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## **A Theory of Optimal Green Defaults**

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# A Theory of Optimal Green Defaults

by

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This paper develops an analytical framework for studying the Baumol-Oates efficiency of traditional single instrument abatement policies vis-à-vis green defaults in the face of price inertia and deliberate defaulting by subpopulations. In this special case of behavioural heterogeneity, command and control approaches can outperform price-based instruments while pure tax/subsidy schemes need to be adjusted in order to achieve politically desired levels of abatement. We also prove that choice-preserving nudges are superior to any single-instrument policy in this case. An average marginal abatement cost rule is developed to optimise the green defaults and traditional policies of standards and prices under different degrees of market rigidity.

Keywords: (JEL: H21, H23, L51, Q52, Q58).

## 1 Introduction

Behavioural economists have observed a great number of seemingly irrational human behaviours, including inertia to price incentives and a stickiness of ‘defaults’ caused by indifference or a naive belief in experts and authorities. These behavioural traits are often observed in subpopulations such as elderly people or youngsters, but are also evident in comparisons of small and large firms. This gives rise to the profound problem of behavioural heterogeneity in economic policy. The notion that individuals, firms and corporations respond differently to economic stimuli and default rules has obvious consequences for the effectiveness and optimality of regulation. The long-standing debate about ‘Quantities versus Prices’ (Weitzman [25]) is just one of the candidates potentially affected by this; others are theories of enforcement (Malik [10]) and rules of liability and contract law (Jolls et al. [8]).

A more recent approach within behavioural economics is nudging (Thaler and Sunstein [23]). A nudge, according to Thaler and Sunstein, is “any aspect of the choice architecture that alters people’s behavior in a predictable way without forbidding any options or significantly changing their economic incentives.” In their classic “cafeteria example” a

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cafeteria owner arranges the food she has on offer in such a way that healthy foods are displayed at the front to stimulate customers to buy and eat more healthfully. Other famous examples of nudges are smaller plates in canteens to reduce calory intake, or technical and contractual defaults such as double page printer settings and pre-defined retirement plans (from opt-in to opt-out). By definition, a nudge does not change the set of choices, and so any attentive and otherwise unbounded, rational economic agent will not be affected by it.

Nudges have recently been applied in various policy contexts. In the US, President Obama selected Cass Sunstein as head of the Office of Information and Regulatory Affairs to “clarify the role of the behavioral sciences in formulating regulatory policy” following his 2009 memorandum on regulatory review (The White House [24]). In a parallel move, David Cameron created the Behavioral Insights Team (BIT) “to help organisations in the UK and overseas to apply behavioural insights in support of social purpose goals” ([www.behaviouralinsights.co.uk/](http://www.behaviouralinsights.co.uk/)). Similar efforts are underway in the EU, France and the Netherlands (Piniewski et al. [16], Oullier and Sauneron [13], Council of the Environment and Infrastructure [4]) and are being undertaken by international organizations such as the OECD (OECD [14]).

The use of nudges by social planners is assumed to improve people’s welfare; as such, it can be viewed as a form of paternalism. Indeed it has been coined “libertarian paternalism” (Sunstein and Thaler [22]) or, in the language of behavioural heterogeneity, “asymmetric paternalism”, as it will only affect subgroups with certain flaws in their rational decision-making (Camerer et al. [2]; Hausman and Welch [6], 126). Thaler and Sunstein recommend that the regulator should influence consumers’ choices in a way that make consumers better off, “as judged by themselves” (Thaler and Sunstein [23], 5). But, as Croson and Treich [3] emphasize, this “implicitly assumes that the regulator is rational and benevolent”, whereas there is ample evidence to the contrary in the literature, namely, of biased regulation . Nudging, in this critical view, “systematically put[s] the reader in the mind of the regulator” (Sugden [21]).

Another ethical issue relates to the potentially manipulative nature of nudges. Hansen and Jespersen [5] differentiate between a non-transparent manipulation of choice and behaviour by means of nudges and a transparent facilitation of behaviour (“empowerment nudges”). While this juxtaposition is stylized (and more work should be done on clarifying the categories), there seems to be a consensus in the literature that technical ‘green defaults’ (e.g. preset double-sided print options) are non-manipulative and ethically defensible within the terms of “Rawls’ Publicity Principle” (Thaler and Sunstein [23]). These rather complex ethical issues do not arise in this paper because we refer to the well-established Baumol-Oates approach of politically defined standards and efficiency-enhancing prices (Baumol and Oates [1]), while our concern is non-manipulative ‘green defaults’.

This paper deals with the effects of behavioural heterogeneity on environmental policy. Departing from the traditional taxes-versus-quotas debate in environmental economics, we demonstrate that direct regulation by means of command-and-control can outperform price-based policies under certain circumstances, and that the design of environmental subsidies and taxes as policy instruments needs to reflect behavioural heterogeneity. Moreover, we make the economic case for using green defaults as a choice-preserving policy mix of regulatory standards and price-based incentives, which lead to superior results compared to any single-instrument policy in populations that display behavioural heterogeneity.

## 2 The model

We consider emitting firms of  $K$  different technologies. These technologies are ordered with respect to abatement costs  $C_k(a), k = 1, 2, \dots, K$  where  $a$  is abatement. The technologies exhibit the following properties

$$\begin{aligned} C_1(a) &< C_2(a) < \dots < C_K(a), \quad \forall a > 0 \\ C'_1(a) &< C'_2(a) < \dots < C'_K(a), \quad \forall a > 0 \\ C_k(0) &= C'_k(0) = 0 \end{aligned} \tag{1}$$

To keep the analysis simple we assume a quadratic abatement cost function

$$C_k(a) = \frac{b_k}{2} a^2, \quad k = \{1, 2, \dots, K\}, \quad b_1 < b_2 < \dots < b_K \tag{2}$$

which satisfies (1).

Finally, we assume that there are  $N_k, k = \{1, 2, \dots, K\}$  emitters within each technology class. Hence, the total sum of emitters amounts to

$$N = \sum_{k=1}^K N_k \tag{3}$$

Environmental policy enters into the model by utilizing the price-standard approach introduced by Baumol and Oates [1]. The public authority introduces an emission reduction requirement. We start from unrestricted emissions  $\{e_1^{max}, e_2^{max}, \dots, e_K^{max}\}$  where  $e_k^{max}$  are emissions from technology  $k$  unrestricted by policy measures. We could also imagine that these amounts refer to historic emissions from a base year.

The authority fixes a minimum total reduction obligation for all emitting firms such that

$$\sum_{k=1}^K \sum_{i=1}^{N_k} a_{ik} \geq \gamma E = \gamma \sum_{k=1}^K N_k e_k^{max}, \quad 0 < \gamma < 1 \tag{4}$$

The efficient allocation of abatement across emitters can be achieved by minimizing total abatement costs, i.e.

$$\sum_{k=1}^K \sum_{i=1}^{N_k} C_k(a_{ik}) \tag{5}$$

subject to (4).

From the first order conditions we know that

$$C'_k(a_{ik}) = \lambda, \quad i = \{1, 2, \dots, N_k\}, k = \{1, 2, \dots, K\} \tag{6}$$

where  $\lambda$  is the Lagrangean.

Since the abatement cost functions are the same within each technology class we have

$$a_{ik} = a_k, \quad i = \{1, 2, \dots, N_k\}, k = \{1, 2, \dots, K\} \tag{7}$$

The optimal allocation of abatement effort  $\mathbf{a}^* = \{a_1^*, a_2^*, \dots, a_K^*\}$  equates marginal abatement costs to each other.

From the literature it is well known that a single emission price achieves an efficient allocation of both emissions and abatement levels.

Each emitter of technology class  $k$  minimizes her abatement costs while taking into account the costs of paying for her residual emissions.

$$\min_{a_k} [C_k(a_k) - \tau(a_k - \delta e_k^{max})] \Rightarrow C'_k(a_k) = \tau, \quad k = \{1, 2, \dots, K\} \quad (8)$$

where  $\tau$  is a tax rate and  $\delta = \{0, 1\}$ . If  $\delta = 0$  the environmental authority apply a tax-based approach. If  $\delta = 1$  the policy maker adopts subsidies to encourage abatement efforts. We could also conceive  $\tau$  as the equilibrium price on a certificate market where  $\delta = 0$  refers to an auction approach and  $\delta = \gamma$  could be described as grandfathering approach. Notice, that we have omitted index  $i$  because each emitting firm in class  $k$  choose the same abatement level  $a_k$ .

Since each emitter sets her marginal abatement costs equal to the tax rate an efficient allocation of emissions is achieved (see (6)). The environmental target is achieved by choosing the tax such that the reduction goal (4) is satisfied. Hence,  $\tau^*$  is chosen such that

$$\sum_{k=1}^K N_k a_k^{\tau^*} = \gamma E \quad (9)$$

where  $a_k^{\tau^*}$  solves (8). Alternatively, a command and control approach could be applied. In this case an overall uniform lower limit of abatement levels  $A$  is introduced such that the environmental objective is achieved. To do so, the limit per emitter is set such that

$$A = \frac{\gamma E}{\sum_{k=1}^K N_k} \quad (10)$$

Needless to say, this policy is inefficient if marginal abatement cost functions differ.

## 2.1 The performance of traditional policy instruments under behavioural heterogeneity

In the following we analyse how the policy instruments reviewed in the previous section affect the allocation of abatement levels when emitters do not always behave rationally across the population, i.e. when they choose their abatement levels so as to minimize their costs. Let us assume that emitting firms behave either rationally with probability  $\pi$  or exhibit passive behaviour with probability  $(1 - \pi)$  by neglecting any optimizing efforts (inertia). We assume that these probabilities are independent of technology type  $k$ .

Passive behaviour implies that firms do not respond to price incentives such as taxes or subsidies. They only comply with measures imposed in the context of an command and control approach. If the policy maker relies only on a price oriented policy (taxes, subsidies, etc.), she will have to take this heterogeneous behaviour into account. The same applies to the determination of a single overall abatement level for firms. In addition, the policy has to take account the stochastic nature of abatement behaviour, which requires the calculation of expected values.

To begin with, let us assume that the policy maker relies exclusively on a tax approach. In this case the environmental authority needs to calculate expected abatement levels. Take e.g. technology class  $k$  consisting of  $N_k$  emitters. It is a standard tenet of probability theory<sup>1</sup> that the probability of one out of two events occurring  $i$  times ( $i : 0 < i < N_k$ ) is distributed according to the binomial distribution function

$$\frac{N_k!}{(N_k - i)!i!} \pi^i (1 - \pi)^{(N_k - i)} \quad (11)$$

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<sup>1</sup>See e.g. Mood, Graybill and Boes [12]

Here, the one event is that emitters behave rationally. The complementary event is that emitters behave passively. Accordingly, this probability applies to  $N_k - i$  firms behaving passively.

To calculate the expected aggregate abatement level under behavioural heterogeneity we first have to determine the expected abatement level of each technology class. If a firm behaves rationally it will choose abatement according to (8), thus leading to a level  $a_k^\tau$ . Hence, expected aggregate emissions of class  $k$  will be<sup>2</sup>

$$\sum_{i=0}^{N_k} \left( \frac{N_k!}{(N_k - i)!i!} \pi^i (1 - \pi)^{(N_k - i)} i \right) a_k^\tau = \pi N_k a_k^\tau \quad (12)$$

The same procedure is applied to passively behaving firms that merely simply comply with a abatement prescription  $A = 0$ . The probability of this behaviour is  $1 - \pi$ . Hence, the expected abatement level of technology class  $k$  is

$$\sum_{j=0}^{N_k} \left( \frac{N_k!}{(N_k - j)!j!} (1 - \pi)^j \pi^{(N_k - j)} j \right) A = (1 - \pi) N_k A \quad (13)$$

The aggregated expected abatement level of all  $k$  technology classes follows directly by adding (12) and (13) across all classes:

$$\pi \sum_{k=1}^K N_k a_k^\tau + (1 - \pi) \sum_{k=1}^K N_k A \quad (14)$$

It is a straightforward matter to calculate the aggregate expected abatement costs in a similar way:

$$\begin{aligned} AAC &= \sum_{k=1}^K \left[ \sum_{i=0}^{N_k} \left( \frac{N_k!}{(N_k - i)!i!} \pi^i (1 - \pi)^{(N_k - i)} i \right) C_k(a_k^\tau) \right. \\ &\quad \left. + \sum_{j=0}^{N_k} \left( \frac{N_k!}{(N_k - j)!j!} (1 - \pi)^j \pi^{(N_k - j)} j \right) C_k(A) \right] \\ &= \pi \sum_{k=1}^K N_k C_k(a_k^\tau) + (1 - \pi) \sum_{k=1}^K N_k C_k(A) \end{aligned} \quad (15)$$

In the following we analyse the performance of three traditional policy instruments under the behavioural heterogeneity introduced above.

### 1. Tax policy

Under a tax regime, rational emitters behave according to (8), leading to abatement levels  $a_k^\tau$ . Notice, that  $\delta = 0$ . Since the policy maker relies solely on an emissions tax there are no constraints on quantity, hence  $A = 0$ . Thus the tax rate  $\tau = \bar{\tau}$  has to be fixed such that the expected aggregate abatement level complies with the environmental target (see (4)). Thus we have

$$\pi \sum_{k=1}^K N_k a_k^\tau = \gamma E \quad (16)$$

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<sup>2</sup>This derivation follows the usual proof in the standard literature. See e.g. Mood, Graybill and Boes [12], 89.

## 2. Abatement subsidies

Again, the policy maker introduces a price incentive to subsidize abatement. In this case, (8) is valid for  $\delta = 1$ . The subsidy rate has to be chosen such that (16) is met.

## 3. Direct abatement regulation

In this case, the regulatory authority does not rely on prices. Instead, it fixes an abatement standard  $A > 0$  with which each emitting firm has to comply. Thus, all firms will abate according to this provision irrespective of their behavioural type. The standard  $A = \bar{A}$  must be set such that the environmental target is achieved, i.e.

$$\bar{A} \sum_{i=1}^K N_k = \gamma E \quad (17)$$

From the traditional model we know that a price setting policy always guarantees that the environmental target will be achieved in an efficient way, provided the emission price level is set properly. In contrast to this, introducing a mandatory abatement level is inefficient as it leads to higher aggregated abatement costs than in the case of a tax/subsidy-approach. At this point it is interesting to analyse whether this assessment applies also in a world where emitters display heterogeneous behaviour.

### Result 1

- *In the case of behavioral heterogeneity the tax/subsidy rate must be higher than in the case of a pure price-standard approach, i.e.  $\bar{\tau} > \tau^*$ .*
- *A price oriented policy is not always better than a quantity-setting regulation. The relative performance depends on technological properties, the distribution of technology classes and the proportion of rational firms.*

Proof:

The first part follows directly by comparing (9) with (16). The second part will be shown by example in section 2.3 below.

Obviously, if a certain proportion of firms is price resistant, a tax policy can only achieve the abatement target if the tax rate is higher than in the classical price standard approach case. This inertia calls for the use of an additional instrument, namely, the green defaults introduced in the following section.

## 2.2 Green defaults as optimal policy mix

We have assumed that a certain proportion of emitters do not actively choose their emission levels by minimizing their abatement costs. One remedy against this inertia could be a command and control-style quantity regulation which forces emitters to achieve certain level of abatement irrespective of their abatement costs. The other more flexible option is to introduce green defaults. In our model a green default is a requirement of a fixed abatement level with which each emitter has to comply. However, in contrast to the traditional quantity constraint of a command and control policy, here emitters are allowed to deviate from the prescribed level if they wish to do so. The decision to deviate leads to additional costs (benefits) in terms of tax payments (subsidies). If the active

emitter increases her abatement level beyond the default value she receives subsidies; if she reduces her abatement efforts she is required to pay tax. This mechanism resemble the ‘flexibility regulations’ of the early U.S. Clean Air Act (‘bubble’ and ‘offsets’) but can also be seen in any standard-based rule, for example a speed limit, which gives rise to monetary sanctions, fines or liability, if the choice of speeding-and-paying can be modeled as a deliberate economic decision of the agent<sup>3</sup>.

To capture this mechanism in the model we rewrite (8) as follows:

$$\min_{a_k} [C_k(a_k) - \tau(a_k - A)] \quad (18)$$

As before,  $\tau$  is a tax rate to be fixed and  $A$  is the default value. The rational emitter of technology class  $k$  minimizes total abatement costs leading to

$$C'_k(a_k) = \tau, \Rightarrow a_k^\tau, \quad k = \{1, 2, \dots, K\} \quad (19)$$

In contrast to rational firms passive emitters will stick to the green default  $A$ . Having thus described the behaviour of all emitting firms we can now proceed to the task the policy maker has to solve.

As in the traditional policy setting the task consists in choosing the policy that minimizes aggregate abatement costs. Since emission behaviour is random the relevant object function is expected aggregate abatement costs derived in (15). In contrast to the traditional setting, the policy maker does not choose between a price or a quantity approach but instead seeks to utilize both instruments. Thus, green nudging can be modelled as the application of a policy mix approach consisting of prices (taxes/subsidies) and quantities (green defaults).

Minimizing aggregate expected abatement costs (15) subject to the environmental constraint

$$\pi \sum_{k=1}^K N_k a_k^\tau + (1 - \pi) \sum_{k=1}^K N_k A \quad \gamma E \quad (20)$$

leads to the following first order conditions<sup>4</sup>

$$\pi \sum_{k=1}^K N_k (C'_k(a_k^\tau) - \lambda) \frac{\partial a_k^\tau}{\partial \tau} = 0 \quad (21)$$

$$(1 - \pi) \sum_{k=1}^K N_k (C'_k(A) - \lambda) = 0 \quad (22)$$

where  $\lambda$  is the Lagrangean. Bearing in mind that  $\frac{\partial a_k^\tau}{\partial \tau} > 0$  and utilizing (19) we can transform (22) to

$$\frac{\sum_{k=1}^K N_k C'_k(A)}{\sum_{k=1}^K N_k} = \tau \quad (23)$$

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<sup>3</sup>In the more general terms of nudging it would be any behavioral standard which preserves the choice of disobedience (over-obedience) with the consequence of additional psychological or situational economic costs (benefits) such as the ‘costs’ of changing TV settings from energy-saving to time-saving stand-by modes or the ‘benefits’ of having healthy foods within arms reach.

<sup>4</sup>These conditions are also sufficient to characterize the optimal policy due to the assumed properties of the abatement cost functions.



The green default should be set such that the average marginal abatement costs of all emitters is equated to the tax rate, which is in turn equal to the marginal abatement costs of rational firms. We call this optimality condition the *average marginal abatement cost rule* (AMAC). This rule is easily explained if one multiplies the nominator and the denominator by  $(1 - \pi)$  exhibiting the ratio as the average marginal abatement costs of passive firms<sup>5</sup>. Since passive emitters do not exploit efficiency gains by equating their marginal abatement costs to the tax rate the policy maker should set the green default such that these firms' average marginal abatement costs are equal to the marginal abatement costs of each rational firm.

Together with the environmental constraint (20) the AMAC can be used to determine the optimal policy mix  $\{\tau^o, A^o\}$  whose properties are summarized in the following proposition.

## Result 2

1. *Optimality of policy mix: It is optimal to introduce a green default, i.e. a pure price policy approach is suboptimal. An exclusively quantity approach is likewise suboptimal. In formal terms:*

$$0 < A^o < \frac{\gamma E}{(1 - \pi) \sum_{k=1}^{N_k} N_k} \quad (24)$$

2. *The tax rate of the policy mix approach is higher than the tax rate of the price standard approach. Formally:*

$$\bar{\tau} > \tau^o > \tau^* \quad (25)$$

*Hence, under a green default approach every rational emitter will invest more in abatement than in the price standard approach case.*

Proof: See appendix.

The first assertion simply states that both instruments should be utilized. Price responsive firms react to the tax rate and passive emitters follow the green default. Since aggregated abatement costs are to be minimized both instruments are deployed such that the marginal abatement costs of both behavioural groups are equated, as stated by the average marginal abatement cost rule (36). Figure 1 illustrate this finding. The AMAC-rule is satisfied at the point  $\{A_o, \tau^o\}$ . From figure 1 one also can easily see that  $\bar{\tau} > \tau^o$  In the pure tax approach the tax rate  $\bar{\tau}$  is chosen such that the abatement target  $\gamma E$  is achieved (point pT). The tax rate must be set rather high to meet this target. Aggregated abatement costs can be reduced by lifting the abatement level of passive emitters and thereby making it possible to reduce the tax rate.

The first part of the proposition and the tax relation  $\bar{\tau} > \tau^o$  is easily to understand. This does not extend to the relation between  $\tau^o$  and  $\tau^*$  which follows from the AMAC-rule and the convexity of the abatement cost curve. The proof contained in the appendix shows that under the green default the sum of abatement levels of rational firms is always higher than the sum of regulated abatements of the passive emitters, i.e.

$$\sum_{k=1}^K N_k a_k^{\tau^o} > \sum_{k=1}^K N_k A^o \quad (26)$$

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<sup>5</sup>The equivalence of total average marginal abatement costs with the average marginal costs of passive firms comes from the independence of  $\pi$  from the technology classes.

Inserting this relation into (20) immediately yields the result, that the tax rate  $\tau^o$  would lead to higher total abatement efforts than required in the textbook case, i.e.

$$\sum_{k=1}^K N_k a_k^{\tau^o} > \gamma E. \quad (27)$$

It is interesting to observe that the presence of passive emitters ( $\pi < 1$ ) requires a higher tax rate on emissions than in the classical price standard approach despite the introduction of a green default that secures the abatement by passive emitters.

### Corollary 1

- *The strictness of environmental policy decreases (increases) with the fraction of rational (passive) emitters. In formal terms:*

$$\frac{\partial \tau^o}{\partial \pi} < 0 \quad \text{and} \quad \frac{\partial A^o}{\partial \pi} < 0 \quad (28)$$

- *Aggregated abatement costs decrease as the proportion of price responsive firms increases, i.e.*

$$\frac{\partial AAC}{\partial \pi} < 0 \quad (29)$$

This corollary re-emphasizes the findings of result 2 by following the optimal policy trajectory with respect to the fraction of rational firms. Starting from the textbook case  $\pi = 1$ , it becomes clear that environmental policy must be strengthened. Both, the tax rate and the green default must be increased as  $\pi$  decreases in order to guarantee the environmental target  $\gamma E$ . The larger the fraction of passive emitters the higher the green standard and, at the same time, the higher the tax rate.

The fraction of passive emitters can be seen as a measure of the rigidity of markets. More rigid markets demand stronger regulatory interventions. In the case of pure taxes, regulators need to consider that some passive parties can not be moved by taxes. They will have to adopt higher taxes for rationally acting emitters to achieve the overall desired level of abatement.

The impact on aggregate abatement costs (see (15)) is also rather obvious. The larger the fraction of rational firms minimizing their abatement costs the lower aggregate abatement costs are.

## 2.3 Example: two technology classes

The results obtained can be exemplified for the case of two technologies  $b_1 < b_2$  and  $N_1 = N_2$  emitters within each technology class. Utilizing the abatement cost function (2) we can derive from (19) the optimal abatement efforts of rational emitters

$$a_k^\tau = \frac{\tau}{b_k}, \quad k = 1, 2 \quad (30)$$

Inserting (30) into (20) establishes the default value  $A$  as a function of  $\tau$  such that the emissions standard  $\gamma E$  is met. In the following figure<sup>6</sup> the emissions restriction is represented by the blue line.

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<sup>6</sup>Figure 1 is plotted for the example:  $b_1 = 0.01$ ,  $b_2 = 0.04$ ,  $\pi = 0.5$ , and  $\gamma E = 8000$ .

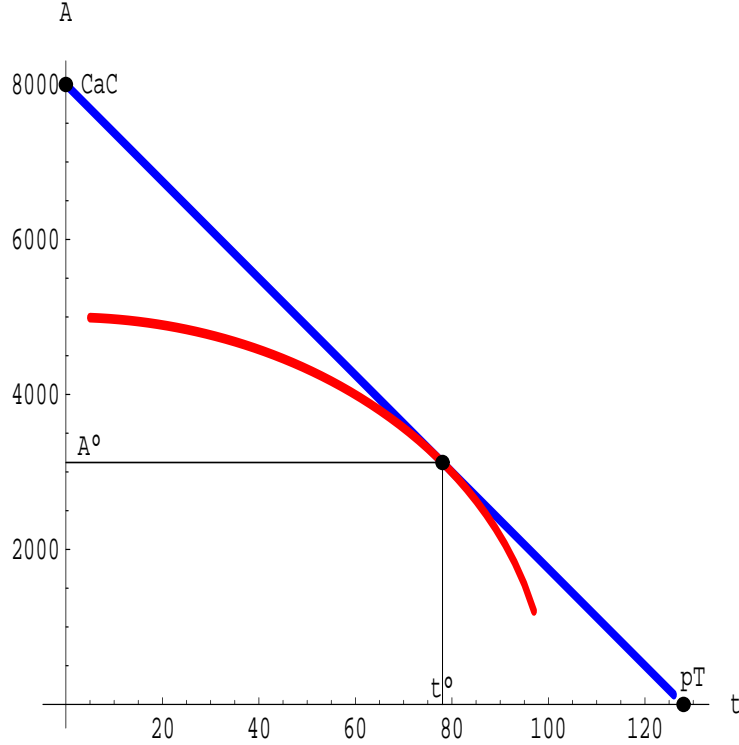


Figure 1: Optimal Policy

Similarly we can draw iso-abatement-costs curves by utilizing (15). Iso-abatement cost curves can be obtained by inserting (30) into (15) for a predefined cost level  $CC$ . The red curve gives the iso-abatement cost curve for the cost level which relates to the optimal solution characterized by (23) and (20). Iso-abatement curves to the south west (north east) represent lower (higher) costs. The optimal policy mix  $\{t^\circ, A^\circ\}$  is located where the slopes of both curves are equated. Figure 1 also enables us to demonstrate the findings of Result 1. A pure tax policy approach (point  $pT^7$ ) leads to a tax rate that is higher than the optimal tax rate. Vice versa, the abatement provision given by the pure command and control approach (point  $CaC^8$ ) is higher than the green default  $A^\circ$ . Needless to say, points ( $pT$ ) and ( $CaC$ ) lead to higher aggregate abatement costs than under the optimal policy mix.

Whether  $pT$  or  $CaC$  leads to higher aggregate abatement costs (see result 1) has yet to be evaluated. In the following Figure we have drawn total abatement costs for the pure tax case (hatched surface) and for the command-and-control approach (plain surface). The hatched surface is obtained by inserting the pure tax policy approach into the sum of both abatement cost functions. From (16) we obtain

$$a_1^\tau + a_2^\tau = \left[ \frac{1}{b_1} + \frac{1}{b_2} \right] \tau = \gamma E / \pi \quad (31)$$

<sup>7</sup>At point  $pT$  we have  $\tau = \bar{\tau}$ .

<sup>8</sup>At point  $CaC$  we have  $A = \bar{A}$ .

which can be solved for  $\bar{\tau}$ . Inserting  $\bar{\tau}$  into the quadratic abatement cost function yields the total<sup>9</sup>

$$\pi[C_1(a_1^{\bar{\tau}}) + C_2(a_2^{\bar{\tau}})] = \frac{(\gamma E)^2 b_1 b_2}{2\pi(b_1 + b_2)} \quad (32)$$

Notice, that the aggregated abatement costs depend on technologies ( $b_i$ ) and on the proportion of rational emitters. The surface is drawn as a function of  $b_1$  and  $b_2$ . Similarly, total abatement costs under a command and control approach can also be derived. Utilizing the abatement cost functions and (17) we get

$$C_1(\bar{A}) + C_2(\bar{A}) = \frac{(b_1 + b_2)(\gamma E)^2}{2 \cdot 4} \quad (33)$$

Again, total costs are a function of  $b_1$  and  $b_2$ .

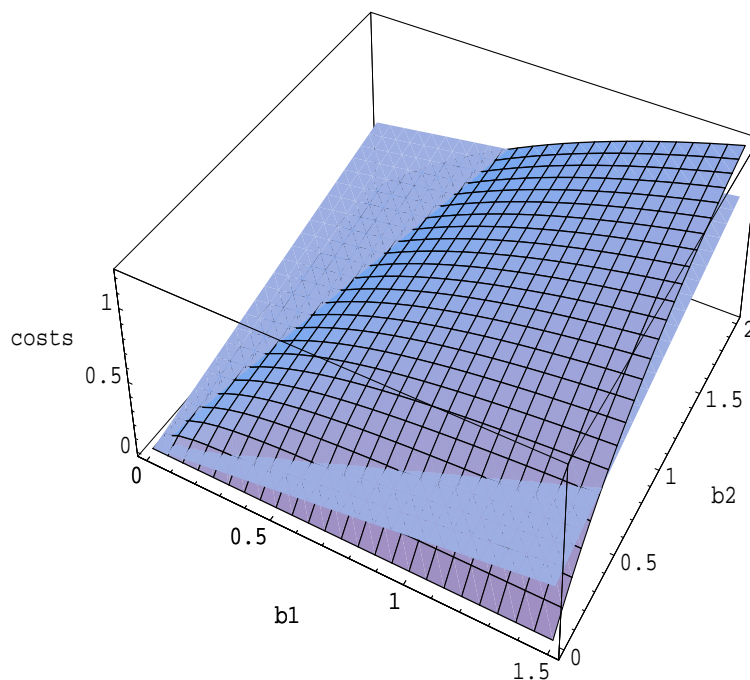


Figure 2: A pure policy comparison

The figure<sup>10</sup> clearly shows that the success of both pure policies depends on the structure of technologies. If technologies are very diverse, i.e. if the absolute amount of the difference of  $b_1 - b_2$  is large, then the pure tax policy approach fares better than the command-and-control-approach, and vice versa. This result is easily understood. In the pure tax case the tax rate must be rather high due to the fact that only a fraction of all emitters will respond. Hence, to fulfill the standard  $\gamma E$  the policy must be fairly strict, leading to relatively high aggregate abatement costs due to the convexity of cost curves (Note, that passive firms do not abate in the pure tax case). By contrast, an overall standard

<sup>9</sup>Abatement costs for passive emitters are nil, since  $A = 0$ . They simply pay the full tax burden on their unreduced emissions baseline ( $e_i^{max}$ ). Notice, that in these partial equilibrium models it is assumed that tax receipts are returned to the emitting industry sector on a lump-sum basis.

<sup>10</sup>To keep numerical values low, we have rescaled the vertical axes by dividing aggregate abatement costs of both policies by  $(\gamma E)^2$ .

applied to all emitters can be relatively weak since all firms have to fulfill the provision A. However, this command and control approach is rather inefficient in the case of heterogeneous marginal abatement cost curves. Thus, there are two countervailing forces that affect total abatement costs under the two regulatory regimes. On the one hand, the pure tax approach is highly efficient but covers only the proportion of rational emitters. On the other hand, we have the command and control approach covering all emitters but being inefficient. The more technologies differ the greater this inefficiency is. This can be seen by the area in the  $b_1 - b_2$  plane where aggregate abatement costs under a pure tax policy are higher than under the command and control approach decreases if the fraction of rational firms increases. If we equate (32) and (33) and solve for, say,  $b_2$  we get the two solutions

$$b_{21} = \frac{(2 + \pi) + 2\sqrt{(1 - \pi)}}{\pi} b_1 \quad b_{22} = \frac{(2 + \pi) - 2\sqrt{(1 - \pi)}}{\pi} b_1 \quad (34)$$

Both solutions are the mathematical expression of the cut lines of the hatched with the plain surface. If we derive (34) with respect to  $\pi$  we can observe that the slope of the left (right) solution for  $b_2$  decreases (increases). If the fraction of rational firms increases (decreases) the set of  $b_1 - b_2$ -combinations where total abatement costs under a pure tax policy are higher than under a command and control approach contracts (broadens). The implication is quite obvious. The more rational emitters there are the more appropriate is a price-oriented policy approach and vice versa: the more passive firms exist the more a command and control approach is appropriate.

### 3 Summary and outlook

This paper has demonstrated that the existence of subpopulations with price resistant behaviour and deliberate defaulting has important implications for the design of environmental policy. Uniform command and control approaches can outperform price-based instruments, and pure tax/subsidy schemes need to be adjusted to achieve the politically desired level of total emissions. As a choice-preserving policy mix green defaults are superior to any single-instrument policy in the case of behavioural heterogeneity. Much remains to be done. There are many examples of the effectiveness of nudges in environmental policies, for example in policies to improve energy efficiency and the choice of green energy (Shogren et al.[17] and [18]). However, most of the literature is concerned with individual and household environmental behaviour. Few studies have looked at organizational nudges despite pervasive evidence of managerial inattention and organizational routines (Sims [20]; Wiederholt [26]; Henderson and Kaplan [7]). Both of these could help reveal important factors that contribute to price inertia and deliberate defaulting in firms. Additionally, the interplay of consumer inertia and dynamic pricing (Zhao et al. [9]) has not been sufficiently considered in the nudging literature. Time-variant pricing of energy usage, for example, would increase the difference in profits from behavioural inertia compared to rational choice and consequently reduce the probability of deliberate defaulting within a population, as we demonstrate in this paper. The more general question arising from these analyses is how the fraction  $\pi$  of behavioural inertia within a population could be reduced by means of tailored policy efforts. While environmental awareness raising and education could clearly contribute to a lower  $\pi$  and thus to greater regulatory efficiency according to our findings, they would also involve additional costs of implementation etc. Consideration of these additional instrument costs and benefits as well as the remaining

behavioural inertia may lead to even more policy mixing. Green defaults combined with any such instrument may prove superior to both traditional single-instrument policies (such as quotas and taxes) and stand-alone nudges. Finally we would expect important insights to be gained from applying our theory of optimal nudging to different special cases. For example, empirical findings show that the default inclusion of natural hazards in general homeowners insurance makes a considerable difference in the uptake of natural hazards insurance compared to a rule of separation of both lines (Schwarze and Wagner [17]). Based on our theory of optimal defaults we would expect that ‘insurance nudging’ is economically superior to mandatory insurance (with no choice-preserving mechanism) or direct regulation of private risk mitigation. Another promising area of study, following the recent findings of Parry et al.[15], would be to compare emissions standards (which allow a trade-off between activity level and technology choice) and technology fixes such as fuel efficiency standards for cars.

## 4 Appendix

### 4.1 Proof of result 2

To prove the first statement assume, per absurdum, that  $A^o = 0$ . From (23) it follows that  $\tau^o = 0$  and, hence, by (19) that  $a_k^o = 0, \forall k$ . But this contradicts the environmental constraint (20). Next assume, per absurdum, that

$$A^o = \frac{\gamma E}{(1 - \pi) \sum_{k=1}^K N_k} \quad (35)$$

From the environmental constraint (20) it follows that  $\tau^o = 0$  so as to reduce the abatement levels to zero, i.e.  $a_k^o = 0$ . But from (23) it follows that  $\tau^o > 0$  which is a contradiction.

To prove the second statement we utilize the assumed quadratic form of the abatement cost function (see (2)). Utilizing (19) AMAC can be rewritten as:

$$\frac{\sum_{k=1}^K N_k b_k A}{\sum_{k=1}^K N_k} = \tau = b_j a_j^{\tau^o}, \forall j = \{1, 2, \dots, K\} \quad (36)$$

Multiplying both sides by  $N_j$  and summing up leads to

$$\sum_{k=1}^K N_j b_j (A^o - a_j^{\tau^o}) = 0 \quad (37)$$

From (37) we can infer that there must be a  $i \in \{1, 2, \dots, K\}$  such that  $a_{i-1}^{\tau^o} > A$ ,  $a_i^{\tau^o} \leq A^o$  and  $a_{i+1}^{\tau^o} < A^o$ . (37) can be rewritten as

$$b_i (A^o - a_i^{\tau^o}) = - \sum_{k=1}^{i-1} N_k b_k (A^o - a_k^{\tau^o}) - \sum_{k=i+1}^K N_k b_k (A^o - a_k^{\tau^o}) \quad (38)$$

Adding to both sides  $b_i \sum_{k \neq i}^K N_k (A^o - a_k^{\tau^o})$  leads to

$$b_i \sum_{k=1}^K N_k (A^o - a_k^{\tau^o}) = \sum_{k=1}^{i-1} N_k (b_i - b_k) (A^o - a_k^{\tau^o}) + \sum_{k=i+1}^K N_k (b_i - b_k) (A^o - a_k^{\tau^o}) \quad (39)$$

From the assumed properties of the abatement costs function and from (8) we know, that

$$\begin{aligned} b_1 &< b_2 < \dots < b_K \\ a_1^{\tau} &> a_2^{\tau} > \dots > a_K^{\tau} \end{aligned} \quad (40)$$

Taking these properties into account it follows from (39), that

$$\sum_{k=1}^K N_k(A^o - a_k^{\tau^o}) < 0 \Rightarrow \sum_{k=1}^K N_k a_k^{\tau^o} > \sum_{k=1}^K N_k A^o \quad (41)$$

Define the difference

$$\epsilon = \sum_{k=1}^K N_k a_k^{\tau^o} - \sum_{k=1}^K N_k A^o > 0 \quad (42)$$

Then it follows from (20)

$$\sum_{k=1}^K N_k a_k^{\tau} = \gamma E + (1 - \pi)\epsilon \Rightarrow \sum_{k=1}^K N_k a_k^{\tau} > \gamma E \quad (43)$$

Since  $a_k^{\tau}$  is a positive monotone function with respect to  $\tau$  a comparison of (9) with (43) shows immediately that  $\tau^o > \tau^*$ .

#### 4.1.1 Proof of corollary 1

Differentiating (23) and (20) with respect to  $\pi$  leads to

$$\begin{pmatrix} -\sum_{k=1}^K N_k & \sum_{k=1}^K N_k C_k''(A) \\ \pi \sum_{k=1}^K N_k a_k^{\tau^o} & (1 - \pi) \sum_{k=1}^K N_k \end{pmatrix} \begin{pmatrix} \frac{\tau^o}{\pi} \\ \frac{A^o}{\pi} \end{pmatrix} = \begin{pmatrix} 0 \\ -\sum_{k=1}^K N_k a_k^{\tau^o} \end{pmatrix} \quad (44)$$

From (44) it is easy to calculate

$$\frac{\partial \tau^o}{\partial \pi} = \frac{(\sum_{k=1}^K N_k a_k^{\tau^o})(\sum_{k=1}^K N_k C_k''(A))}{|\Sigma|} < 0 \quad (45)$$

and

$$\frac{\partial A^o}{\partial \pi} = \frac{(\sum_{k=1}^K N_k)(\sum_{k=1}^K N_k C_k''(A))}{|\Sigma|} < 0 \quad (46)$$

where the determinant of the system matrix is  $|\Sigma| < 0$ .

The second part of the corollary can be proved by recalling (15)

$$AAC = \pi \sum_{k=1}^K N_k C_k(a_k^{\tau}) + (1 - \pi) \sum_{k=1}^K N_k C_k(A) \quad (47)$$

Utilizing the envelope theorem the derivative of AAC with respect to  $\pi$  is

$$\frac{\partial AAC}{\partial \pi} = \sum_{k=1}^K N_k C_k(a_k^{\tau}) - \sum_{k=1}^K N_k C_k(A) < 0 \quad (48)$$

The sign follows from the AMAC-rule (36) and the cost minimizing behaviour of rational firms (see (19)).

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