e_j) - D(\hat{E}_j^{\bar{S}} - \hat{e}_i^S + \tilde{e}_i^S + \tilde{E}_j^S)\}.$$

The net reduction in costs for a firm $j \in S$ resulting from firm i joining the coalition is equal to

$$K_j^S(\tilde{e}_j^S) - K_j^{S'}(\tilde{e}_j^{S'}) = K_j^S(\tilde{e}_j^S) + [K_j^S(e_j^*) - K_j^S(e_j^*)] - K_j^{S'}(\tilde{e}_j^{S'}) \tag{9}$$

$$= \underbrace{[K_j^S(\tilde{e}_j^S) - K_j^S(e_j^*)]}_{\text{Effect } a} + \underbrace{[K_j^S(e_j^*) - K_j^{S'}(\tilde{e}_j^{S'})]}_{\text{Effect } b} \tag{10}$$

Effect a. Effect a is the cost change caused by adaptation of the abatement decision by firm j after receiving reliable information on the abatement decision of firm i.

Effect b. Effect b is the cost change caused by adaptation of the other firms in the coalition due to reception of information on the abatement decision of firm i.

End of proof.

If $\hat{E}_j^{\bar{S}} - \hat{e}_i^S + \tilde{e}_i^S + \tilde{E}_j^S + e_j$ is closer to ${}^R E_i^{\bar{S}} + \tilde{E}_i^S$ than $\hat{E}_i^{\bar{S}} + \hat{E}_i^S$, then the first effect will have a downward effect on the costs of firm j. If knowledge of the true emission level of firm i is closer to the realized emission level, then Effect α will lower the cost. This will in general be the case. Because the sign of the second effect is unclear, it is to be expected - if systematic deception fails - firms in the coalition gain from new members entering the coalition.

We will formulate this as an assumption:

Assumption 8 *Firms $j \in S$ believe the negative Effect a on their costs to be larger than the (potentially positive) Effect b.*

Summarizing the results of our analysis in this section so far: in general one can say firms will be inclined to form 'information exchange and commitment coalitions' if the value of the information with respect to the true emission decisions by the other firms is higher than the lower tax payment and reduction costs caused by successful deception of the other firms. The latter ability is likely to be affected by the distrust by the other firms who are aware of this attitude, making joining the coalition more sensible for individual firms.

We are now ready to formulate the main result of this paper:

Theorem 9 *If*

- *information exchange and legal services are relatively cheap, and*
- *firms do not believe their abatement decisions will simultaneously change other firms' emission levels, and*
- *assumptions 6 and 8 hold,*

then the announcement of tax level $D(E) - D(E_i)$ for firms $i \in I$, an announcement preceding abatement decisions of the firms, automatically results in a the socially efficient abatement level through the formation of a coalition consisting of all firms that exchange and commit themselves to emission reaction curves.

Proof: Theorem 9 follows directly from corollary 3, theorem 4, and lemmas 5 and 7.

If the firms are made aware of this mechanism they might as well start committing to reaction curves with respect to the largest possible coalition I, instead of starting with small coalitions. This would reduce the total sum of transaction costs to only a fraction of the original costs. This observation makes the first condition in theorem 9 less stringent. Please note also that the standard Cournot assumption (the second condition in theorem 9) gets more realistic the more polluting firms there are.

5 Conclusions and discussion

Kim and Chang (1993) showed that the Nash equilibrium resulting from the implementation of a simple non-linear 'differential pollution tax' is socially efficient without the regulator knowing marginal abatement costs. This equilibrium will, however, only be attained if firms know the emissions of other firms and can costless adapt to abatement decisions by other firms. This seems to be restrictive because usually abatement decisions involve sunk costs or take time to be implemented.

McKitrick (1999) addressed this problem and showed that under the 'differential pollution tax' suggested by Kim and Chang (1993), firms might follow a clever abatement adaptation strategy, and will - by sequentially adapting their emission levels - eventually emit the socially optimal amount. As a result, McKitrick concluded that the 'differential tax' triggers the socially efficient emission level *in the long run*, where 'long run' refers to the fact that it takes several abatement adaptation decisions by the firm to reach the socially efficient emission level.

In this paper it was shown that in the presence of the 'differential tax'

- firms will emit at the socially efficient level if they are member of a coalition of firms that mutually exchange information with respect to their future abatement decisions and committed themselves to act accordingly, and
- firms have - under mild conditions - an incentive to join the coalition of firms that exchange information and commit themselves to act accordingly.

These results hold under the condition that firms assume they cannot influence the emission of other firms by means of their emission decision - the standard Cournot assumption that is not unreasonable in case of many polluting firms. As a result, the 'differential pollution tax' suggested by Kim and Chang (1993) leads *instantly* - i.e. without abatement adaptation - to efficient abatement levels, without any information requirement for the regulator.

Consequently, the differential pollution tax leads to lower social costs than traditional non-linear pollution taxation adaptation schemes that only reach the efficient emission levels after an usually unspecified period of time in which firms adapt their emissions to new tax levels until an equilibrium is reached. During this period marginal abatement costs are not equal to marginal damage costs which results in higher social costs than under the differential tax scheme that reduces social costs to the theoretical minimum instantly.

This result suggests that the differential tax should play a major role in the analysis of environmental policy instruments when (future) abatement costs are uncertain, for example in the presence of innovation with respect to pollution reducing technologies.

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(lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002
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(lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003
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(lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

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