Tax uniformity:
A commitment device for restraining opportunistic behaviour

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Abstract: We investigate whether and to what extent uniform and differentiated tax systems diverge in their propensity to create distortionary opportunistic behaviour. The set-up in which we carry out our analysis features polluting firms that are confronted with a Pigovian emission tax. Firms can invest in pollution abatement. We first show that the existence of emission taxes, although optimally chosen, create strategic incentives for firms to distort their abatement investment. Second, we find that a system of differentiated emission taxes has a greater propensity to foster strategic distortions in abatement investment than a uniform emission tax regime.

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1. Introduction

When policy makers try to regulate the behaviour of economic agents, one can expect those affected by the policy to behave opportunistically. The modern economic literature offers many examples of unanticipated responses to policy activism and policy induced opportunistic behaviour[1]. In fact, even the pioneers of economics were aware of this phenomenon. Adam Smith (1790) described the problem allegorically:

"[The man of system] seems to imagine that he can arrange the different members of a great society with as much ease as the hand arranges the different pieces upon a chessboard;... but..., in the great chess-board of human society, every single piece has a principle of motion of its own, altogether different from that which the legislator might choose to impress upon it." [2].

In this paper, we investigate whether and to what extent different tax systems diverge in their propensity to create distortionary opportunistic behaviour. More specifically, we compare uniform and differentiated tax regimes in terms of vulnerability to strategic behaviour by the firms that are targeted by the taxes. To our knowledge, this issue has hitherto largely been neglected in spite of the fact that its policy implications are far from trivial. Our analysis seeks to close this gap in the literature. We make a case for tax uniformity as a policy commitment device for counteracting firms' opportunistic behaviour. One might naturally conjecture that this argument requires an assumption that the government does not intend simply to maximise welfare but is a political support maximiser, influenced by lobbying of powerful interest groups [3]. This is, however, not the case. To show that our argument is more generally valid, we model the government as a benevolent welfare maximiser.

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[1] One example among many is given in Rodrik (1987). He argues that, even when a policy is fully successful in correcting the distortion it was aimed at, it can create a secondary distortion elsewhere. In his framework, the distortion arises because the government is myopic in setting its policy.

[2] The Theory of Moral Sentiments, Part VI, Section II, Chapter 2.

[3] In the political economy literature, private sector agents engage in "directly unproductive" rent-seeking behaviour in order to manipulate governments (see, among many others, Bhagwati (1982) and Grossman and Helpman (1994); for a survey on the political economy literature, see Rodrik (1995)). Farzin and Zhao (2003) examine how pollution abatement investment is affected when firms lobby against environmental regulation. Typically and unlike in our paper, the government in such a set-up does not maximise national welfare because it is concerned with its political support.

The specific set-up in which we carry out our analysis features polluting firms that are confronted with a Pigovian emission tax. Firms can invest in pollution abatement. We start by showing that the existence of emission taxes creates strategic incentives for firms to distort their abatement investment. The cause of the investment distortion lies in the fact that the government, as often is the case in the real world, has commitment power in the short run but fails to extend that commitment power to the longer run[4]. One simple reason for this is that governments often are relatively short-lived. Indeed, Laffont and Tirole (1993) argue that constitutional and administrative rules can in fact prohibit long-term policy commitment, thereby allowing policies to be amended by future administrations. Although governments can commit in the long run by signing up to international treaties and investment in infrastructure, other policies including the setting of emission taxes typically do not involve any commitment beyond a short horizon.

We subsequently show that the choice of tax regime –a uniform or a differentiated tax rate system– makes a substantial difference to firms' strategic investment behaviour and thus to overall welfare. We argue that, if the possible existence of strategic distortions is disregarded, the relative merits of a differentiated tax system will, at its best, be seriously overrated and, at its worst, lead to perverse policy recommendations. Our insights therefore contradict the received wisdom that the merits from extra flexibility engendered by tailored tax policies must always dominate the straightjacket of a one-size-fits-all uniform policy. Our point is that tax uniformity allows governments to tie their hands in order to limit the strategic behaviour of other agents. Indeed, the government will find this commitment device particularly useful when it lacks intertemporal commitment to a tax level. Then, tax uniformity can act as a partial substitute for the long-run commitment associated with moving first. As such, our analysis contributes to the old but ongoing debate on the relative merits and drawbacks of differentiated versus uniform tax regimes[5].

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[4] This assumption is used in other models, among others by Neary and Leahy (2000) and Zigic (2003). In the environmental economics literature, a similar move order is, for instance, assumed in Petrakis and Xepapadeas (1999).
[5] The optimal commodity taxation literature teaches us that the advantage of differentiated taxes is that they can be tailored to each commodity's innate characteristics (see Ramsey (1927); since then, several

Although our analysis is carried out in an environmental policy set-up, its message stretches well beyond the particulars of this case. Our choice of this particular application is motivated by the fact that environmental regulation is currently a leading issue in both local and global policy debates. In particular, a lot of effort is being undertaken in collecting firm-specific information regarding pollution as a means to design more flexible –in other words, more differentiated− environmental policy[6]. While detailed reliable information on firms' activities makes a system of differentiated taxes undoubtedly more feasible, our analysis suggests that the strong propensity of such a tax system to engender strategic behaviour by firms also works towards making it less socially desirable.

The analysis leading to our main result is developed in sections 2 and 3. Section 2 outlines the basic general model and determines the optimal differentiated taxes and uniform emission tax, as well as firms' investment decisions under the alternative tax systems. Section 3 examines the welfare implications of our findings. In section 4, we show how a differentiated tax system can yield outcomes that are, from a social perspective, as bad as those that arise when firms collude in setting their investment levels. Section 5 extends the analysis and investigates the robustness of our result. Section 6 concludes.

2. The model

Consider an economy with *n* polluting industries. For simplicity, we assume initially that each industry consists of a single firm and that these monopolist firms export all their output. The assumption that all output is exported allows us to ignore consumer interests. Also, by reducing the number of distortions in the model to just one, caused by the negative pollution externality, it serves the purpose of allowing us to isolate the strategic

modifications of the original Ramsey rule have been proposed, for instance, Diamond (1975) and, more recently, Holcombe (2002)). In an environmental economics context, Lee (1975) shows that differentiated emission taxes are superior to a uniform emission tax when monopolist firms have different degrees of market power. However, a practical drawback of differentiated taxes is that they can be both difficult and costly to implement.

[6] For instance, Frisvold (2000) states that current trends in the collection of environment-related farm-level data can help in the design of more flexible environmental regulation.

interaction between firms and the government in a clean way. We also assume initially that firms are symmetric. Obviously, the well known advantages of tax differentiation in terms of tailoring tax rates to individual firms are best shown (and indeed have been shown in many set-ups) in a framework with asymmetric firms. Abstracting from firm and industry differences and thus from some of the well understood arguments for non-uniform taxes, our symmetry assumption allows us to focus more clearly on tax uniformity as a commitment device to restrain opportunistic behaviour[7]. With firm symmetry, one would expect that it would not make any difference whether the government were to use differentiated tax rates or a uniform tax. We show that it does make a difference. It is important to stress that our results do not hinge on the assumption of symmetry. Indeed, as we show in section 5, our analysis can easily be extended to asymmetric firms and more complex set-ups without changing our qualitative results[8].

Firm i's output is denoted by q^i and p^i stands for the price at which the product is sold. Demand for good i is given by:

$$p^i = p^i(q^i) \tag{1}$$

with $p^{i\prime} < 0$. As a by-product of its goods production, each firm generates pollution which can be reduced by investment in emission-reducing technology, denoted by k^i. The level of pollutant emissions, e^i, is given by:

$$e^i = e^i(q^i, k^i) \tag{2}$$

with $e^i_{q^i} > 0$, $e^i_{k^i} < 0$ and $e^i_{k^i k^i} \geq 0$. Here and henceforth, subscripts denote partial derivatives. For now, we assume $e^i_{q^i k^i} = 0$[9], but this assumption is relaxed in Appendix B.

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[7] Obviously, in an environment with asymmetric firms and industries the government needs to choose a policy that correctly takes account of these two counteracting effects.

[8] In section 5 we allow for asymmetric firms (see section 5.1), we relax the assumption that all production is exported, thereby enhancing the welfare function with consumer surplus (see section 5.2) and we allow for multiple firms within an industry (see section 5.3).

[9] Since the assumption of additive separability in the emission function considerably simplifies the analysis, it is commonly used, for instance, Katsoulacos and Xepapadeas (1995), Bruneau (2005), David and

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Firm i's costs are given by:

$$C^i(q^i) + \Gamma^i(k^i) \qquad (3)$$

with $C^i_{q^i} > 0$ and $\Gamma^i_{k^i} > 0$.

The government aims to limit pollution by imposing a tax on emissions. It has a choice between setting a uniform emission tax (t), which is the same across industries, or setting a differentiated emission tax (t^i), which is industry specific. In either case, when determining the tax rate, the government maximises welfare (W), defined by:

$$W = \sum_i \{\pi^i - D^i + T^i\} \qquad (4)$$

The first component of the welfare function is profit; π^i denotes monopolist profits in industry i, with

$$\pi^i = R^i(q^i) - C^i(q^i) - \Gamma^i(k^i) - T^i \qquad (5)$$

where $R^i(q^i) = q^i p^i(q^i)$ denotes firm i's revenues. T^i is the amount of emission taxes paid by firm i, with $T^i = t^i e^i$ when taxes are differentiated and $T^i = te^i$ under a uniform tax regime. Thus, in expression (4), $\sum_i T^i$ represents the government's tax revenues.

We further assume that the firm's gross cost function (i.e., tax inclusive costs) is convex in k^i ($\Gamma^i_{k^i k^i} + T^i_{k^i k^i} > 0$). D^i stands for the damage caused by industry i's emission of pollutants:

$$D^i = D^i(e^i) \qquad (6)$$

with $D^{i\prime} > 0$ and $D^{i\prime\prime} > 0$.

Firms and the government play a three-stage game. The government has commitment power in the short run but cannot extend that commitment power to the longer run. While a firm's output choice is a short-run decision and hence tend to have little commitment value, a firm's investment is typically a long-run decision and entails,

Sinclair-Desgagné (2005) and Lahiri and Ono (2007), among many others. However, as we show in Appendix B, the main message of the paper will be preserved without the additive separability assumption.

because of its irreversibility[10], a great deal of commitment value. Thus, in our model firms make their long-run investment decisions in the first stage, the government –able to influence short-run decisions only– sets its emission tax in the second stage, and firms choose output levels, which have very little commitment value, in the final stage[11].

Using backward induction, we first turn to the final stage (section 2.1). Subsequently, we determine the optimal emission tax, when the government sets a differentiated and a uniform emission tax, respectively (section 2.2). Finally, we derive firms' investment levels under the alternative tax regimes (section 2.3). We will show that, in spite of the fact that firms are symmetric and hence the expressions for the optimal differentiated and the optimal uniform tax rate are the same, firms' investment levels differ. Since the latter determine the *actual* level of the tax rate, the *actual* optimal tax rate under the two tax systems will differ.

2.1. Output

In stage three, each monopolist firm maximises profits with respect to output, implying $\pi^i_{q^i} = 0$. Hence, we obtain the following condition for firm i's optimal output:

$$R^i_{q^i} = C^i_{q^i} + t^i e^i_{q^i} \tag{7}$$

Since this stage of the game is the same under both tax systems, substituting t^i for t yields the corresponding expressions under the uniform tax system.

We differentiate expression (7) with respect to the tax rate and obtain:

$$dq^i / dt^i = -\pi^i_{q^i t^i} / \pi^i_{q^i q^i} \tag{8}$$

with $\pi^i_{q^i q^i} < 0$, guaranteeing that second-order conditions hold. Since $\pi^i_{q^i t^i} = -e^i_{q^i} < 0$, we have $dq^i / dt^i < 0$: faced with an increase in the –differentiated or uniform– emission tax, firm i will cut back production.

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[10] As argued by Dixit and Pindyck (1994), irreversibility is one of the key features of investment.
[11] Neary and Leahy (2000) argue that this is a plausible move order in games between firms and the government, the sequence of moves is dictated by the relative commitment power of players' actions.

2.2. The optimal tax rate

We first derive the optimal tax rate when taxes are differentiated. Subsequently, we calculate the optimal uniform emission tax.

2.2.1. The optimal differentiated emission tax

The government maximises W with respect to t^i, taking into account how t^i will affect firm i's output. The first-order condition is given by:

$$\frac{dW}{dt^i} = W_{t^i} + W_{q^i} \frac{dq^i}{dt^i} = 0 \tag{9}$$

with $W_{t^i} = \pi^i_{t^i} + e^i = 0$, $W_{q^i} = (-D^{i\,\prime} + t^i)e^i_{q^i}$ (since $\pi^i_{q^i} = 0$ from stage three) and dq^i / dt^i given by expression (8). Rearranging terms and simplifying, expression (9) reduces to:

$$t^i = D^{i\,\prime} \tag{10}$$

Thus, the optimal industry specific tax rate is fully determined by the marginal damage that will be caused by firm i's emissions.

Importantly, because the tax rate is set *after* firms choose investment levels, each firm can influence the tax rate imposed on its industry. More specifically, we have:

$$\frac{dt^i}{dk^i} = D^{i\,\prime\prime} \left(e^i_{k^i} + e^i_{q^i} \frac{dq^i}{dk^i} \right) \tag{11}$$

where $dq^i / dk^i = -D^{i\,\prime\prime} e^i_{q^i} e^i_{k^i} / \Delta$ with $\Delta \equiv -\pi^i_{q^i q^i} + D^{i\,\prime\prime}(e^i_{q^i})^2$ (from the total differentiation of $\pi^i_{q^i} = 0$ with respect to k^i and using expression (11)). Since $\Delta > 0$, we have $dq^i / dk^i > 0$. The first term between brackets in expression (11) is the direct effect of abatement investment on emissions, which is negative, while the second term represents the indirect effect of abatement investment through output, which is positive. So, at first sight, whether or not firms can use abatement investment to lower the tax rate appears to be ambiguous. However, making use of the expression for dq^i / dk^i, expression (11) simplifies to:

$$\frac{dt^i}{dk^i} = -\frac{D^{i\,\prime\prime}}{\Delta} e^i_{k^i} \pi^i_{q^i q^i} \tag{12}$$

It is clear from expression (12) that dt^i / dk^i is unambiguously negative, implying that a firm's abatement investment lowers its emission tax rate. So, firms can use k^i strategically to lower the tax rate.

2.2.2. The optimal uniform emission tax

When setting a uniform emission tax, the government maximises welfare with respect to t, taking into account that firms' output levels in *all* industries will be affected:

$$\frac{dW}{dt} = W_t + \sum_i \left(W_{q^i} \frac{dq^i}{dt} \right) = 0 \tag{13}$$

with $W_t = \sum_i (\pi_t^i + e^i) = 0$ and $W_{q^i} = (-D^{i\prime} + t)e_{q^i}^i$. Hence, the optimal uniform emission tax is:

$$t = \frac{\sum_i [D^{i\prime} e_{q^i}^i (dq^i / dt)]}{\sum_i [e_{q^i}^i (dq^i / dt)]} \tag{14}$$

With symmetry, expression (14) reduces to $t = D^{i\prime}$, which is identical to the expression for the optimal differentiated tax[12]. Formally:

Proposition 1: *With symmetric firms, the optimal emission tax rate is equal to the marginal damage of emissions, both under a uniform and under a differentiated tax system.*

Importantly, expression (14) also shows that, unlike in the case of a differentiated tax, the optimal uniform emission tax will be influenced by firms' investment in *all* industries. The effect of an individual firm's investment on the tax rate is now:

$$\frac{dt}{dk^i} = \frac{D^{i\prime\prime}}{n} \left(\sum_j^n e_{q^j}^j \frac{dq^j}{dk^i} + e_{k^i}^i \right) \tag{15}$$

As shown in Appendix A, expression (15) reduces to:

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[12] Our result here differs from Barnett (1980) since we assume all output is exported, implying that there is no domestic consumer surplus. The presence of domestic consumer surplus will lower the optimal emission tax. We discuss this in an extension of the basic model (see section 4).

$$\frac{dt}{dk^i} = -\frac{D^{i\,\prime\prime}}{n\Delta} e^i_{k^i} \pi^i_{q^i q^i}$$ (16)

It is clear from expression (16) that the tax rate falls by a smaller amount in firm i's investment as the number of industries increases. Furthermore, given the same values of q^i and k^i in expressions, a comparison of expressions (12) and (16) informs us that $dt/dk^i = (1/n)(dt^i/dk^i)$ for $n > 1$. Thus, for $n > 1$ the impact of a firm's investment on the uniform emission tax is always smaller than in the case with a differentiated tax. As the number of industries subject to the emission tax increases, the effect of any one firm's abatement investment on the emission tax becomes smaller, reducing to zero as $n \to \infty$.

2.3. Investment

Firms choose investment levels in the first stage of the game. In doing so, they will influence the actual tax rate. We first derive firms' investment levels under the non-strategic benchmark. Subsequently, we derive investment levels when firms will choose abatement investment strategically, under a differentiated and a uniform emission tax regime, respectively.

2.3.1. The non-strategic investment benchmark

Before discussing the strategic term, it proves useful to take a closer look at the case in which firms are not able to act strategically; that is, the case in which monopolist firms in each industry choose capital levels at the same time as the government determines its tax. Firm i's respective first-order conditions for abatement investment under a differentiated and uniform tax system are then given by:

$$\pi^i_{k^i} = -\Gamma^i_{k^i} - t^i e^i_{k^i} = 0$$ (17a)

and

$$\pi^i_{k^i} = -\Gamma^i_{k^i} - t e^i_{k^i} = 0$$ (17b)

With symmetric firms, the government's respective first-order conditions for the optimal tax rate under a differentiated and a uniform tax regime are:

$$t^i = D^{i\,\prime}$$ (18a)

and

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$$t = D^{i\,\prime} \tag{18b}$$

Firm i's output is given by expression (7). Given q^i and k^i, expressions (18a) and (18b) imply $t^i = t$. It then follows from expressions (17a) and (17b) that the non-strategic abatement investment level under differentiated taxes is identical to the one under a uniform tax; in fact, the non-strategic abatement under both tax regimes is equal to the firm's cost-minimising investment level, denoted by k^{iN}.

The non-strategic equilibrium is depicted in Figure 1, which depicts the case with differentiated tax rate setting (the case with the uniform tax setting can be similarly represented). In the diagram, $t^i(k^i)$ is the government's tax reaction function to the symmetric-firm investment level (given by expression (18a)). From our earlier discussion, we know that the government's reaction function is negatively sloped ($dt^i / dk^i < 0$). Figure 1 also shows firm i's investment reaction function to the emission tax, $k^i(t^i)$ (given by expression (17a)). The slope of firm i's reaction function is given by $dk^i / dt^i = -\pi^i_{k^i t^i} / \pi^i_{k^i k^i}$. Since $\pi^i_{k^i k^i} < 0$ and with $\pi^i_{k^i t^i} = -e^i_{k^i} > 0$, $k^i(t^i)$ is positively sloped. Also, when the emission tax is zero, the firm has no incentive to invest in abatement (thus, its reaction function starts out of the origin). The non-strategic equilibrium, characterised by the firm's cost-minimising investment level k^{iN} and the government's tax rate t^{iN}, is indicated by N, the intersection of the reaction functions.

[Figure 1 about here]

2.3.2. Strategic investment under a differentiated emission tax

Each firm maximises its profits with respect to k^i, taking into account how its capital investment will affect the industry's emission tax (dt^i / dk^i):

$$\frac{d\pi^i}{dk^i} = \pi^i_{k^i} + \pi^i_{t^i} \frac{dt^i}{dk^i} = 0 \tag{19}$$

The first term in expression (19) is the direct marginal effect of k^i on total −that is, tax inclusive− costs ($\pi^i_{k^i} = -\Gamma^i_{k^i} - t^i e^i_{k^i}$). The second term in expression (19) represents firm

i's strategic incentive to manipulate the emission tax. Since the emission tax lowers firm profit ($\pi_{t^i}^i < 0$) and abatement investment lowers the tax rate ($dt^i / dk^i < 0$), the strategic term in expression (7) is positive. Hence, the direct effect (the first term in expression (7)) has to be negative ($\pi_{k^i}^i < 0$). Given the assumption made earlier that the firm's tax inclusive costs are convex in k^i ($\Gamma_{k^i k^i}^i + T_{k^i k^i}^i > 0$), it follows that firm *i* overinvests relative to the cost minimising non-strategic benchmark in order to lower the emission tax[13].

In terms of the diagram in Figure 1, firm *i* picks the point of the government's reaction function that is associated with the highest profit. This point is indicated by D, the tangency point of isoprofit contour π^D to the government's reaction function, which entails a different emission tax rate than the non-strategic benchmark ($t^{iD} \neq t^{iN}$).

2.3.3. Strategic investment under a uniform emission tax

With a uniform tax system in place, firm *i*'s first-order condition for choosing capital in stage one is given by:

$$\frac{d\pi^i}{dk^i} = \pi_{k^i}^i + \pi_t^i \frac{dt}{dk^i} = 0 \qquad (20)$$

Like with differentiated emission taxes, the strategic term is positive since $\pi_t^i < 0$ and $dt / dk^i < 0$. So, the firm here too overinvests relative to the non-strategic benchmark.

Proposition 2: *When firms set their abatement investment before the government chooses its abatement tax, they over-invest relative to the non-strategic cost-minimising abatement investment level, both under a uniform and under a differentiated tax system.*

From a comparison of the formulas for dt^i / dk^i in (12) and dt / dk^i in (16), one could say that the incentive for strategic overinvestment is larger in the differentiated tax regime than in the uniform tax regime. However, because we have general functional

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[13] This terminology is commonly used in the literature on strategic investment (see, for instance, Tirole, 1988).

forms, one should not prematurely conclude from this that the level of investment is higher in the differentiated tax regime than in the uniform tax regime. In the next section, we formally show that this intuition is correct, subject to some mild regularity assumptions.

Note that, with differentiated taxes, firms' capital levels are strategically independent. However, with a uniform tax, even though firms do not compete in the product markets, firms' capital variables are interdependent. At the symmetric equilibrium, they typically are strategic substitutes: firm i's abatement investment lowers the uniform emission tax, thereby reducing other firms' incentives to invest in abatement.

3. Welfare
In this section, we explore how the alternative tax systems perform from a social point of view. It is therefore useful to examine the first-best and subsequently compare the performance of the alternative tax systems to the socially optimal benchmark.

3.1. The first best
We derive the first-best benchmark by deriving the output and abatement investment levels (which together determine emissions) a social planner would choose. We can rewrite expression (4) as

$$W = \sum_i [R^i(q^i) - C^i(q^i) - \Gamma^i(k^i) - D^i(e^i(q^i, k^i))] \tag{21}$$

The first-order condition for the socially optimal q^i is:

$$R^i_{q^i} - C^i_{q^i} - D^{i\,\prime} e^i_{q^i} = 0 \tag{22a}$$

while the first-order condition for the socially optimal level in abatement investment is:

$$-\Gamma^i_{k^i} - D^{i\,\prime} e^i_{k^i} = 0 \tag{22b}$$

A comparison of expressions (22a) and (7) tells us that firm i will produce the socially optimal output level provided that $t^i = D^{i\,\prime}$ under a differentiated tax system and, given symmetry, $t = D^{i\,\prime}$ under a uniform tax regime. Since we have shown that, even if firms choose abatement investment before the emission tax is set, $t^i = D^{i\,\prime}$, in both tax systems

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output is in fact optimally chosen, given the investment level. However, given $t^i = D^i{}'$, it is clear from a comparison of expression (22b) to expressions (19) and (20) respectively, that under neither of the two tax regimes do firms choose the socially optimal level of abatement investment. In fact, the first-best investment level is actually the abatement that minimises costs ($\pi^i_{k^i} = -\Gamma^i_{k^i} - t^i e^i_{k^i} = 0$), which firms would choose only if they were unable to act strategically (see expressions (17a) and (17b)).

3.2. Tax uniformity versus tax differentiation: A social ranking

We now wish to derive the social ranking of the alternative tax systems. Due to symmetry, the government always chooses the taxes optimally *given* the *investment* levels set by the firm (that is to say the government cannot do better by differentiating its tax.) However, as we have seen, investment levels depend on the tax regime.

As a preliminary to deriving a social ranking of the alternative tax systems, we compare the abatement level that would be chosen by a social planner and the levels of abatement investment in the alternative tax regimes.

Define κ as a symmetric level of k and $\omega(\kappa)$ as the level of welfare as a function of κ. From our earlier analysis we know that the level of κ that maximises this function is the cost-minimising investment level κ^N, where $\kappa^N = k^{iN}$ for all i. To compare investment levels in the different tax regimes without imposing special functional forms, we impose, here and henceforth, a mild regularity assumption.

Assumption 1: *Assume (i) that the profit function of the typical firm in the differentiated tax case is concave in investment in the region of investment that includes k^{iD}, k^{iU}, k^{iN} and (ii) that $\omega(\kappa)$ is concave in investment in the region of investment that includes $\kappa^D, \kappa^U, \kappa^N$*

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Proposition 3: *For $1 < n < \infty$, the symmetric investment level under the differentiated tax system is higher than the one under the uniform tax regime, which in turn is higher than the non-strategic cost-minimising abatement investment level ($k^{iD} > k^{iU} > k^{iN}$).*

Proof: See Appendix C

Given that the only distortion under the two tax regimes occurs in abatement investment and given the difference in abatement investment levels under the alternative tax regimes, we are now able to give a social ranking of the two tax regimes relative to the first-best.

Proposition 4: *With symmetric firms, the welfare level under a uniform emission tax system exceeds the welfare level under a differentiated emission tax system.*

Proof: See Appendix C

Figure 2 shows the welfare gap between the first-best and the alternative emission tax regimes, depicted as a function of the number of industries. The welfare level attained under a differentiated tax system is independent of the number of industries since the capital level remains unaffected by the latter. Hence, the welfare gap with the first-best is constant in n. Under the uniform tax system, the welfare gap with the first-best decreases in n and vanishes in the limit when $n \rightarrow \infty$.

[Figure 2 about here]

4. Strategic behaviour and collusion

In our model, firms choose pollution abatement non-cooperatively. In this section, we compare the social performance of a differentiated and a uniform tax system when firms collude to strategically manipulate the government. While it is well known that collusion

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between firms often has negative welfare effects[14], the same negative welfare effects are typically not attributed to a differentiated tax system. We show here that, in fact, a differentiated tax system is, from a social point of view, equally harmful as allowing firms that are behaving strategically to collude when choosing their investments.

Clearly, when the government sets differentiated taxes, the firms are playing independently against the government and so cannot gain anything from coordinating their investment levels. However, when the tax is uniform, each firm ignores the beneficial effect of its strategic behaviour on other firms. From the firms' viewpoint, there is a free-riding problem with respect to strategic behaviour. From a social point of view, this is a good thing as it reduces a firm's incentive to overinvest in abatement, which limits the strategic distortion. However, when firms collude in investment, they internalise the free-rider problem, which leaves them in a stronger position to manipulate government policy and will therefore give them a stronger incentive to invest strategically. Formally, when firms cooperate in pollution abatement, they choose investment levels by maximising joint profits with respect to k^i. Let $\Pi = \sum_i \pi^i$. The first-order condition for the cooperatively chosen investment levels is given by:

$$\frac{d\Pi}{dk^i} = \Pi_{k^i} + \Pi_t \frac{dt}{dk^i} = 0 \qquad \forall i \qquad (23)$$

We have $\Pi_{k^i} = \pi^i_{k^i}$ (since $\pi^j_{k^i} = 0$ for $j \neq i$) and $\Pi_t = n\pi^i_t$ under symmetry, while dt/dk^i is given by expression (16). Thus, expression (23) reduces to $\pi^i_{k^i} - \pi^i_t (D^{i\prime\prime} \pi^i_{q^i q^i} e^i_{k^i} / \Delta) = 0$. This is identical to the expression for the firm's investment choice under the differentiated tax system (expression (19) with dt^i/dk^i substituted by expression (12)). In fact, if firms, facing a uniform tax, are able to act as if they were a single firm, they will choose the same investment level as firms under a differentiated tax regime, which implies that actual tax rate would be the same too. Or, put differently, a system of differentiated taxes effectively mimics investment collusion under the uniform

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[14] Of course, we focus here only on the negative aspects of investment cooperation. Investment joint ventures could also involve information or cost sharing or other synergies that result in an increase in social efficiency.

tax system and has therefore the same negative welfare implications as investment collusion. Summarising:

Proposition 5: *With symmetric firms, if firms, facing a uniform emission tax, collude in abatement investment, investment levels, the actual emission tax rate and hence the welfare level are the same as under differentiated tax rates.*

Showing that tax differentiation yields the same outcome as collusive behaviour under a uniform tax illustrates rather vividly how harmful the differentiated tax regime can be.

5. Extensions

In this section, we will briefly discuss a few extensions of the basic model. In turn, we will allow for asymmetric firms, a welfare function that includes consumer surplus and oligopolistic industries.

5.1. Asymmetric firms

It is well known that, if firms are asymmetric (for instance, they have different costs or different degrees of market power[15]), differentiated emission tax rates have –unlike a uniform emission tax– the advantage that each firm can have a tax rate imposed on it that is tailor made to its emissions Hence, one has to trade-off this advantage of a differentiated tax system against its disadvantage in terms of its propensity to create greater strategic distortions, as we have argued, and against the well known disadvantages in terms of greater administrative costs.

5.2. Consumer surplus

In our basic model, we assumed firms' production was not intended for domestic consumption, thus there was no consumer surplus in the welfare function. Obviously, with domestic consumption, the first-best policy would require the use of two types of policy instruments: production subsidies to correct the output distortion and Pigovian emission taxes to correct the negative externality. When production subsidies are not

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[15] See Lee (1975).

available, the optimal (second-best) emission tax is smaller than the one derived in section 3[16]. Also, since the strategic investment behaviour to lower the emission tax is stronger under a differentiated tax regime than under a uniform tax system, the average differentiated emission tax rates tend to be lower than the uniform emission tax. Therefore, output and hence consumer surplus will be higher under differentiated emission taxes. Again, when choosing emission tax rates, one will need to trade off the disadvantages of differentiated emission tax rates against the advantages, one of which is a larger consumer surplus.

5.3. Oligopolistic industries

Our analysis can be extended in a straightforward way to multiple-firm industries[17]. Suppose that there are m symmetric firms in an industry, engaging in Cournot competition. Then, firm i's revenues will not only be affected by its own output (as in expression (5)), but also by its rivals' outputs, i.e., $R^i = R^i(q^i, \sum_{j, j \neq i}^{m} q^j)$ with $R^i_{q^i} > 0$ and $R^i_{q^j} < 0$ $(j \neq i)$; output levels of firms belonging to the same industry are strategic substitutes ($R^i_{q^i q^j} < 0$).

We will focus on a single (m-firm) industry as *across* industries, firms' behaviour is discussed in the basic model. However, *within* each industry, firms' strategic behaviour will also depend on whether emission taxes are uniform or firm-specific.

With *differentiated* (i.e., firm-specific) emission taxes, firms' face an additional strategic incentive under oligopoly that is not present in a monopolistic industry. Under Cournot oligopoly, higher rival output has a negative effect on a firm's profits. Hence, each firm *within* a particular industry will now, in addition to a strategic incentive to lower its own

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[16] See Barnett (1980).
[17] There is a number of recent papers addressing environmental policy in an oligopolistic set-up. Those models are mainly concerned with a comparison between emission taxes and standards in oligopoly (see, for instance, Van Long and Soubeyran (2001) and Lahiri and Ono (2007)) and do not compare uniform and differentiated emission taxes. Other papers have discussed the effects of environmental policy on market structure (see, for instance, Conrad and Wang (1993) and Kohn (1997)).

emission tax, also have a strategic incentive to lower its rival's market share through changing the *relative* tax rates. Given rival abatement, investment works to lower own taxes by *more* than the rivals' and thus will benefit the investing firm through increasing its market share. This additional strategic incentive suggests that firm-specific emission taxes generate even more severe distortions in abatement investment in oligopolistic than in monopolistic industries.

With a *uniform* emission tax, the strategic incentive to influence its rivals' output levels through manipulation of the relative tax rate is absent. Therefore, with a uniform emission tax, firms' strategic investment incentives in oligopolistic industries are not any different from those in monopolist industries.

This implies that the key result that differentiated emission tax systems have a stronger propensity to create strategic distortions in abatement investment than a uniform emission tax system holds *a fortiori* when industries are oligopolistic.

6. Conclusion

As a starting point of our analysis, we showed that the very existence of emission taxes creates strategic incentives for polluting firms that lead to new distortions. When the long-run commitment power implied by irreversible investment on the part of firms is combined with a short-run commitment to emission taxes on the part of the government, firms invest strategically in order to manipulate the government's emission taxes. This strategic incentive distorts firms' investment.

We found that a system of differentiated emission taxes has a greater propensity to foster strategic distortions in abatement investment than a uniform tax regime. Furthermore, under uniform taxation, strategic investment behaviour gets weaker as the number of firms subjected to the emission tax increases. Hence, given sufficient symmetry between firms, when firms choose their investment levels before governments set taxes, a system of differentiated emission taxation is socially inferior to a uniform tax system. In fact, we

showed that a system of differentiated emission taxes lowers social welfare to the same extent as collusion in pollution-abatement investment would.

In spite of its significance and harmfulness, strategic investment behaviour promoted by a policy package of differentiated tax rates may be easily overlooked, especially when it does not involve any directly unproductive rent-seeking activities, such as lobbying. While our analysis was carried out in a set-up with pollution and emission taxation, its message about the relative merits of uniform versus differentiated taxation extends far beyond the specific framework of our model[18]. We therefore argue more generally that, apart from a tax policy's efficiency and administering costs, one should also consider its propensity to engender strategic distortions when designing or assessing various tax policy packages.

Appendix A

In expression (14), let $\sum_i D'(e_{q^i}^i)^2 / \pi_{q^i q^i}^i \equiv M$ and $\sum_i (e_{q^i}^i)^2 / \pi_{q^i q^i}^i \equiv N$. Then,

$$\frac{dt}{dk^i} = \frac{1}{N^2}\left[n\frac{(e_{q^i}^i)^2}{\pi_{q^i q^i}^i}\frac{dM}{dk^i} - nD^{i\,\prime}\frac{(e_{q_i}^i)^2}{\pi_{q^i q^i}^i}\frac{dN}{dk^i} \right]$$

with $\dfrac{dM}{dk^i} = \dfrac{(e_{q^i}^i)^2}{\pi_{q^i q^i}^i}\left[D^{i\,\prime\prime}\left[e_{q_i}^i\dfrac{dq^i}{dk^i} + e_{k^i}^i \right] + (n-1)D^{j\,\prime\prime}\left[e_{q^j}^j\dfrac{dq^j}{dk^i} \right] \right] + D^{i\,\prime}\dfrac{dN}{dk^i}$. Simplifying

and using symmetry ($D^{i\,\prime\prime} = D^{j\,\prime\prime} = D^{\prime\prime}$), we obtain

$$\frac{dt}{dk^i} = \frac{D^{\prime\prime}}{n}\left[e_{q^i}^i\frac{dq^i}{dk^i} + (n-1)e_{q^j}^j\frac{dq^j}{dk^i} + e_{k^i}^i \right] \tag{A.1}$$

To derive dq^i / dk^i and dq^j / dk^i, we totally differentiate the first-order conditions for q^i and q^j and obtain, respectively:

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[18] One could, for instance, examine the same issue in a setting with positive production externalities and Pigovian subsidies. Prior to the subsidy being set, firms will strategically invest, that is, they will deviate from cost minimisation (they will, for instance, strategically overinvest in technologies that reduce marginal production costs) in order to raise the actual subsidy, but will do so to a larger extent when subsidy rates are differentiated.

$$\pi^i_{q^i q^i}\frac{dq^i}{dk^i}+\pi^i_{q^i t}\frac{dt}{dk^i}+\pi^i_{q^i k^i}=0 \tag{A.2a}$$

$$\pi^j_{q^j q^j}\frac{dq^j}{dk^i}+\pi^j_{q^j t}\frac{dt}{dk^i}+\pi^j_{q^j k^i}=0 \tag{A.2b}$$

with $\pi^j_{q^j k^i}=0$. Substituting dt/dk^i for expression (A.1), we formulate expressions (A.2a) and (A.2b) in matrix form:

$$\begin{bmatrix} \pi^i_{q^i q^i}+\pi^i_{q^i t}\dfrac{D''}{n}e^i_{q^i} & \pi^i_{q^i t}\dfrac{D''}{n}(n-1)e^j_{q^j} \\[2ex] \pi^i_{q^i t}\dfrac{D''}{n}e^j_{q^j} & \pi^i_{q^i q^i}+(n-1)\pi^i_{q^i t}\dfrac{D''}{n}e^i_{q^i} \end{bmatrix} \begin{bmatrix}\dfrac{dq^i}{dk^i}\\[2ex]\dfrac{dq^j}{dk^i}\end{bmatrix}= \begin{bmatrix}-(\pi^i_{q^i t}\dfrac{D''}{n}e^i_{k^i}+\pi^i_{q^i k^i})\\[2ex]-\pi^i_{q^i t}\dfrac{D''}{n}e^i_{k^i}\end{bmatrix} \tag{A.3}$$

Hence, we have

$$\frac{dq^i}{dk^i}=\frac{1}{\nabla}\left[-\left(\pi^i_{q^i t}\frac{D''}{n}e^i_{k^i}+\pi^i_{q^i k^i}\right)\left(\pi^i_{q^i q^i}+(n-1)\pi^i_{q^i t}\frac{D''}{n}e^i_{q^i}\right)+\pi^i_{q^i t}\frac{D''}{n}e^i_{k^i}\pi^i_{q^i t}\frac{D''}{n}(n-1)e^j_{q^j}\right] \tag{A.4a}$$

and

$$\frac{dq^j}{dk^i}=\frac{1}{\nabla}\left[-\pi^i_{q^i t}\frac{D''}{n}e^i_{k^i}\left(\pi^i_{q^i q^i}+\pi^i_{q^i t}\frac{D''}{n}e^i_{q^i}\right)+\left(\pi^i_{q^i t}\frac{D''}{n}e^i_{k^i}+\pi^i_{q^i k^i}\right)\pi^i_{q^i t}\frac{D''}{n}e^i_{q^i}\right] \tag{A.4b}$$

with the determinant of the coefficient matrix in (A.3) denoted by ∇, which simplifies to $\nabla\equiv\pi^i_{q^i q^i}(\pi^i_{q^i q^i}+\pi^i_{q^i t}D''e^i_{q^i})$ when we invoke symmetry. Using expressions (A.4a) and (A.4b), we can write

$$\frac{dq^i}{dk^i}+(n-1)\frac{dq^j}{dk^i}=-\frac{\pi^i_{q^i k^i}+\pi^i_{q^i t}D''e^i_{k^i}}{\pi^i_{q^i q^i}+\pi^i_{q^i t}D''e^i_{q^i}} \tag{A.5}$$

Substituting expression (A.5) into expression (A.1), using symmetry $(e^i_{q^i}=e^j_{q^j})$ and assuming $e^i_{q^i k^i}=0$ (and hence $\pi^i_{q^i k^i}=-te^i_{q^i k^i}=0$), we obtain:

$$\frac{dt}{dk^i}=\frac{D''}{n}\frac{-\pi^i_{q^i q^i}e^i_{k^i}}{-\pi^i_{q^i q^i}+D''(e^i_{q^i})^2}\quad\text{with }-\pi^i_{q^i q^i}+D''(e^i_{q^i})^2\equiv\Delta.$$

Appendix B

Like many papers in the literature we have imposed additive separability on the emission function so that $e^i_{q^i k^i} = 0$. We now consider what difference it makes when we relax this assumption.

Expressions (1)-(10) in the text remain. Expression (11) also remains valid, but now we have $dq^i / dk^i = (\pi^i_{q^i k^i} - D^{i\,\prime\prime} e^i_{q^i} e^i_{k^i}) / \Delta$ with $\pi^i_{q^i k^i} = -t^i e^i_{q^i k^i} \neq 0$; expression (12) is now replaced by:

$$\frac{dt^i}{dk^i} = \frac{D^{i\,\prime\prime}}{\Delta}(-\pi^i_{q^i q^i} e^i_{k^i} + \pi^i_{q^i k^i} e^i_{q^i}) \tag{B.1}$$

The first term between brackets in expression (B.1) is negative while the second (new) term will be positive if $\pi^i_{q^i k^i} = -t^i e^i_{q^i k^i} > 0$. Then –depending on the relative magnitudes of the two terms–, a firm's investment either lowers or raises its emission tax rate. Importantly however, while its sign is ambiguous, dt^i / dk^i is unlikely to be zero. Hence, firms can use k^i strategically to alter the differentiated tax rate.

Expressions (13)-(14) in the text and expressions (A.1)-(A.5) in Appendix A remain unaltered. However, since we now have $\pi^i_{q^i k^i} = -t e^i_{q^i k^i} \neq 0$, substituting expression (A.5) into expression (A.1) and using symmetry ($e^i_{q^i} = e^j_{q^j}$) yields:

$$\frac{dt}{dk^i} = \frac{D^{i\,\prime\prime}}{n\Delta}(e^i_{q^i} \pi^i_{q^i k^i} - e^i_{k^i} \pi^i_{q^i q^i}) \tag{B.2}$$

instead of expression (16). Hence, regardless of the sign of dt^i / dk^i and dt / dk^i, it remains that, like in the case in which $e^i_{q^i k^i} = 0$, $dt / dk^i = (1/n)(dt^i / dk^i)$ for $n > 1$. Expressions (17a)-(23) and the rest of the discussion in the text continue to hold.

Appendix C

Proof of proposition 3:

In this proposition we compare different *symmetric* levels of investment κ. The strategy of the proof is as follows. We first compare marginal profits from investment in different regimes at a common κ and then, with the use of *Assumption 1* (which is a mild regularity

assumption), we show that, the ranking of marginal returns to investment corresponds to the ranking of symmetric investment levels.

Substitute $\pi_{t^i}^i = -e^i$ into equation (19) to write marginal profits from investment under the differentiated tax regime as: $\dfrac{d\pi^i}{dk^i} = \pi_{k^i}^i - e^i \dfrac{dt^i}{dk^i}$. This is a continuous function of the level of investment and can be written more compactly as $m^D(\kappa)$ with $m^D(\kappa^D) = 0$. We will assume (reasonably) that profits in the differentiated tax case are strictly concave in k^i in the region that includes κ^N, κ^U and κ^D. Thus, $m^D(\kappa)$ falls in κ in that region. Similarly when we use $\pi_t^i = -e^i$ in equation (20) we can write the marginal profits from investment under the uniform tax regime as: $\dfrac{d\pi^i}{dk^i} = \pi_{k^i}^i - e^i \dfrac{dt}{dk^i}$. This function is also continuous, depends on the level of investments and can be written more compactly as $m^U(\kappa)$ with $m^U(\kappa^U) = 0$. Now compare these marginal returns at a common κ-level.

$$m^D(\kappa) - m^U(\kappa) = -e^i \left(\dfrac{dt^i}{dk^i} - \dfrac{dt}{dk^i} \right) = e^i \left(1 - \dfrac{1}{n} \right) \dfrac{D''}{\Delta} e_k^i \pi_{q^i q^i}^i \geq 0. \quad \text{Hence,} \quad m^U(\kappa) < m^D(\kappa)$$

provided that $1 < n < \infty$. We also need to compare the investment levels chosen by the firms in the different tax regimes with the non-strategic level. At the non-strategic investment level, $\pi_{k^i}^i = 0$. We can write this as $m^N(\kappa^N) = 0$ and we assume that $m^N(\kappa)$ is falling in κ in the relevant region (this is reasonable because, as we show later, $\pi_{k^i}^i = 0$ also implies the marginal social return to investment is at the optimal level and we assume that the social return to investment is concave in the relevant region). It is clear that at common κ-levels both of the bilateral comparisons $m^D(\kappa) - m^N(\kappa) = -e^i(dt^i/dk^i)$ and $m^U(\kappa) - m^N(\kappa) = -e^i(dt/dk^i)$ are positive.

Summarising: *(i)* $m^N(\kappa)$ and $m^D(\kappa)$ are monotonically falling in the relevant region; *(ii)* $m^N(\kappa^N) = 0$ at κ^N; $m^D(\kappa^D) = 0$ at κ^D and $m^U(\kappa^U) = 0$ at κ^U; *(iii)* at any common κ, $m^N(\kappa) < m^U(\kappa) < m^D(\kappa)$.

Now we can compare levels of κ in the different equilibria N, D and U. The proof that $\kappa^N < \kappa^U < \kappa^D$ is immediate. At κ^U, we have $m^N(\kappa^U) < m^U(\kappa^U) = 0 < m^D(\kappa^U)$. Furthermore, $m^N(\kappa)$ and $m^D(\kappa)$ are falling in κ and are zero only at the respective equilibrium levels ($m^N(\kappa^N) = 0$ and $m^D(\kappa^D) = 0$), thus $\kappa^N < \kappa^U$ and $\kappa^D > \kappa^U$ (see Figure 3).

[Figure 3 about here]

Proof of proposition 4:

Suppose the social planner was to choose the investment levels, then as we saw in the text it would set the investments at the non-strategic level. As we saw in the text, given symmetry of the firms we can write the social planner's objective function as $\omega(\kappa)$, which from assumption 1 is concave. The derivative of $\omega(\kappa)$ is $m^N(\kappa)$, which is falling in κ and the first-order condition for maximisation of $\omega(\kappa)$ implies $m^N(\kappa^N) = 0$. Given the concavity of $\omega(\kappa)$ welfare is falling the further away from κ^N and since $\kappa^N < \kappa^U < \kappa^D$ (from proposition 3), the welfare level under a uniform emission tax system exceeds the welfare level under a differentiated emission tax system.

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Figure 1: Non-strategic versus strategic investment
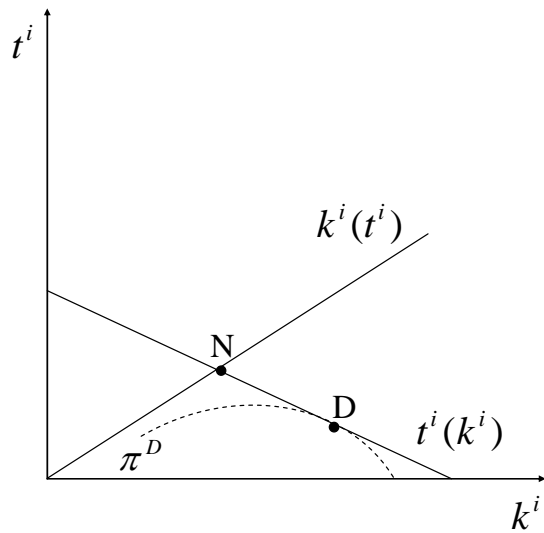
Figure 2: Social performance of a uniform and a differentiated emission tax system
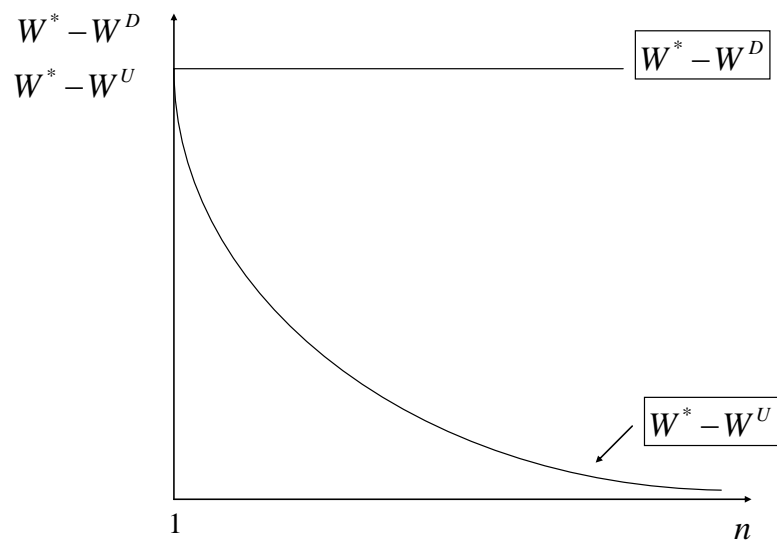
Figure 3: m(κ)-functions and equilibrium κ-levels