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Time Consistency and Investment Incentives in Environmental Policy

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Abstract. We study environmental policy for a polluting firm that can invest in extra capacity. The optimal levels of allowed output as well as the tax rate are increasing in investment. With divisible investment, commitment always leads to the first best, under direct regulation and taxation. Time-consistent policy results in overinvestment with direct regulation and underinvestment with taxation. With indivisible investment and direct regulation, commitment leads to the first best. With taxation however, commitment may not lead to the first best and time consistency can lead to higher welfare. This remarkable result occurs because the firm can influence the tax rate.

JEL Classification: D62, Q28

Key words: Environmental policy, instruments, commitment, time consistency

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1 Introduction

Many government policies are effective only if the government can credibly commit. Take for instance the Dutch government's policy to contain aircraft noise from Schiphol airport in the 1990s. The airport was given an annual noise quota, but it chose to schedule so many flights that it had consumed this quota by October. Compliance would imply shutting down the airport for the rest of the year, which was clearly not a credible option. In the end, the government would tolerate Schiphol's violation of the noise limits.

The example suggests that when the government cannot commit to regulation that directly or indirectly limits a firm's size, the firm will grow faster than the government would like. When the government cannot commit, the firm knows that the government will set more lenient regulation after the firm has invested in extra capacity. The firm may then invest just to obtain more lenient regulation.

We shall see in this paper that when the government can commit to strict output regulation, the firm will make the socially optimal investment decision. With time-consistent policy, however, there will be overinvestment. This holds for investment of continuously variable as well as of fixed size.

This result leads us to ask two questions. First, what can the government do if it cannot reach the first best with direct regulation? In this paper, we shall look at the options of directly regulating the investment and choosing a different instrument. This brings us to the second question: Do similar problems exist with the alternative instrument of taxation? Our paper thus fits into the long tradition of comparing price and quantity instruments for environmental policy (Weitzman (1974), Hoel (1998)).

We find that with divisible investment, the government can reach the first best with taxation as well. Time-consistent policy now results in underinvestment. The firm will invest less in order to reduce the tax rate.

When the investment is of fixed size, however, the government can no longer reach the first best with taxation. The firm may invest when it should not, or it may not invest when it should. Whereas the former problem has not been noted before in the literature, the latter problem has received quite a lot of attention. Rose-Ackerman (1973) was the first to note that a firm may not make a socially desirable investment under environmental taxation, because with increasing marginal damage, the tax bill exceeds social cost. In order to reach the first best in these circumstances, Collinge and Oates (1982) have proposed a rental emission permit scheme. On the other hand, Schulze and D'Arge (1974) and Spulber (1985) have shown that a tax rate equal to marginal damage will result in the efficient number of firms. However, this optimality result is irrelevant when we look at one indivisible firm or an indivisible investment.

Given that with taxation and indivisble investment, neither commitment nor time consistency always yields the first best, it is unclear a priori which regime is best for social welfare. In fact, as we shall see, there are cases where time consistency actually improves upon commitment.

It is worthwhile to study this outcome more closely, since from its inception by Kydland and Prescott (1977) and Fischer (1980), the literature has almost unanimously found that with perfect information, commitment is always at least as good as time consistency.[1] But as Dijkstra (2002) shows, this is not a universal truth. There are two sufficient conditions under which commitment is better than time consistency. The first condition is when commitment leads to the first best. This will happen when the government has enough instruments to handle all the distortions or when an agent's action only affects his own payoff. In the present paper, the former is true with divisible investment and the latter holds with indivisible investment and direct regulation.

Even when commitment does not implement the first best, it can still be better than time consistency. The second sufficient condition is that agents cannot influence time consistent policy. The government then has the option to "commit" to the time consistent policy. This condition holds in macroeconomic policy settings, where each individual agent is too small to influence government policy. This is the setting in which time consistency has mostly been analyzed so far. However, in the present paper, there

[1] The analysis has been applied to trade policy by a.o. Tornell (1991), Leidy (1994) and Leahy and Neary (1999), and to environmental policy by Malik (1991), Kennedy and Laplante (1999) and Gersbach and Glazer (1999). Obviously, when information is revealed in the course of the game, the advantage of time-consistent policy is that the government can take this information into account (Malik (1991)).

is only one firm playing the government, and the firm can influence government policy.

Until now, the only other paper that has found that time consistency can improve upon commitment is Petrakis and Xepapadeas (2001). Their paper studies environmental taxation in an imperfectly competitive industry. As in the present paper, the government cannot reach its first best with commitment, because it only has a single instrument (environmental taxation) to deal with two distortions. In Petrakis and Xepapadeas (2001), the distortions are pollution and imperfect competition. In the present paper, they are pollution and indivisible investment.

The rest of the paper is organized as follows. In Sections 2 and 3, we analyze direct regulation and taxation under commitment and time consistency. In Section 2, the size of the firm's investment is treated as a continuous variable. In Section 3, we look at an investment of given size. Section 4 compares the welfare effects of commitment and time consistency. It explains why time consistency may be better for welfare. In Section 5, we look at possibilities for the government to improve upon the outcome of time-consistent direct regulation. We discuss the options of commitment, regulating the investment and instrument choice. Section 6 concludes the paper.

2 Perfectly divisible investment

2.1 The model

We look at an activity by one firm which causes environmental damage to the rest of society. We will apply a partial equilibrium framework. The total and marginal social cost of production are given by $SC(q)$ and $MSC(q)$ respectively, with:[2]

$$\begin{aligned} MSC(q) &\equiv SC'(q) > 0 \\ MSC'(q) &> 0 \end{aligned} \tag{1}$$

Thus, marginal social cost MSC is increasing in production.[3]

[2]We do not explicitly model the product market. When the (international) product market is perfectly competitive, we do not have to model the product market. An imperfectly competitive product market can be incorporated by interpreting social cost as the difference between environmental damage and the consumer surplus.

[3]In a more general setting, environmental damage would be caused by the firm's emissions, instead

The firm's payoff, gross of investment cost c, is a function $PB(q, c)$ of its investment c and output q. The firm needs to invest in order to be able to produce. The investment itself is not polluting. We have:

$$\begin{array}{lll} PB_q > 0 & q \in [0, Q(c)) & \\ PB_c > 0 & & \\ PB_{qq} < 0 & PB_{cc} < 0 & PB_{qc} > 0 \end{array} \tag{2}$$

Thus, marginal private benefits of output are decreasing in q. The investment increases private benefits as well as marginal private benefits of output throughout. It can be thought of as a new plant of continuously variable size.[4] Marginal private benefits are positive for $0 < q < Q(c)$. $Q(c)$ is the profit-maximizing output quantity in the absence of government intervention. This profit-maximizing quantity is nondecreasing in the size of the investment: $Q'(c) \geq 0$.

We define aggregate social benefits by AB:

$$AB(q, c) = PB(q, c) - SC(q) - c \tag{3}$$

The first-best levels of output and investment, q^{opt} and c^{opt} respectively, follow from the maximization of AB with respect to q and c:

$$PB_q(q^{opt}, c^{opt}) = MSC(q^{opt}) \tag{4}$$

$$PB_c(q^{opt}, c^{opt}) = 1 \tag{5}$$

The firm's profits under output regulation (with allowed output equal to $\bar{q}$) and taxation at rate t respectively are:

$$\Pi(\bar{q}, c) = PB(\bar{q}, c) - c \tag{6}$$

$$\Pi(q, c, t) = PB(q, c) - tq - c \tag{7}$$

In all situations we will discuss, the firm's profits are positive, so that the firm will actually invest.

of its output, and the firm would have the possibility to reduce emissions per unit of output. Taking this into account would affect the analysis, if the output market were imperfectly competitive and the firm could invest in a reduction of marginal abatement cost. Then the government would no longer be able to reach the first best with environmental policy alone. Petrakis and Xepapadeas (2001) bring these two elements together in an analysis of abatement investment by a monopolist under emission taxation. We shall discuss their findings in Section 4.

[4] In Section 3, we consider indivisible investment.

2.2 Commitment

Under direct regulation, the firm sets the investment at the level $c(\bar{q})$ that maximizes its profits (6), taking allowed output $\bar{q}$ as given:

$$PB_q(\bar{q}, c(\bar{q})) = 1 \tag{8}$$

Under taxation, the firm sets the output and investment levels that maximize its profits (7), taking the tax rate t as given:

$$PB_q(q(t), c(t)) = t \tag{9}$$

$$PB_c(q(t), c(t)) = 1 \tag{10}$$

Proposition 1 *With perfectly divisible investment and commitment, the government reaches its first best with output regulation as well as with output taxation.*

2.3 Time consistency

Under direct regulation, the government sets the allowed output level that maximizes aggregate benefits (3), taking the investment level as given:

$$PB_q(\bar{q}(c), c) = MSC(\bar{q}(c)) \tag{11}$$

In stage one, the firm sets the investment level $\tilde{c}$ that maximizes its profits (6), taking into account that allowed output $\bar{q}(\tilde{c})$ depends on its investment level:

$$PB_c + PB_q\bar{q}'(c) - 1 = 0 \tag{12}$$

Proposition 2 *With perfectly divisible investment and time consistency, the firm invests more than socially optimal under output regulation.*

We know from Propositon 1 that if the firm would take allowed output as given, it would set investment at the socially optimal level. However, if the firm can influence the allowed output level, it will invest too much. This is because the firm's investment increases its marginal benefit of output. This prompts the welfare-maximising government to allow more output.

Under taxation, the government sets the tax rate that maximizes aggregate benefits (3), taking the investment level as given:[5]

$$t(c) = PB_q(q(c), c) = MSC(q(c)) \tag{13}$$

In stage one, the firm sets the investment level $\hat{c}$ that maximizes its profits (6), taking into account that the tax rate $t(c)$ depends on its investment level:

$$PB_c - t'(c)q - 1 = 0 \tag{14}$$

Proposition 3 *With perfectly divisible investment and time consistency, the firm invests less than socially optimal under output taxation.*

We know from Proposition 1 that if the firm would take the tax rate as given, it would set investment at the socially optimal level. However, if the firm can influence the tax rate, it will invest too little. This is because the more the firm invests, the higher the tax rate on output will be.

Note that there is only a problem with taxation if marginal environmental damage is increasing. If marginal damage were constant at d, the time-consistent tax rate would always equal d and the firm would not be able to influence it. Kennedy and Laplante (1999) have noticed this before in the context of investment in abatement technology.

3 Indivisible investment

3.1 The model

We now assume that the investment is indivisible. Social costs SC are still given by (1).

The payoff to the firm depends on whether the firm makes a certain investment.[6] When the firm does not make the investment, its payoff is denoted by $PB_0(q)$. When the firm makes the investment, the payoff is $PB_1(q) - c$. The cost of investment is

[5] The first equality follows from (9).

[6] We shall use the term "payoff" for the firm's revenue minus variable and investment cost. "Profits" or "private benefits" will denote the firm's revenue minus variable cost. "After-tax profits" stands for revenue minus variable cost minus tax payments.

denoted by c. The investment itself is not polluting. Denoting marginal private benefits by MPB, we have:

$$\begin{array}{l} MPB_j(q) \equiv PB_j'(q) > 0 \quad q \in [0, Q_j) \quad j = 0, 1 \\ MPB_1(q) > MPB_0(q) \\ MPB_i'(q) < 0 \end{array}$$

Thus, marginal private benefits are decreasing in q. The investment increases marginal private benefits throughout. It can be thought of as a plant of fixed size. Marginal private benefits are positive for $0 < q < Q_j, j = 0, 1$. Q_j is the profit-maximizing output quantity in the absence of government intervention. This profit-maximizing quantity is larger with the investment: $Q_1 \geq Q_0$.

We define aggregate social benefits without and with the investment by AB_0 and AB_1, respectively:

$$AB_0(q) = PB_0(q) - SC(q) \tag{15}$$

$$AB_1(q, c) = PB_1(q) - c - SC(q) \tag{16}$$

Figure 1 illustrates the analysis. In this Figure, the curves for marginal private benefits MPB_0 and MPB_1 and for marginal social cost MSC are drawn as straight lines, and the investment shifts the MPB curve up in parallel fashion. It should be noted, however, that our results do not rely on these assumptions. All we assume is that the MSC curve is rising and the MPB curves are declining in q, and the investment shifts the MPB curve up.

Let us now determine the first-best outcome. Without investment, total aggregate benefits are given by (15). The optimal output level q_0^{opt}, also depicted in Figure 1, is defined by:

$$MPB_0(q_0^{opt}) = MSC(q_0^{opt}) \tag{17}$$

With investment, total aggregate benefits are given by (16). The optimal output level q_1^{opt}, also depicted in Figure 1, is defined by:

$$MPB_1(q_1^{opt}) = MSC(q_1^{opt}) \tag{18}$$

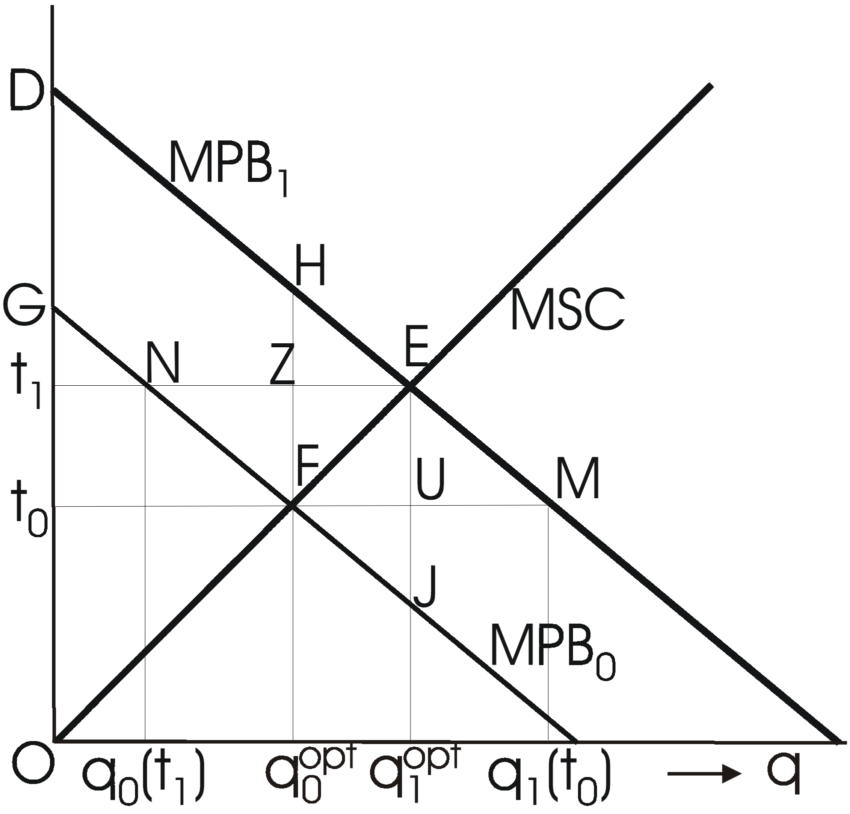

Figure 1: The effect of investment

Note that $q_1^{opt} > q_0^{opt}$, because $MPB_1(q) > MPB_0(q), MPB_j' < 0$ and $MSC' > 0$. From (15) and (16), the investment is socially beneficial when it costs less than b_s:

$$b_s \equiv PB_1(q_1^{opt}) - PB_0(q_0^{opt}) - SC(q_1^{opt}) + SC(q_0^{opt}) \tag{19}$$

The term b_s denotes the increase in gross aggregate benefits due to the investment, given that allowed output before and after the investment is set at the optimal level. In Figure 1, this increase in gross aggregate benefits is denoted by $DEFG$.

The first best outcome is thus:

- when $c < b_s$: investment and output at q_1^{opt};
- when $c > b_s$: no investment and output at q_0^{opt}.

3.2 Commitment

In this subsection, we analyze government policy under commitment. Let us first look at output regulation. It turns out that, as with divisible investment, the government can always reach the first best in this case. We shall first illustrate this with the aid of Figure 1 and then give the formal result.

Remember that in Figure 1, the area $DEFG$ denotes the increase in gross aggregate benefits from the investment. Suppose the government tries to implement the first best with output regulation. Then for $c > DEFG$, it would set allowed output at q_0^{opt} and hope that the firm would not invest. Given q_0^{opt}, the firm's benefits from the investment are $DHFG$. The firm will not invest, because when the investment costs exceed $DEFG$, they also exceed the increase in private benefits $DHFG < DEFG$. Thus, the first best is implemented. For $c < DEFG$, the government would set allowed output at q_1^{opt} and hope that the firm would invest. Given q_1^{opt}, the firm's benefits from the investment are $DEJG$. The firm will invest, because when the investment costs are below $DEFG$, they are also below the increase in private benefits $DEJG > DEFG$. Again, the first best is implemented.

Stated formally:

Proposition 4 *With indivisible investment and commitment, the government can reach the first best under output regulation.*

Now let us look at the instrument of taxation. Given the firm's investment decision, we can write its choice of q_j as a function of the tax rate t:

$$t = MPB_j\left[q_j(t)\right] \quad j = 0, 1 \tag{20}$$

Let us denote the optimal tax rate, in case the investment has (not) been made, by t_1 (t_0):

$$t_j = MPB_j(q) = MSC(q) \quad j = 0, 1$$

or equivalently, using (17), (18) and (20):

$$q_j(t_j) = q_j^{opt} \quad j = 0, 1$$

with $q_j(t)$ given by (20). Note that $t_1 > t_0$, because $q_1^{opt} > q_0^{opt}$ and $MSC' > 0$.

Now let us analyze taxation. It turns out that, unlike with divisible investment, the government cannot always reach the first best in this case. We shall first illustrate this with the aid of Figure 1 and then state the result formally.

For low investment cost ($c < b_s$, as defined by (19)), first best implies investment and a tax rate of t_1. Given that the tax rate is t_1, the firm will produce $q_0(t_1)$ when it does not invest and $q_1(t_1) = q_1^{opt}$ when it does. In Figure 1, the increase in after-tax profits, upon which the firm bases its investment decision, is given by $DENG$. This is below the socially optimal threshold level of $DEFG$. Thus for investment cost between $DENG$ and $DEFG$, the government cannot reach the first best. The government would like the firm to invest at the first-best tax rate of t_1, but with the tax rate at t_1, the investment is not profitable for the firm.

For high investment cost ($c > b_s$), first best implies no investment and a tax rate of t_0. Given that the tax rate is t_0, the firm will produce $q_0(t_0) = q_0^{opt}$ when it does not invest and $q_1(t_0)$ when it does. In Figure 1, the increase in after-tax profits, upon which the firm bases its investment decision, is given by $DMFG$. This exceeds the socially optimal threshold level of $DEFG$. Thus for investment cost between $DEFG$ and $DMFG$, the government cannot reach the first best. The government would like the firm to refrain from investing at the first-best tax rate of t_0, but with the tax rate at t_0, the investment is profitable for the firm.[7]

Formally stated:

Proposition 5 *With indivisible investment and commitment, the government can reach the first best under taxation if and only if either $c < b_1^t$ or $c > b_0^t$, where:*

$$b_0^t \equiv PB_1[q_1(t_0)] - t_0 q_1(t_0) - PB_0[q_0(t_0)] + t_0 q_0(t_0) \quad (21)$$

$$b_1^t \equiv PB_1[q_1(t_1)] - t_1 q_1(t_1) - PB_0[(q_0(t_1)] + t_1 q_0(t_1) \quad (22)$$

For investment cost between b_1^t and b_0^t, we can determine the second-best tax rate. This is the tax rate that maximizes aggregate benefits, given that the government sets

[7] Obviously, if the government could commit to a tax rate contingent on the firm's investment decision, it would always be able to reach the first best. The government would then threaten to set a very high tax rate when the firm does not make the socially optimal investment decision (i.e. it invests when it should not or it does not invest when it should).

the tax rate before the firm's investment decision. We find that the second-best tax rate just allows the investment for low investment cost and just prohibits it for high investment cost:

Proposition 6 *With indivisible investment and commitment, the second best tax rate is* $t^i(c) - \varepsilon$ *for* $b_1^t < c < c^d$ *and* $t^i(c) + \varepsilon$ *for* $c^d < c < b_0^t$*, with* b_0^t *defined by (21),* b_1^t *by (22),* $t^i(c)$ *by*

$$PB_1\left[q_1\left(t^i\left(c\right)\right)\right] - t^i\left(c\right)q_1\left(t^i\left(c\right)\right) - c = PB_0\left[q_0\left(t^i\left(c\right)\right)\right] - t^i\left(c\right)q_0\left(t^i\left(c\right)\right) \tag{23}$$

where $q_j(t), j = 0, 1,$ *is given by (20), and* c^d *defined by:*

$$PB_1[q_1(t^i(c^d))] - SC[q_1(t^i(c^d))] - c^d = PB_0[q_0(t^i(c^d))] - SC[q_0(t^i(c^d))]$$

3.3 Time consistency

In this subsection, we analyze environmental policy when the government cannot commit. First we look at output regulation. When the firm does not invest, the government will set allowed output at q_0^{opt}, defined by (17). When the firm has invested, the government will set q_1^{opt}, defined by (18). In Figure 1, the increase in private benefits from investment is then given by the area $DEFG + q_0^{opt}FEq_1^{opt}$. Obviously this area exceeds the increase $DEFG$ in gross aggregate benefits. Thus, for a certain range of investment cost, the firm invests when this is not first best. The problem is that the firm is not confronted with the environmental cost of its investment decision. It receives the increase in private benefits, but it does not have to pay for the increase in environmental cost.

Stated formally:

Proposition 7 *With indivisible investment and time consistency, the firm invests under output regulation if and only if* $c < b_r$*, where* b_r *is defined by:*

$$b_r \equiv PB_1(q_1^{opt}) - PB_0(q_0^{opt}) \tag{24}$$

Since $b_r > b_s$*, defined by (19), the firm invests when this is not first best for* $b_s < c < b_r$*.*

Now we look at taxation. The tax rate will be t_0 when the firm does not invest and t_1 when it does. In Figure 1, the increase in after-tax profits due to the investment is $DEt_1 - GFt_0 = DENG - t_1NFt_0$. This increase is clearly smaller than the increase in gross aggregate benefits $DEFG$. Thus, for investment cost between $DENG - t_1NFt_0$ and $DEFG$, the firm does not invest when it should. Intuitively, the first best could be implemented with a tax rate of t_0 for production below q_0^{opt} and a tax rate according to marginal social cost for production between q_0^{opt} and q_1^{opt}, reaching t_1 for q_1^{opt}. However, the firm must actually pay t_1 for all units of production when it has invested. Thus, the increase in the tax bill exceeds the increase in social cost.

Proposition 8 *With indivisible investment and time consistency, the firm invests under taxation if and only if $c < b_t$, where b_t is defined by:*

$$b_t \equiv PB_1(q_1^{opt}) - t_1 q_1^{opt} - PB_0(q_0^{opt}) + t_0 q_0^{opt} \tag{25}$$

Since $b_t < b_s$, defined by (19), the firm does not invest when this is first best for $b_t < c < b_s$.

4 Commitment versus time consistency

4.1 Comparing commitment and time consistency

In this section, we compare the outcomes of commitment and time consistency on welfare. The analysis for taxation and direct regulation under divisible investment, as well as for direct regulation under indivisible investment, is straightforward. Commitment leads to the first best, and time consistency cannot improve upon that. With taxation and indivisible investment however, commitment does not always lead to the first best. Then time consistency may improve upon commitment. We shall now analyse this case in more detail, with the aid of Table 1.

As we know from Section 3.1, the first best is investment and production of q_1^{opt} for investment cost below b_s, as defined by (19), and no investment and production of q_0^{opt} for investment cost above b_s. Optimal policy under commitment is given by Proposition 6. Note that for $b_1^t < c < c^d$, the firm would not invest at a tax rate of t_1,

Table 1: Taxation and indivisible investment: Comparing commitment and time consistency

	First best	Commitment	Time consistency	Better?
$c < b_t$	inv, q_1^{opt}	inv, q_1^{opt}	inv, q_1^{opt}	both first best
$b_t < c < b_1^t$	inv, q_1^{opt}	inv, q_1^{opt}	no inv, q_0^{opt}	commitment
$b_1^t < c < \min[c^d, b_s]$	inv, q_1^{opt}	inv, $q > q_1^{opt}$	no inv, q_0^{opt}	?
$c^d < c < b_s$	inv, q_1^{opt}	no inv, $q < q_0^{opt}$	no inv, q_0^{opt}	time consistency
$b_s < c < c^d$	no inv, q_0^{opt}	inv, $q > q_1^{opt}$	no inv, q_0^{opt}	time consistency
$\max[c^d, b_s] < c < b_0^t$	no inv, q_0^{opt}	no inv, $q < q_0^{opt}$	no inv, q_0^{opt}	time consistency
$c > b_0^t$	no inv, q_0^{opt}	no inv, q_0^{opt}	no inv, q_0^{opt}	both first best

but the tax rate $t^i(c) - \varepsilon$ is such that the firm will invest. Thus, the tax rate is below t_1 and the firm will produce more than q_1^{opt}. Conversely, for $c^d < c < b_0^t$, the firm would invest at a tax rate of t_0, but the tax rate $t^i(c) + \varepsilon$ is such that the firm will not invest. Thus, the tax rate exceeds t_0 and the firm will produce less than q_0^{opt}. Finally, under time consistency, the firm invests and produces q_1^{opt} when investment cost is below b_t, as defined by (25), and produces q_0^{opt} without investment when investment cost exceeds b_t.

We now have to compare the parameters that determine the outcome under first best, commitment and time consistency. We know from subsection 3.2 that $b_1^t < b_s < b_0^t$. In general, c^d can be smaller or larger than b_s.[8] We know from Proposition 8 that $b_t < b_s$. Finally, comparing time consistency and commitment, it can be shown that:

Lemma 1 $b_t < b_1^t$, *with* b_1^t *given by (22) and* b_t *by (25).*

We are now ready to compare commitment and time consistency, as in Table 1. First, for investment cost below b_t, it is optimal for the firm to invest and to produce q_1^{opt}. Both commitment and time consistency implement the first best. For investment cost between b_t and b_1^t, commitment still implements the first best of investment and q_1^{opt}. However, time consistency no longer implements the first best, because the firm will not invest and produce q_0^{opt}. Under both regimes, the tax rate will be t_1 when the

[8] In the special case where the marginal cost and benefit curves are linear and the investment shifts the MPB curve vertically, as in Figure 1, we have $c^d = b_s = \frac{1}{2}(b_1^t + b_0^t)$. In general, however, we must allow for c^d both to be smaller and to be larger than b_s.

firm invests. But when the firm does not invest, the tax rate will be $t_0 < t_1$ under time consistency and t_1 under commitment. Thus, not investing is more attractive under time consistency. This is unfortunate from a social welfare point of view, because it is socially optimal for the firm to invest. Thus, commitment leads to a better outcome than time consistency.

In the next cost bracket, $b_1^t < c < \min\,[c^d, b_s]$, the first best is still investment and q_1^{opt} and time consistency again leads to no investment and q_0^{opt}. However, commitment does not lead to the first best anymore. The government has to reduce its tax rate below t_1 in order to get the firm to invest. As a result, the firm will produce more than the optimal amount q_1^{opt}. With neither commitment nor time consistency implementing the first best, neither scenario dominates the other for the whole cost bracket. By continuity, since commitment is better for the previous cost bracket, it will also be better for investment cost in the low range of this bracket. And since, as we shall see shortly, time consistency is better for the next cost bracket, it will also be better for investment cost in the high range of this bracket.

Which is the next cost bracket depends on whether c^d is above or below b_s. Let us first look at the case $c^d < b_s$, so that there is a cost bracket with $c^d < c < b_s$. The first best is still investment and q_1^{opt}, with time consistency again leading to no investment and q_0^{opt}. Commitment now leads to no investment and output below q_0^{opt}. Output is below q_0^{opt}, because the government has to set the tax rate above t_0 in order to discourage the investment. Although neither commitment nor time consistency implements the first best, it can be seen that time consistency is actually better. This is because neither scenario leads to investment. Given that the firm does not invest, optimal output is q_0^{opt}. Time consistency results in q_0^{opt}, but commitment results in a lower output level. Thus, in both scenarios, investment is discouraged. Under time consistency, investment is discouraged because investment will cause the tax rate to rise from t_0 to t_1. Under commitment, the government is restricted to setting the same tax rate whether or not the firm invests. It then has to set the tax rate above t_0 to discourage investment.

The second possibility is that $c^d > b_s$, so that there is a cost bracket with $b_s < c < c_d$.

Time consistent policy still leads to q_0^{opt} without investment and commitment still leads to output higher than q_1^{opt} with investment. However, the first-best outcome has now changed to q_0^{opt} without investment. Thus, time consistent policy implements the first best and commitment does not. Again, time consistent policy leads to a better result than commitment. The firm does not invest under time consistency, because the tax rate would rise from t_0 to t_1 if it did. The government cannot reproduce this result under commitment, because it would have to keep the tax rate at t_0 if the firm invested. Given a tax rate of t_0, the firm would invest. Then it is better to set the tax rate at a higher level to keep overproduction to a minimum, given the investment.

In the next cost bracket $\max\left[c^d, b_s\right] < c < b_0^t$, time consistency implements the first best of q_0^{opt} without investment. Commitment now leads to no investment and production below q_0^{opt}. Again, the government cannot reproduce the first best with commitment, because the firm would invest given a tax rate of t_0. The government then chooses to set the tax rate above t_0 which discourages the investment but also leads to output below the first best level of q_0^{opt}.

Finally, for investment cost above b_0^t, both commitment and time consistency implement the first best of q_0^{opt} without investment.

4.2 Discussion

The result that time consistency can be better than commitment may come as a surprise. Until now, most analyses have found, or simply taken for granted, that commitment is always at least as good as time consistency. The only exception is Petrakis and Xepapadeas (2001), who study environmental taxation of an imperfectly competitive industry, with firms investing in abatement. In this subsection, we discuss two necessary conditions for time consistency to be better than commitment and apply them to the game of the present paper and to Petrakis and Xepapadeas (2001).[9]

The first necessary condition for time consistency to improve upon commitment is that commitment does not implement the first best. In the present paper, commitment implements the first best under divisible investment, and with direct regulation under

[9] See Dijkstra (2002) for a more elaborate discussion.

indivisible investment. With divisible investment, there is a single instrument (either direct regulation or taxation) to tackle a single distortion (pollution).

Indivisible investment introduces another distortion. Now it is no longer clear that commitment will always lead to the first best, since the government only has one instrument to deal with two distortions. However, output regulation still leads to the first best. The reason is that given the output level allowed by the government, the firm's investment decision only affects its own profits. The firm makes the decision that maximizes its profits, but since this is the only effect of its decision, it also maximizes aggregate benefits.[10]

This also explains why the government cannot always reach its first best with commitment under taxation. Given the tax rate, the firm's investment decision not only affects its own profits, but also environmental damage and government revenue. When investment is perfectly divisible, the latter two effects cancel each other out, because the tax rate equals marginal environmental damage. However, with indivisble investment and increasing marginal environmental damage, this no longer holds.

In Petrakis and Xepapadeas (2001) as well, the government only has one instrument (emission taxation) for two distortions: pollution and imperfect competition. Also, the firm's decision does not only affect its own profits. If the firm would increase its output, keeping emissions constant, it would increase consumer surplus.

The condition that the government cannot implement the first best is a necessary, but not a sufficient condition for time consistency to be better than commitment. Indeed, in most games studied in the literature so far, commitment cannot implement the first best, but it is still better than time consistency. This is because the literature has mainly concentrated on games with many small agents playing the government. In these games, each agent considers himself so small that he cannot influence time-consistent policy. In this setting, when the government can commit, it can "commit" to the time-consistent policy and thereby reproduce the outcome of time consistency with commitment. Commitment must then be at least as good as time consistency.

[10] This result is analogous to the Samaritan's dilemma in the theory of altruism, which says that in a game with sequential moves between an altruist and a selfish agent, the altruist can only reach her first best if she moves first (Buchanan (1975), Dijkstra (2000)).

The second necessary condition for time consistency to lead to higher welfare than commitment is thus that the regulated agent(s) can influence time-consistent policy. This is true in the present paper and in Petrakis and Xepapadeas (2001), because there is only one (or a few) firm(s) playing the government. In the present paper, the government will increase the tax rate when the firm invests. In Petrakis and Xepapadeas (2001), an increase in a firm's abatement investment causes a decrease in the tax rate. Thus, the government cannot (always) reproduce the outcome of time consistency with commitment.

When commitment does not implement the first best and private agents can influence time-consistent government policy, time consistency may be better than commitment. However, these are only necessary and not sufficient conditions for time consistency to be best. With taxation and indivisible investment in the present paper, for instance, commitment is better for investment cost c just above b_1^t (see the discussion of Table 1). In Petrakis and Xepapadeas (2001), time consistency is always better for a monopoly and the specific functional forms selected. However, for a larger number of firms, commitment is actually better. In the same vein, Poyago-Theotoky and Teerasuwannajak (2002) find that commitment is better for a heterogeneous duopoly when the products are more similar. Furthermore, Petrakis and Xepapadeas (1999), using different functional forms, find that commitment always leads to higher welfare for a monopoly.

5 Remedies

In this section, we ask what the government can do if it cannot reach the first best with direct regulation under time consistent policy. We examine the options of commitment, delegation, directly regulating the investment and instrument choice.

The most obvious remedy is for the government to commit to environmental policy. The big question, however, is whether such commitment is credible. It may for instance imply that the government does not allow extra production when the firm invests. The firm may be tempted to test the government by making the investment. The firm could further try to make commitment unpleasant for the government, as in the Schiphol airport example in the Introduction.

If the government cannot commit, it may be able to regulate the investment directly, because the firm needs a licence for the investment. However, licences are not needed for many investments in nontangibles like R&D. Licences are needed, for instance, for building a new plant. One might think that the government could then withhold the licence if the investment would reduce welfare. However, this will only be the case if the issuing of building and environmental licence is coordinated. In the Netherlands, for instance, there was no such coordination until March 1993 (Michiels (1998), p. 188). Before that date, a firm could receive a building licence in anticipation of an environmental licence. Thus, the firm could start building the plant without the environmental licence, thereby putting pressure on the environmental department to issue an environmental licence. Without the environmental licence, the investment in the plant would be wasted. The legislator has recognized this problem and mandated the coordinated issue of building and environmental licence in the March 1993 Act on the Environment.

When a firm expects a tightening of environmental regulation in the future, it will precipitate investments subject to government approval in order to benefit from existing lenient regulation. The firm may expect a tightening of environmental regulation for several reasons:

- there is a secular increase in environmental awareness;
- after the next elections, a more environmentally friendly government will take office;[11]
- the government has announced a time path according to which emissions of a target group should decrease. This is translated in increasingly strict regulations for new plants.

[11] When a government expects to be replaced by a more environmentally friendly government, it may even approve of an investment that results in too much pollution by its own standards. In this way, the government can frustrate the next government's attempts to have a more stringent environmental policy, analogous to Persson and Svensson (1987) and Brett and Keen (2000).

Finally, when the firm needs government approval for its investment, it may acquire this approval on the basis of misleading information. The firm may understate the costs or overstate the benefits of the investment. When the government discovers the true costs and benefits, the investment has already been made and cannot be reversed. Of course, the firm should take into account that the government may have other ways of punishing the firm for providing misleading information.

Delegation is often discussed in the literature as a way out of the time consistency problem. The government could delegate the implementation of environmental policy to the Department of the Environment or the Environmental Protection Agency. This agency will in general be staffed by more environmentally-minded people who are less inclined to allow more pollution to an investing firm. Delegation can also take place on another level: The voters could vote for a government that values the environment more than they do (analogous to Besley and Coate (2001)).

As a final route for the government to reach its first best, we consider instrument choice. If the government has not committed to an instrument beforehand, it can tailor instrument choice to the problem at hand. With indivisible investment, the firm may invest when it should not under output regulation, and may not invest when it should under taxation. The government could then apply direct regulation to all cases where the firm should invest ($c < b_s$ as in (19)) and taxation to all cases where the firm should not invest ($c > b_s$).

With divisible investment, the government can implement the first best if it applies direct regulation in case the firm's investment is less than or exactly the optimal amount ($c \leq c^{opt}$) and taxation if the firm invests too much ($c > c^{opt}$). The firm's payoff is then increasing for $c \leq c^{opt}$, dropping discretely at $c = c^{opt}$ and decreasing for $c > c^{opt}$. Thus the firm will invest the optimal amount c^{opt}.

Note that the threat to apply taxation is credible insofar that the government is indifferent between taxation and output regulation, given the firm's investment decision. In that sense, the threat to apply taxation is a "weak threat".

6 Conclusion

In this paper, we have studied environmental policy for a polluting firm that can invest in extra capacity. We have looked at commitment and time consistency, direct regulation of output and output taxation, and divisible and indivisble investment.

We found that the government can reach the welfare optimum under commitment and with divisible investment. With time-consistent policy, the first best can no longer be implemented. The firm overinvests with direct regulation, in order to achieve more allowed output. With taxation on the other hand, the firm underinvests in order to achieve a lower tax rate.

Indivisible investment introduces another distortion. Since the government only has one instrument (either direct regulation or taxation) for two distortions (pollution and indivisible investment), we would expect that commitment cannot always implement the first best anymore. This is true for taxation, but with direct regulation, the government can still reach the first best. The reason is that given allowed output, the firm's investment decision only affects its own payoff.

With taxation, neither commitment nor time-consistency always results in the first best. We can therefore not rank the two regimes on that basis. In fact, there are cases where time consistency is better for welfare than commitment. This result may come as a surprise, since the literature so far has overwhelmingly concluded that commitment is always at least as good as time consistency. This is because the focus has mainly been on macroeconomic applications, with many private agents playing the government. Each agent is then too small to influence time-consistent policy. The government then has an option to "commit" to the time-consistent policy. It could also commit to a different policy, but it would only do so if it yielded a better outcome than the time-consistent policy. By contrast, the present paper analyzes a game between a single firm and the government. The firm can influence government policy, and thus the government cannot reproduce the outcome of time-consistent policy with commitment.

In the present paper, only the firm can invest to influence the government's decision. But one could also imagine that the victims of pollution (like environmental organizations, the agricultural and the tourism sector) invest strategically in their benefits of environmental quality. Dijkstra (2001) analyzes the resulting investment contest between polluters and victims of pollution.

7 Appendix

Proof of Proposition 1. For output regulation, it follows from (4), (5) and (8) that $c(q^{opt}) = c^{opt}$. For taxation with $t^{opt} = MSC(q^{opt})$, it follows from (4), (5), (9) and (10) that $q(t^{opt}) = q^{opt}$ and $c(t^{opt}) = c^{opt}$.

Proof of Proposition 2. The firm's investment level is determined by (12), where the value of $\bar{q}'(c)$ follows from the total differentiation of (11) with respect to c:

$$\bar{q}'(c) = \frac{PB_{qc}}{MSC' - PB_{qq}} > 0$$

The inequality follows from $PB_{qc}, MSC' > 0$ and $PB_{qq} < 0$ according to (1) and (2). Comparing (12) to (5), we see that the LHS of (12) is positive for $c = c^{opt}$ and $q = q^{opt}$, since $\bar{q}'(c),\ PB_q > 0$. Since $PB_{cc} < 0$, $\tilde{c} > c^{opt}$ is needed for (12) to hold.

Proof of Proposition 3. The firm's investment level is determined by (14), where the value of $t'(c)$ follows from the total differentiation of (13) with respect to c:

$$t'(c) = \frac{MSC' PB_{qc}}{MSC' - PB_{qq}} > 0$$

The inequality follows from $PB_{qc}, MSC' > 0$ and $PB_{qq} < 0$ according to (1) and (2). Comparing (14) to (5), we see that the LHS of (14) is positive for $c = c^{opt}$ and $q = q^{opt}$, since $t'(c),\ PB_q > 0$. Since $PB_{cc} < 0$, $\hat{c} < c^{opt}$ is needed for (12) to hold.

Proof of Proposition 4. There are two cases to consider. The first case is $c > b_s$, with b_s given by (19). The first best is reached when the firm does not invest at the allowed output level of q_0^{opt}, defined by (17). Given that allowed output is q_0^{opt}, the firm will invest when the investment cost is below the increase in private benefits b_0^r:

$$b_0^r \equiv PB_1(q_0^{opt}) - PB_0(q_0^{opt}) \tag{26}$$

It can be shown that $b_0^r < b_s$:

$$PB_1(q_0^{opt}) - PB_0(q_0^{opt}) < PB_1(q_1^{opt}) - PB_0(q_0^{opt}) - SC(q_1^{opt}) + SC(q_0^{opt})$$

Rearranging gives:

$$PB_1(q_0^{opt}) - SC(q_0^{opt}) < PB_1(q_1^{opt}) - SC(q_1^{opt})$$

or $AB_1(q_0^{opt}) < AB_1(q_1^{opt})$, because q_1^{opt} maximizes AB_1.

Thus, the firm does not invest, because $c > b_s > b_0^r$, and the first best is implemented.

The second case to consider is $c < b_s$. The first best is reached when the firm invests at the allowed output level of q_1^{opt}, defined by (18). Given that allowed output is q_1^{opt}, the firm will invest when the investment cost is below the increase in private benefits b_1^r:

$$b_1^r \equiv PB_1(q_1^{opt}) - PB_0(q_1^{opt}) \tag{27}$$

It can be shown that $b_1^r < b_s$ from (19):

$$PB_1(q_1^{opt}) - PB_0(q_1^{opt}) > PB_1(q_1^{opt}) - PB_0(q_0^{opt}) - SC(q_1^{opt}) + SC(q_0^{opt})$$

Rearranging gives:

$$PB_0(q_0^{opt}) - SC(q_0^{opt}) > PB_0(q_1^{opt}) - SC(q_1^{opt})$$

or $AB_0(q_0^{opt}) > AB_0(q_1^{opt})$, because q_0^{opt} maximizes AB_0.

Thus, the firm invests, because $c < b_s < b_0^r$, and the first best is implemented.

Proor of Proposition 7. When the firm has invested, the government will set the output level at q_1^{opt}, defined by (18). When the firm has not invested, the government will set q_0^{opt}, defined by (17)). The firm invests when the investment cost is below b_r as defined by (24). The increase in private benefits b_r exceeds the socially optimal threshold level b_s from (19):

$$b_r \equiv PB_1(q_1^{opt}) - PB_0(q_0^{opt}) > PB_1(q_1^{opt}) - PB_1(q_0^{opt}) - SC(q_1^{opt}) + SC(q_0^{opt})$$

The inequality follows from $SC(q_1^{opt}) > SC(q_0^{opt})$.

Proof of Proposition 8. When the firm does not invest, the tax rate will be t_0 and the firm will produce q_0^{opt}. When the firm invests, the tax rate will be t_1 and the firm will produce q_1^{opt}. The firm will invest when the cost of investment is below b_t, defined by (25). We shall now see that $b_t < b_s$:

$$PB_1(q_1^{opt}) - t_1 q_1^{opt} - PB_0(q_0^{opt}) + t_0 q_0^{opt} < PB_1(q_1^{opt}) - PB_0(q_0^{opt}) - SC(q_1^{opt}) + SC(q_0^{opt})$$

This can be rewritten as:

$$t_0 q_0^{opt} - SC(q_0^{opt}) < t_1 q_1^{opt} - SC(q_1^{opt})$$

The inequality follows from the fact that $t(q)q - SC(q)$, with $t(q) \equiv MSC(q)$, is increasing in q :

$$\frac{d}{dq}\left[t(q)q - SC(q)\right] = MSC'(q)q > 0$$

Proof of Proposition 5. Given that the tax rate is t_0, the firm will invest when the cost of investment is below the increase in after-tax profits b_0^t, defined by (21). It can be shown that b_0^t exceeds the socially optimal threshold level b_s from (19):

$$\begin{aligned} &PB_1[q_1(t_0)] - t_0 q_1(t_0) - PB_0[q_0(t_0)] + t_0 q_0(t_0) > \\ &> PB_1[q_1(t_1)] - PB_0[q_0(t_0)] - SC[q_1(t_1)] + SC[q_0(t_0)] \end{aligned}$$

Rearranging and introducing the term $t_0 q_1(t_1)$ yields:

$$\begin{aligned} &\{PB_1[q_1(t_0)] - PB_1[q_1(t_1)] - t_0[q_1(t_0) - q_1(t_1)]\} + \\ &+ \{SC[q_1(t_1)] - SC[q_0(t_0)] - t_0[q_1(t_1) - q_0(t_0)]\} > 0 \end{aligned} \qquad (28)$$

Both terms between curly brackets on the LHS of (28) are positive. The first term is positive by because $q_1(t_0) > q_1(t_1)$, $MPB_1\left[q_1(t_0)\right] = t_0$ and $MPB_1' < 0$. The second term is positive by $q_1(t_1) > q_0(t_0)$, $MSC\left[q_0(t_0)\right] = t_0$ and $MSC' > 0$. The first term corresponds to the area EMU in Figure 1 and the second term corresponds to the area FEU.

Thus, for $c > b_0^t$ with b_0^t given by (21), the government can achieve the first best. It sets the tax rate at t_0 and the firm does not invest. For $b_s < c < b_0^t$, however, the government cannot achieve the first best. When the tax is set at its first-best rate of t_0, the firm will invest, which is not first best.

At t_1, the firm will invest when the cost of investment is below the increase in after-tax profits b_1^t, defined by (22). It can be shown that b_1^t is below the socially optimal threshold level b_s from (19):

$$PB_1[q_1(t_1)] - t_1 q_1(t_1) - PB_0[(q_0(t_1)] + t_1 q_0(t_1) <$$
$$< PB_1[q_1(t_1)] - PB_0[q_0(t_0)] - SC[q_1(t_1)] + SC[q_0(t_0)]$$

Rearranging and introducing the term $t_1 q_0(t_0)$ yields:

$$\{t_1[q_0(t_0) - q_0(t_1)] + PB_0[q_0(t_1)] - PB_0[q_0(t_0)]\} +$$
$$+ \{t_1[q_1(t_1) - q_0(t_0)] + SC[q_0(t_0)] - SC[q_1(t_1)]\} > 0 \qquad (29)$$

Both terms between curly brackets on the LHS of (29) are positive. The first term is positive by $q_0(t_0) > q_1(t_1)$, $MPB_0\,[q_0(t_1)] = t_1$ and $MPB_0' < 0$. The second term is positive by $q_1(t_1) > q_0(t_0)$, $MSC\,[q_1(t_1)] = t_1$ and $MSC' > 0$. The first term corresponds to the area ZEF in Figure 1 and the second term corresponds to NZF.

Proof of Lemma 1. From (22) and (25), we need to show that:

$$PB_1(q_1^{opt}) - t_1 q_1^{opt} - PB_0(q_0^{opt}) + t_0 q_0^{opt} < PB_1[q_1(t_1)] - t_1 q_1(t_1) - PB_0[(q_0(t_1)] + t_1 q_0(t_1)$$

which reduces to:

$$PB_0\,[q_0(t_1)] - t_1 q_0(t_1) < PB_0\,[q_0(t_0)] - t_0 q_0(t_0)$$

The inequality follows from the fact that $t_1 > t_0$ and $PB_0\,[q_0(t)] - t_1 q_0(t)$, with $q_0(t)$ defined by (20), is declining in t:

$$\frac{d}{dt}\left[PB_0\,[q_0(t)] - t_1 q_0(t)\right] = -q_0(t) < 0$$

References

[1] Besley, Timothy and Stephen Coate (2001), "Lobbying and welfare in a representative democracy", Review of Economic Studies 68: 67-82.

[2] Brett, Craig and Michael Keen (2000), "Political uncertainty and the earmarking of environmental taxes", Journal of Public Economics 75: 315-340.

[3] Buchanan, James M. (1975), "The Samaritan's dilemma", in: E.S. Phelps (ed.), Altruism, Morality, and Economic Theory, Sage Foundation, New York, 71-85.

[4] Collinge, Robert A. and Wallace E. Oates (1982), "Efficiency in pollution control in the short and long runs: A system of rental emission permits", Canadian Journal of Economics 15: 346-354.

[5] Dijkstra, Bouwe R. (2000), "Samaritan vs rotten kid: Another look", Discussion Paper 322, Faculty of Economics, University of Heidelberg.

[6] Dijkstra, Bouwe R. (2001), "An investment contest for environmental policy", European Public Choice Conference, Paris, 18-21 April.

[7] Dijkstra, Bouwe R. (2002), "Policy commitment vs time consistency", School of Economics, University of Nottingham.

[8] Fischer, Stanley (1980), "Dynamic inconsistency, cooperation and the benevolent dissembling government", Journal of Economic Dynamics and Control 2: 93-107.

[9] Gersbach, Hans and Amihai Glazer (1999), "Markets and regulatory hold-up problems", Journal of Environmental Economics and Management 37: 151-164.

[10] Hoel, Michael (1998), "Emission taxes versus other environmental policies", Scandinavian Journal of Economics 100: 79-104.

[11] Kennedy, Peter W. and Benoit Laplante (1999), "Environmental policy and time consistency: Emission taxes and emission trading", in: E. Petrakis, E.S. Sartzetakis, A. Xepapadeas (eds), Environmental Regulation and Market Power, Edward Elgar, Cheltenham, 116-144.

[12] Kydland, Finn E. and Edward C. Prescott (1977), "Rules rather than discretion: The inconsistency of optimal plans", Journal of Political Economy 85: 473-491.

[13] Leahy, Dermot and J. Peter Neary (1999), "Learning by doing, precommitment and infant-industry protection", Review of Economic Studies 66: 447-474.

[14] Leidy, Michael P. (1994), "Trade policy and indirect rent seeking: A synthesis of recent work", Economics and Politics 6: 97-118.

[15] Malik, Arun S. (1991), "Permanent versus interim regulation: A game-theoretic analysis", Journal of Environmental Economics and Management 21: 127-139.

[16] Michiels, F.C.M.A (1998), De Wet Milieubeheer, WEJ Tjeenk Willink, Deventer.

[17] Persson, Torsten and Lars E.O. Svensson (1987), "Why a stubborn conservative would run a deficit: Policy with time-inconsistent preferences", Quarterly Journal of Economics 104: 325-345.

[18] Petrakis, Emmanuel and Anastasios Xepapadeas (1999), "Does government precommitment promote environmental innovation?", in: E. Petrakis, E. Sartzetakis and A. Xepapadeas (eds), Environmental regulation and market power, Edward Elgar, Cheltenham, 147-161.

[19] Petrakis, Emmanuel and Anastasios Xepapadeas (2001), "To commit or not to commit: Environmental policy in imperfect markets", paper presented at the European Association of Environmental and Resource Economists, Southampton, June 28-30.

[20] Poyago-Theotoky, Joanna and Khemarat Teerasuwannajak (2002), "The timing of environmental policy: A note on the role of product differentiation", Journal of Regulatory Economics 21: 305-316.

[21] Rose-Ackerman, Susan (1973), "Effluent charges: a critique", Canadian Journal of Economics 6: 512-527.

[22] Schulze, William and Ralph C. d'Arge (1974), "The Coase proposition, informational constraints, and long-run equilibrium", American Economic Review 64: 763-772.

[23] Spulber, Daniel F. (1985), "Effluent regulation and long-run optimality", Journal of Environmental Economics and Management 12: 103-116.

[24] Tornell, Aaron (1991), "Time inconsistency of protectionist programs", Quarterly Journal of Economics 106: 963-974.

[25] Weitzman, Martin L. (1974), "Prices vs. quantities", Review of Economic Studies 41: 477-491.