Environmental Incentives: Nudges or Tax?*

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Abstract

We consider a model where individuals can voluntarily contribute to improve the quality of the environment. They differ with regards to their confidence in the announcement of the regulator about the risk of pollution, modelized in a RDEU model, and their environmental sensitivity. We compare the efficiency of a tax to increase individual contributions with the advantages of a nudge based on the announcement of the social optimum to each individual. Under some conditions, a nudge performs better than a tax, in particular, because the individual reaction depends directly on sensitivity, while only indirectly with a tax. Moreover, contrary to a tax based on the contributions that are not provided compared to the social optimum, a nudge does not require as much information as in the case of such a tax. Lastly, its implementation is much cheaper. We propose simulations to illustrate our results.

Key Words : incentives, nudge, environmental sensitivity, probability distortion, tax.

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1 Introduction

In Economics, there has been a long tradition of market-based incentives to regulate environmental pollution. Regulations through prices (monetary constraints) and regulations through quantities (volume constraints) are commonly used. In both cases, the objective is to change consumers' behavior to pollute less. However, these tools are not without drawbacks. Considering taxes, they are sometimes difficult to implement from a political point of view. Lobbies and/or political parties struggle against their implementation. Recently, the French government intended to implement an ecological tax on heavy trucks (in Bretagne). However, because of the public pressure it faced, in October 2014 the government postponed this tax *sine die*. Experimental evidence (Kallbekken et al. (2011)) also highlights the lack of public support to Pigouvian taxes. One reason is that individuals do not perceive the difference between a Pigouvian tax (intended to correct an externality) and a Ramsey one (intended to raise revenue). Once implemented, the governments need to consider the costs due to the collection of the tax. Finally, because agents are generally reluctant to the implementation of taxes, there exists a "social cost" of taxes. Turning to subsidies, the main problem comes from the financial limits governments have to deal with. Moreover, inefficiencies can occur given that firms may be only interested in the subsidy. Similar concerns are raised with norms or permits. Indeed tradable permits can restore an optimum, and present also the advantage to let firms bargain between them. However, transaction costs must be low and the number of permits that a given sector should receive must be correctly estimated. The research of an alternative, or a complementary tool, is thus justified.

One direction can be found in Thaler and Sunstein's (2009) book. They argue in favor of *nudges* that are ways of improving consumers' behavior by alerting them on their behaviour and/or on the neighbors' behaviors, through the dissemination of information or the use of simple techniques such as default options[1]. In this paper, we focus on the dissemination of information. A nudge must be simple to implement, costless and should not constrain individuals[2]. These desired properties correspond to some drawbacks of the market-based instruments.

This new tool has been recently studied both by psychologists and economists. Nolan et al. (2008) use descriptive norms[3] to make individuals increase their conservation behavior, that is to say to use less energy. They show that those who received the descriptive norm message reduced their electricity consumption, compared to the control group. Goldstein et al. (2008), still using descriptive norms, obtain a towel reuse rate of 49.3% in hotels. Schultz et al. (2007) emphasize the boomerang effect that may be created by the use of descriptive norms: those discovering that they contribute more than similar individuals might decrease their contribution. Thus they propose to mix injunctive norms[4] with descriptive norms to counterbalance this possible boomerang effect.

Natural field experiments have also been conducted to study the impact of nudges on energy conservation. In Allcott (2011), the company Opower sent periodic reports to households mentioning their own level of consumption, the average level of consumption of similar households, and the one of the most efficient neighbor. Tips to reduce electricity consumption were also included. A mean reduction of 2,1% was observed among households. Most importantly, such a reduction would correspond to an increase of the prices of electricity of 11% to 22% in the short run. Similar results were found by Ayres et al. (2013) in the context of electricity consumption and natural gas. Ferraro and Price (2013) focused on water use. In their study, they compared three different treatments:

[1] Default options are options that are pre-selected for individuals. For instance, some banks do not send paper reports anymore concerning bank accounts (default option). However the customers can formulate a demand to receive them again.

[2] This means that the set of options that individuals have initially should not be reduced because of the use of a nudge.

[3] Descriptive norms show the usual behavior of a majority of individuals in a given situation.

[4] Injunctive norms show what is socially accepted, or not, by others.

technical advice letter (TAL); TAL and an appeal to prosocial preferences (APP); and TAL, APP and a social comparison. They found that the last combination was inducing the highest reduction in water use (4,8%) for an average household, compared to a control group household. Finally, Costa and Kahn (2013) show that individuals do not react identically to a nudge. In their study, they show that political liberals are much more likely to reduce their electricity consumption when receiving personal reports, than political conservatives. This raises the question of knowing what are the conditions on individuals' preferences that induce a positive impact of a nudge on their behavior.

Although nudges are considered as a rather new incentive tool, politicians already focus on. This can be observed in the reports that have been written on health prevention (see the Behavioural Insights Team's reports (2010, 2013) in Great Britain), and on environmental protection (the report by the Centre d'Analyse Stratégique - CAS (2011), the Behavioural Insights Team's report (2011), or the report of the OECD (2012).

Even if all quoted papers display encouraging results in the field of energy conservation, they miss a theoretical model allowing to obtain predictions. In this paper we propose such a theoretical model. First, this will allow us to modelize the nudge and to analyze its impact on the individuals' behavior. Second, we will be able to compare the impact of a nudge with the impact of a standard tax. And, lastly, theoretical predictions will be tested through economic experiments in the lab.

In the context of energy conservation, a reduction of their own consumption can be seen as a voluntary contribution given that individuals are not constrained. The existing literature on voluntary contributions is quite important (see Ledyard (1995) or the Handbook of Experimental Economics Results (2008) for a complete review). About uncertain pollution, Etner et al. (2007) consider the environmental quality as a public good. They show that optimistic individuals contribute less than pessimistic ones. Etner et al. (2009) also show the importance of initial wealth and of the initial level of environmental quality on the voluntary contributions. Salanié and Treich (2009) study the regulator's point of view. They consider a model in which citizens may hold different beliefs (optimism or pessimism) from the regulator's ones. In particular, they show that a paternalistic regulator (who does not take into account the citizens beliefs) may over-regulate compared to a populist one (who takes into account the citizens beliefs).

In this paper, we consider only optimistic individuals in the sense of the RDEU model (Quiggin, 1982). More precisely, individuals have a more or less high degree of confidence in the announcement made by the regulator about the risk of pollution. This degree of confidence is captured by the distortion function. We also define a disutility function of pollution that depends on the individual sensitivity to the environment, an intrinsic characteristic of her preferences. This sensitivity can be health vulnerability, psychological feelings, personal convictions about environmental considerations, etc. By doing so, we want to capture a diversity of behaviors. We believe that there is not a necessary positive correlation between the degree of probability distortion of the individual and her sensitivity to environmental considerations. For instance, a given individual may strongly distort the probabilities because she believes that the regulator lies about the true risk of environmental pollution, but in the meantime she is sensitive to environmental quality. Finally, contributions to the environmental public good depend on two dimensions: the distorsion probability and a qualitative index of individual environmental sensitivity. In this context, we show that a nudge may be more efficient, under some conditions, than a tax in inducing more contributions. This is good news knowing that implementing a nudge may also mobilize less ressources than a tax policy, as discussed in the paper. We explain that a nudge, contrary to a tax, is able to discriminate between individuals with different intrinsic characteristics. More precisely, two different individuals (regarding their intrinsic characteristics) may contribute the same for environmental quality, and face the same level of taxation. However, we show that this is not possible with the implementation of a nudge because individuals reaction depends on environmental sensitivity: two individuals differing with respect to their environmental sensitivity react differently, even if they contributed the same for environmental quality in the absence of incentives. Some illustrative simulations are provided.

In section 2, first we present the private optima without any incentive regulatory policy. Then we introduce a tax based on individual contributions. In section 3, we define the nudge and we build the individual reaction to the nudge. We evaluate the private optima and compare the impact of a nudge to the impact of the tax policy on individual contributions. In Section 4, simulations are provided. Section 5 concludes the paper.

2 Theoretical predictions when monetary incentives are used

In this section, we present a model in which individuals can voluntarily, and financially, contribute to improve the quality of a public good (let's say the environment). First, there is no outside incentives to contribute. Second a standard tax policy is introduced. In both models, individuals are more or less optimistic regard the announce made by the regulator about the level of the risk of pollution. They are also more or less (psychologically and/or physically) sensitive to environmental quality.

2.1 The benchmark model with probability distortions

We start introducing the model and the different assumptions that we consider. Then we provide the private optima and compare them to the social ones in terms of voluntary contributions.

2.1.1 Assumptions

We consider an economy with a fixed population. Individuals face an aggregate level of pollution (public bad) emitted by human activity. They can voluntarily contribute to make decrease this level of pollution. The current random level of pollution, $\tilde{P}$, is given by

$$\tilde{P} = \tilde{e}Y - b(A) \quad (1)$$

where $\tilde{e}Y$ is the pollution coming from the current production Y. $\tilde{e}$ is a random variable the values of which belong to the interval $[\underline{e}; \overline{e}]$, with $\underline{e} \geq 0$ and $\overline{e} \leq 1$. For the sake of simplicity, we assume that $\tilde{e}$ is uniformly distributed, $F(.)$ being the distribution function and $f(.)$ its density.

A is the sum of individual contributions, $A = \sum_i a_i$, with each individual choosing her level of contribution a_i in a non-cooperative way. Function $b(A)$, with $b'(A) > 0$ and $b''(A) < 0$, represents the public benefit of pollution reduction coming from the individual contributions.

Individuals incur a disutility from pollution formalized by the disutility function $d(\tilde{P}, s^j)$, which is increasing and convex in $\tilde{P}$: $d_P > 0$ and $d_{PP} \geq 0$, with $d_P < +\infty$. The disutility of a given level of pollution P may differ from one individual to another one because of differences in their individual sensitivity to the environmental good, captured by s^j, a qualitative variable[5]. For each individual, s^j can take one of two possible values: $s^j \in \{s^l; s^h\}$ with $s^h > s^l$. s^h represents an individual highly sensitive to the environment, and s^l an individual less sensitive. Finally, we also assume that individual i's sensitivity has only a first order impact on the individual disutility of pollution: $d_{PPs^j} = 0$.

Individuals have also heterogeneous perceptions of the risk of pollution. To simplify, we consider two types of individuals regarding risk perception, both being optimistic about the risk of pollution announced by the regulator (or experts). In that spirit, we are close to Salanié and Treich (2009)[6] and also Etner et al. (2007): individuals may have

[5]This sensitivity can be health vulnerability, psychological feelings, personal convictions about environmental considerations, etc. Hence, two agents facing the same pollution P do not bear the same disutility of this pollution: a higher sensitive agent presents a higher marginal disutility of pollution: $d_{Ps^j} > 0$.

[6]Salanié and Treich (2009) is a particular case of our model where only two probabilities are considered.

different beliefs compared to the regulator. Individuals differ according to their type, $\theta^k = \{\theta^O;\theta^o\}$, with $\theta^O < \theta^o \leq 1$. Type θ^O is highly optimistic, while Type θ^o is less optimistic. The threshold 1 represents an individual who takes the information disclosed by the regulator as given and who does not transform it. To formalize the heterogeneity in risk perception, let us denote by $H(F(e),\theta^k)$ the probability transformation function of individuals of Type θ^k[7]. Because we consider only optimistic individuals, $H(.,.)$ is an increasing function of $F(e)$, the true (or the objective) distribution of the risk of pollution $\widetilde{P}$. Function H satisfies the following properties:

$$\begin{array}{ll} (i) & H(F(\bar{e}),\theta^k) = F(\bar{e}) = 1, \quad \forall\theta^k \\ (ii) & H(F(\underline{e}),\theta^k) = F(\underline{e}) = 0, \quad \forall\theta^k \\ (iii) & \frac{dH}{de} = \frac{\partial H}{\partial F}.F'(e) > 0 \quad \text{and} \quad \frac{d^2H}{de^2} < 0, \quad \forall e \in \,]\underline{e},\bar{e}[\end{array} \tag{2}$$

Type θ^O being more optimistic than Type θ^o, the former underevaluates more the probability of having to bear a given level of pollution or more. Thus we have

$$H(F(e),\theta^O) \geq H(F(e),\theta^o) \geq F(e) \text{ with } \theta^O < \theta^o < 1 \text{ and } \forall e,$$

with at least one strict inequality for each relation[8]. This property corresponds to a first order stochastic dominance: $F(.)$ dominates $H(.)$. The optimistic individuals always overevaluate the probability of having to bear a level of pollution lower than a given threshold, whatever this threshold.

In this configuration, the difference to be made between the risk perception and the environmental sensitivity is essential. On one hand, one can consider risk perception

[7] This formulation is derived from a RDEU formalization (Quiggin (1982)) as in Etner et al. (2007). In Salanié and Treich (2009) there is only one agent apart from the regulator.

[8] An example of function $H(.)$ that satisfies the previous properties is:

$$H[F(e),\theta^k] = \left(\frac{\bar{e}}{\underline{e}}\right)^{1-\theta^k} \times\ F(e) \tag{3}$$

with $\underline{e} > 0$, and θ^k is the degree of distortion. The higher the level of θ^k, the lower the distortion of the objective distribution $F(e)$. Other admissible functional forms exist in the literature as the Tversky and Kahneman function (Tversky and Kahneman, 1992), the Wu and Gonzalez function (Wu and Gonzalez, 1996), or the Prelec function (Prelec, 1998).

as an indicator on how much individuals are confident[9] in the informations they receive from the regulator about the distribution $F(e)$. This is captured by the function $H(.,.)$. For a given individual, this confidence may differ depending on who is providing the information (governments, NGO, experts, etc).[10] On the other hand, sensitivity to the environment is different from risk perception: the qualitative variable s_j is an intrinsic characteristic of the individual preferences and it does not depend on a third party. It characterizes the impact pollution has on the psychological and/or physical welfare of the individual. Contrary to risk perception and in some manner, it cannot be "manipulated". Sensitivity to the environment is something that individuals *live*, while risk perception is linked to something that individuals *interpret*.

Thus each individual is characterized by a subjective type of risk perception θ^k and a level of environmental sensitivity s^j. Individual i can also be called individual (k, j) and four profiles may exist: $(O, h), (O, l), (o, h)$ and (o, l). For instance, individual (O, h) presents a high environmental sensitivity but a low confidence in what is announced by the regulator.

Lastly, each individual receives the fixed wage w, which is shared between private consumption c_i and contributions a_i to the environmental quality. The individual utility of consumption is $u(.)$ with $u'(.) > 0$ and $u''(.) \leq 0$. The total utility of individual i is thus:

$$U_{k,j}(a_i) = \int_{\underline{e}}^{\overline{e}} \left(u(c_i) - d(P, s^j)\right) h\left(F(e), \theta^k\right) f(e) de \tag{4}$$

[9]Sinclair-Desgagné and Gozlan (2003) also deal with a model in which a stakeholder (which can be an activist organization) is more or less confident with a report made by a polluter (a firm for instance) on its level of pollution. We differ from their paper because the individuals in our model do not have the possibility to perform tests to verify the information they receive. Moreover, in our model the regulator provides some information to help individuals choosing their level of contribution, while in Sinclair-Desgagné and Gozlan (2003), the polluter provides information and the stakeholder decides to "accept" or "boycott" the polluters activity. There is thus the possibility to impose financial costs on the polluter.

[10]Siegrist and Cvetkovich (2000) or Slovic (2013) show that a correlation exists between the level of trust of individuals and risk perception.

In the absence of probability distortion, the program of Individual i is:

$$\max_{a_i,c_i} \int_{\underline{e}}^{\overline{e}} \left(u(c_i) - d(P, s^j)\right) f(e)de$$

$$s.t. \quad w = c_i + a_i$$

$$a_i \geq 0$$

It reduces to:

$$\max_{a_i} \int_{\underline{e}}^{\overline{e}} \left(u(w - a_i) - d(P, s^j)\right) f(e)de \tag{5}$$

$$s.t. \quad a_i \geq 0 \tag{6}$$

This program is different from the regulator's one as shown below. Indeed, it does not take into account the benefit of individual's i contribution on the welfare of the other individuals. Each individual is selfish and does not consider the public good effect. The first order condition for an interior solution a_i^P is:

$$-u'(w - a_i^P) + b'(A) \int_{\underline{e}}^{\overline{e}} d_P(P, s^j) f(e)de = 0 \tag{7}$$

Notice that the second order condition is satisfied.[11]

Considering an increase in the contribution to the environmental good, the individual makes a trade-off between the loss of welfare following the decrease in her consumption and the decrease of her expected pollution disutility. In this model, risk perception only affects the marginal benefit of the contribution (second term in (7)), not the marginal cost (first term).

[11] Indeed:

$$u''(w - a_i^P) + b''(A) \int_{\underline{e}}^{\overline{e}} d_P(P, s^j) f(e)de - (b'(A))^2 \int_{\underline{e}}^{\overline{e}} d_{PP}(P, s^j) f(e)de < 0 \tag{8}$$

From the litterature on public goods, it is well known that individuals have an interest in undercontributing to the public good: this is the well-known issue of free riding. Individuals do not take into account the positive impact of their contribution on the welfare of the other individuals (through $b(A)$ here). If the regulator is able to observe the sensitivity s^j of each individual, then the result also holds in our model. Indeed the utilitarian social welfare is simply the sum of the expressions in (5) for all i. Yet the result is no longer immediate if the regulator can only consider a mean level of sensitivity because of unobservable information about s^j. Then individuals with low sensitivity will keep continuing to undercontribute compared to the social optimum (computed with a mean sensitivity). On the contrary highly sensitive individuals may contribute more than this social optimum. In other words, the impact of the personal sensitivity of an individual on her decision to contribute may counter balance the absence of social considerations in her selfish preferences.

In the litterature on environmental economics, it is often assumed that individuals differ either through their utility function or, through their beliefs (Etner et al. (2007), Etner et al. (2009), Salanié and Treich (2009)). As explained, beliefs and vulnerability (or sensitivity) shall be considered in independent ways for they are two different characteristics of the individual. Besides, it is not realistic to assume that the regulator knows all the personal characteristics of individuals. Often s^j is not perfectly known. However regulatory tools, ideally, shall be able to impact differently the individuals behavior regarding their personal sensitivity, even though some characteristics are not observed. This can be done with a nudge but not with a tax as we show it later on. Before considering both tools, let us now consider the more general case in which individuals may have different beliefs on the risk of pollution.

2.1.2 Private optima of optimistic individuals

We now look at the private optimum of each individual, depending on her risk perception and sensitivity to the environment. Each individual i (or (k, j)) considers the following program:

$$\max_{a_i} \int_{\underline{e}}^{\overline{e}} \left(u(w-a_i) - d(P, s^j)\right) h\left(F(e), \theta^k\right) f(e)de \tag{9}$$

$$s.t. \quad a_i \geq 0 \tag{10}$$

The first order condition for an interior solution is given by:

$$-u'(w - a_i^p) + b'(A) \int_{\underline{e}}^{\overline{e}} d_P(P, s^j) h\left(F(e), \theta^k\right) f(e)de = 0 \tag{11}$$

where a_i^p denotes the private level of contribution for individual i. The second order condition is satisfied.

First, notice that the disutility from pollution is more important for an individual highly sensitive to the environment than for an individual less sensitive to the environment. Second, comparing (11) with (7), the expected marginal benefit of the individual contribution is affected by risk distortion, not the marginal cost.

Proposition 1 *Let us consider optimistic individuals with preferences characterized in a RDEU model.*

(i) All individuals contribute less than the social optimum if their degree of individual sensitivity is common knowledge.

(ii) The most optimistic individuals are not systematically the lowest contributors. Precisely, we have: $a_{l,O}^p < a_{l,o}^p < a_{h,o}^P$ *and* $a_{l,O}^p < a_{h,O}^P < a_{h,o}^P$ *but nothing else can be said without additional assumptions.*

(iii) Individuals of types (o, h) *and* (O, h) *may overcontribute if individual environmental sensitivity is private information.*

From Proposition 1, all contributors underinvest in the public good only if the regulator is able to evaluate the social optimum by taking into account the different degrees of individual environmental sensitivity. This is possible only if s^j is common knowledge. Let us precise that our regulator is neither completely utilitarist nor completely paternalist. Indeed, he takes into account the utility and disutility functions of the agent, but he considers the distribution of risk announced by the experts, that is $F(.)$, and not the individuals beliefs, which he does not know. Optimism does no longer induce systematic undercontribution. In particular, from Point (iii) a high sensitivity may induce contributions higher than the social optima computed in an imperfect information setting even for optimistic individuals (types (O, h)): individuals may have grew up in a family in which environmental considerations were part of the fondamental principles of life. Some others may simply have a high physical vulnerability to pollution. Those personal characteristics may give them extra motivation to contribute to environmental quality. This does not preclude them to distrust the regulator or the government and to be optimistic in the sense of the RDEU model (the optimistic individual underevaluates probabilities of high pollution).

In such a setting, the question is whether a market-based instrument such as a tax can restore the incentives to contribute.

2.2 Implementation of a tax

Consider the case in which contributions are observable by the regulator. He implements a tax on the contributions that are not provided by comparison with the social optimum denoted as a_i^* (recall that this social optimum is obtained without any probability distortion and with a mean individual sensitivity: the regulator has no information neither on individuals' sensitivity nor on their personal beliefs). Let us denote as $t(a_i)$ an exogenous tax function[12], which we assume to be continuous with $t'(a_i) < 0$ and $t(a_i^*) = 0$. Now, individuals solve the following program:

[12]A simple example is

$$t(a_i) = \begin{cases} \tau(a_i^* - a_i) & \text{if } a_i < a_i^* \\ 0 & \text{if } a_i \geq a_i^* \end{cases}$$

With $0 < \tau < 1$

$$\max_{a_i} \int_{\underline{e}}^{\overline{e}} \left(u(w - a_i - t(a_i)) - d(P, s^j)\right) h\left(F(e), \theta^k\right) f(e)de \tag{12}$$

$$s.t. \quad a_i \geq 0$$

The first-order condition for a private interior solution a_i^t for individual i (or (k, j)) is:

$$-(1 + t'(a_i^t)).u'(w - a_i^t - t(a_i^t)) + b'(A) \int_{\underline{e}}^{\overline{e}} d_P(P, s^j)h\left(F(e), \theta^k\right) f(e)de = 0 \tag{13}$$

The second order condition is satisfied.

Proposition 2 *Assume that the regulator implements a tax on the socially optimal contributions that are not provided by the individuals:*

i) All individual contributions increase.

ii) The tax policy is not able to discriminate among the different environmental sensitivities. In particular, for individuals (o, l) and (O, h), there exists a marginal rate of taxation τ such that if $a_{o,l}^P = a_{O,h}^P$ then $a_{o,l}^t = a_{O,h}^t$.

The tax policy that is considered in this model is close to a pigouvian tax. Thus from the litterature, Point i) of Proposition 2 is rather immediate. Point ii) is much more interesting and is of particular importance in the issue we are concerned about. The tax cannot directly rely on sensitivity. The reason is identical to the one given in the preceding section when justifying the fact that the social optimum may only be linked to a kind of mean environmental sensitivity of the population. It is a personal and private characteristic of each agent. Yet two agents having chosen the same level of contribution a, but having different sensitivities, may bear the same amount of tax $t(a)$. Moreover, from Condition (13) the tax only affects the utility of consumption, which is certain: in other words two agents with, now, different beliefs about the probability distribution of the risk of pollution, bear identical distortions of the utility of consumption due to the tax policy and no distortion of the expected marginal benefit of contributing to the environmental public good.

In the following section, we show how the introduction of a nudge may partly solve this lack of refinement in the impact of a one dimensional tax policy.

3 Implementation of a nudge

First, we have to modelize the reaction of an individual to a nudge. Second, we calculate the private optima of contribution. Third, we compare the results that we obtain with those relative to the tax policy. Lastly, we illustrate our results with some simulations.

3.1 Modelling the reaction to the nudge

The nudge considered in this model is an action of information dissemination. Once the regulator makes her announcement denoted as $\hat{a}$, we claim that individuals may adjust their contribution differently depending on their own environmental sensitivity s^j. Let $\eta(\hat{a}|s^j)$ model the impact of the nudge $\hat{a}$ on the individual total utility. Knowing that the individual will compare (or not) the announce to her own behavior, it is fair to assume that

$$\eta(\hat{a}|s^j) \equiv g(a_i - \hat{a}|s^j)$$

with $g(0) = 0$, $g_{a_i} \leq 0$and $g_{a_i a_i}(.) \geq 0$. These assumptions are in line with what is observed in random field experiments (Allcott, 2011; Ayres et al., 2013; Ferraro and Price, 2013). In our model, individual contributions may be higher than the social ones. The boomerang effect, discussed in the introduction, is also captured by $g_{a_i} \leq 0$ as we will show it in what follows.

With this design of $g(.|s^j)$ we simply make the assumption that individuals consider the distance between their contribution and the announcement. This is different from Figuieres et al. (2013). Indeed we take into account the individual sensitivity to the environment, which is an intrinsic characteristic. Finally, we assume that the higher the sensitivity to the environment, the higher the reaction to the regulator's announcement:

$$\eta(\hat{a}|s^h) > \eta(\hat{a}|s^l)$$

It is important to notice that, contrary to the implementation of the preceding tax policy, implementing a nudge does not require observable contributions. In particular, the nudge can be the social optimum to be reached, a mean contribution, or the maximum individual contribution whenever this information is available.

Finally, notice that this modelling differs from Bernheim (1994). In his model, individuals make a balance between their intrinsic preferences and their *status*[13]. In particular, individuals want to be perceived as a good type (to have a high *status*). Moreover, it also differs from Akerlof (1997) because individuals are not concerned with their social position in our model.

In the next subsection, we assume that the regulator announces the social contribution. Recall that it corresponds to the contribution that individuals with a medium sensitivity should have made in the absence of probability distortion.

3.2 Private optima

The regulator announces the socially optimal contribution a_i^* to individual i, $i = (O, l), (O, h), (o, l), (o, h)$. Each individual considers the following program:

$$\max_{a_i} \int_{\underline{e}}^{\overline{e}} \left(u(w - a_i) - d(P, s^j)\right) h\left(F(e), \theta^k\right) f(e)de - g(a_i - a_i^*|s^j) \tag{14}$$

$$s.t. \quad a_i \geq 0$$

[13]Defined as "popularity, esteem, or respect" (p. 843). Individuals are esteemed if they act in a way that is well perceived by the others. In this model, *status* is not relevant given that the optimum is announced. However, it could be interesting to consider it in the case the mean contribution is announced. To obtain a high *status*, individuals could contribute more than the mean, or increase their contribution if they were below.

The first order condition for a private interior solution a_i^n is:

$$-u'(w-a_i^n)+b'(A)\int_{\underline{e}}^{\overline{e}} d_P(P,s^j)h\left(F(e),\theta^k\right)f(e)de - g_{a_i}(a_i^n-a_i^*|s^j)=0 \qquad (15)$$

The second order condition is satisfied.[14]

Proposition 3 *Assume that the regulator discloses the information about the social optimum to each concerned individual.*

(i) All individual contributions increase following the introduction of the nudge.

(ii) The nudge permits to discriminate among individuals having different sensitivity although sensitivity is private information. In particular, if for two individuals $a_{O,h}^p = a_{o,l}^p$ *and* $a_{O,h}^t = a_{o,l}^t$*, we also have* $a_{O,h}^n > a_{o,l}^n$*.*

From Proposition 3, we can conclude that a nudge may also induce some "good" reactions of individuals, such as a tax based on individual contributions. The first main difference is that a nudge does not need information about individual contributions contrary to an incentive tax policy. Second, by comparing Point (ii) of Proposition 3 with Point (ii) of Proposition 2 we conclude that a nudge can solve the issue raised by the insensitivity of the tax to individual vulnerability. However, it is important to notice that we obtain these results by ignoring the announcement issue for the nudge. Indeed, the reaction to the nudge could also depend on the confidence in the announcement. Thus, it would be possible that the difference in sensitivity compensates for the divergence in confidence, as for point ii) of Proposition 2. In that case, we could have both individuals reacting the same and thus contributing the same.

Let us go further in the comparison between the tax and the nudge. Thanks to an integration by part, the first order condition (13) can be written

[14] Indeed:

$$u''(w-a_i^n)+b''(A)\int_{\underline{e}}^{\overline{e}} d_P(P,s^j)h\left(F(e),\theta^k\right)f(e)de$$
$$-(b'(A))^2\int_{\underline{e}}^{\overline{e}} d_{PP}(P,s^j)h\left(F(e),\theta^k\right)f(e)de - g_{a_ia_i}(a_i^n-a_i^*|s^j)<0$$

$$-(1+t'(a_i^t)).u'(w-a_i^t-t(a_i^t))+b'(A)\left(d_P(\overline{P},s^j)-Y\int_{\underline{e}}^{\overline{e}} d_{PP}(P,s^j)H\left(F(e),\theta^k\right)de\right)=0,$$

with $\overline{P}=\overline{e}Y-b(A)$. Or :

$$\begin{aligned} u'(w-a_i^t) &= b'(A)\left(d_P(\overline{P},s^j)-Y\int_{\underline{e}}^{\overline{e}} d_{PP}(P,s^j)H\left(F(e),\theta^k\right)de\right) \\ &\quad -t'(a_i^t).u'(w-a_i^t-t(a_i^t))+u'(w-a_i^t)-u'(w-a_i^t-t(a_i^t)) \end{aligned} \tag{16}$$

Thanks to an integration by part, the first order condition (23) can be written:

$$\begin{aligned} u'(w-a_i^n) &= b'(A)\left(d_P(\overline{P},s^j)-Y\int_{\underline{e}}^{\overline{e}} d_{PP}(P,s^j)H\left(F(e),\theta^k\right)de\right) \\ &\quad -g_{a_i}(a_i^n-a_i^*|s^j) \end{aligned} \tag{17}$$

In both conditions (16) and (17), the left-hand-side term and the first expression in the right-hand-side term are identical for a given level of individual contributions. Now, notice that in (16) the remaining terms (second line) do not depend on the environmental sensitivity s^j while the remaining term in (17) does so. The tax does not explicitely incorporate the subjective and personal characteristic s^j. On the contrary, the reaction $g(.)$ of individual i to the nudge depends on her environmental sensitivity: a nudge policy can explicitely build over this personal characteristic of an individual even if it is not observable by the regulator.

Furthermore, a nudge is an announcement and it does not require to collect money from a regulatory agency, contrary to a tax. Thus such a "soft" instrument is cheaper to implement than a traditionnal tax policy. Lastly, a nudge policy seems to be much more socially accepted than a tax policy. However one downside is that a nudge does not create additionnal financial credits contrary to a tax policy. There is no opportunity to opt for a double dividend policy with a nudge. Moreover, there is no boomerang effect with a tax since contributions beyond the social optimal are not taxed.

Section 4 provides some simulations that illustrate our results.

4 Parameterized examples

In this section, we conduct simulations to illustrate the results we found in the previous sections. We still consider two individuals, each with a given level of individual environmental sensitivity and a given perception of the risk that we define below.

4.1 Benchmarck model

We start with the private level of individual contributions in the absence of incentives. The utility of consumption is $u(w, a_i) = 100(w-a_i)-10(w-a_i)^2$. Let us denote as a_1 and a_2 the contributions of individual 1 and 2 respectively. The public benefit of pollution reduction coming from the individual contributions is $b(A) = \sqrt{40(a_1 + a_2)}$. The level of current pollution is $P = Ye - \sqrt{40(a_1 + a_2)}$. The random variable of pollution e follows a uniform distribution, with $\underline{e} = 0$ and $\bar{e} = 1$. The disutility coming from pollution is $d(P, s^j) = \dfrac{(4 + s^j)}{5} \times P^2$. For this simple example, we set $Y = 35$ and $w = 5$. We also set $s^h = 1$ for an individual highly sensitive to the environment, and $s^l = 0$ for an individual less sensitive to the environment. We denote as $a^*_{\bar{s}}$ the social optimum obtained with a mean sensitivity ($\mu = 0.5$). In this setting, $a^*_{\bar{s}} = 1.74$. We consider the following probability transformation function:

$$H[F(e), \theta^k] = \left(\frac{\bar{e}}{\underline{e}}\right)^{1-\theta^k} \times \ F(e)$$

The following figures show the first-order conditions for individuals differing in their intrinsic characteristics (optimism and environmental sensitivity). On the x-axis is represented the level of individual contribution, and the level of the first-order condition is

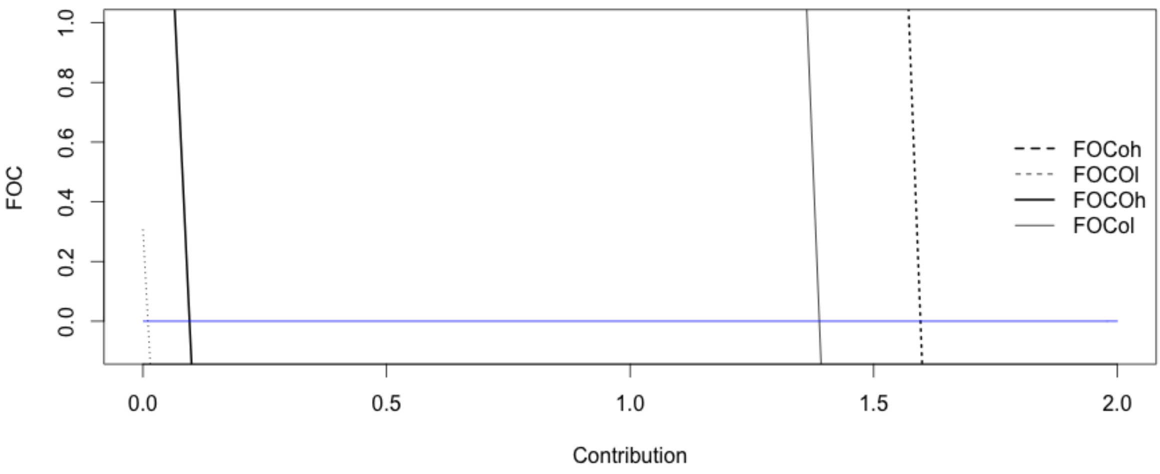

Figure 1: First order conditions for individuals (o,l), (o,h), (O,h) and (O,l)

represented on the y-axis. Private optima are obtained when the first-order conditions are equal to zero.

Figure 1 shows the private level of contributions for an individual highly optimistic and highly sensitive to the environment (O, h), and another one less optimistic and few sensitive to the environment (o, l). This example is of particular interest because we saw that a divergence in sensitivity can compensates for a divergence in risk perception. For this example, we set $\theta = 0.3$ for the highly optimistic individual, and $\theta = 0.7$ for the less optimistic one. We obtain $a^p_{O,h} = 0.10$ and $a^p_{o,l} = 1.39$.

We also plotted the opposite case (dotted lines) with an individual highly optimistic and few sensitive to the environment (O, l), and another one less optimistic and highly sensitive to the environment (o, h). We obtain $a^p_{O,h} = 0.01$ and $a^p_{o,l} = 1.60$. We obtain Points i) and ii) of Proposition 1.

Concerning point ii), we argued that it was not necessarily possible to rank $a^p_{o,l}$ against $a^p_{O,h}$. Going a step further, we can have $a^p_{O,h} > a^p_{o,l}$. Taking $\theta = 0.58$ and $s^h = 1$ for individual (O, h), and $\theta = 0.60$ and $s^l = 0$ for individual (o, l), we get

$a^p_{O,h} = 0.99 > a^p_{o,l} = 0.85$ (see Figure 2). This is of particular interest because, contrary to Etner et al. (2007)[15], we show that sensitivity can more than compensate the difference in risk perception.

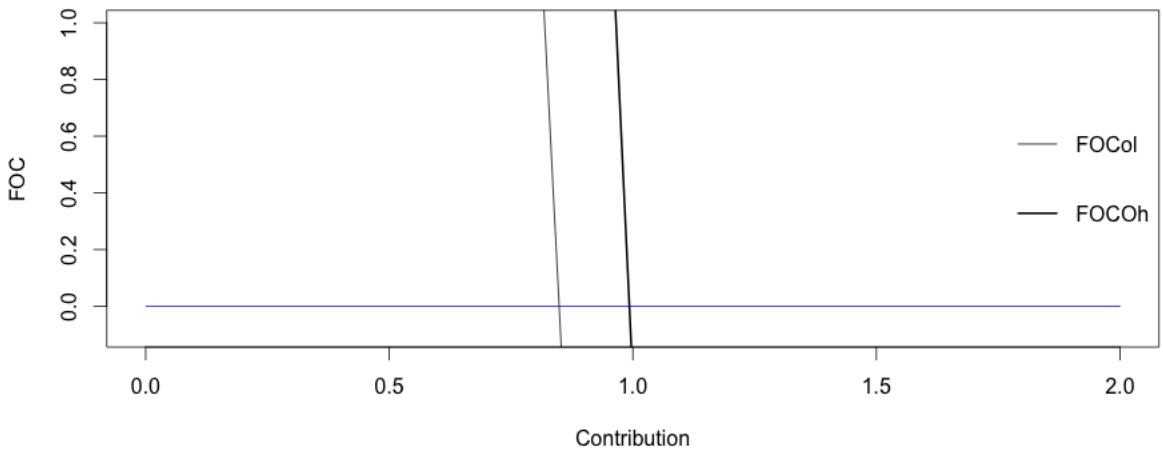

Figure 2: First order conditions for individuals (o,l) and (O,h)

4.2 Incentives

We now consider the implementation of a tax on the contributions that are not provided by comparison with the social optimum (with a mean sensitivity $\mu = 0.5$), and then of a nudge (announcement of $a^*_{\bar{s}}$).

We focus on Point ii) of Propositions 2 and 3 that we consider as the most interesting. To highlight this point, we now consider individuals (O, h) characterized by $\theta = 0.4$ and $s^h = 1$, and (o, l) characterized by $\theta = 0.435$ and $s^l = 0$. In the absence of outside incentives, both individuals contribute $a^p_{O,h} = a^p_{o,l} = 0.69$. This means that the difference in sensitivity compensates for the difference in risk perception.

[15] They found that the most optimistic individuals always undercontribute compared to less optimistic individuals.

We introduce an exogenous linear tax: $t(a_i) = 0.4528(a^*_{\bar{s}} - a_i)$[16]. We get that both individuals increase their level of contribution to $a^t_{O,h} = a^t_{o,l} = 0.71$

We now illustrate the case of the implementation of a nudge. The disutility function from the announcement of the nudge is given by $g(a_i - a^*_{\bar{s}}|s^j) = -\dfrac{(a_i - a^*_{\bar{s}})}{(a_i + 1)} \times (2 + s^j)$. The intuition with this function is that the higher the distance with the announcement, the higher the disutility. This disutility is higher for the most sensitive, following our assumption. We found that $a^n_{O,h} = 0.75$ and $a^n_{o,l} = 0.71$. A nudge has thus the potential for performing as well as a tax. More interesting is the fact that, contrary to the previous point (with the implementation of the tax), we do not have both individuals contributing the same anymore. This is explained by the fact that a nudge can rely *directly* on sensitivity, while a tax will rely *indirectly* on sensitivity.

5 Conclusion

In this paper we have considered individuals who can voluntarily contribute to improve the quality of environment. They differ in their risk perception of pollution and in their environmental sensitivity.

Our first result is that risk perception alone cannot explain the difference between the level of contributions among different individuals contrary to Etner et al. (2007) and Salanié and Treich (2009). We have to take into account environmental sensitivity which can compensate for a difference in risk perception between two individuals.

We have compared the impact of a tax with the impact of a nudge on individual contributions. We have shown that a nudge may perform better than a tax: the reaction to a nudge depends directly on environmental sensitivity contrary to a tax. More precisely, a tax is an *unidimensional* instrument in the sense it depends only on the distance between individuals' level of contribution and the social optimum. On the contrary, the reaction to a nudge depends on this distance, which is more or less important depending

[16] We agree that such a marginal rate of taxation is not politically feasible. However, in our particular setting, we implement such a marginal rate of taxation to illustrate our point.

on individuals' sensitivity to the environment. This is the second main result of this paper. We illustrated it with some simulations.

However, our simulations also showed that a nudge is not able to make increase individual contributions up to the social optimum. From a public policy perspective, it may be necessary not to consider a nudge as a single instrument, but in the context of a complement with another tool.

Appendix

Proof of Proposition 1

i) When sensitivity j, $j = h$ or l, is known by the social regulator, his program is given by

$$\max_{a_h,a_l} \sum_{j=h,l} \int_{\underline{e}}^{\overline{e}} \left(u(w-a_j) - d(P,s^j)\right) f(e)de$$

Let us denote as a_l^* (a_h^*) the social optimum for an agent with a low (respectively high) sensitivity. The first order condition for an interior solution is

$$-u'(w-a_j^*) + b'(A)\int_{\underline{e}}^{\overline{e}} d_P(P,s^j)f(e)de + b'(A)\int_{\underline{e}}^{\overline{e}} d_P(P,s^{-j})f(e)de = 0 \quad j = h,l$$

After an integration by parts, it becomes:

$$-u'(w-a_j^*)+b'(A)\left(d_P(\overline{P},s^j) - Y\int_{\underline{e}}^{\overline{e}} d_{PP}(P,s^j)F(e)de\right)+b'(A)\int_{\underline{e}}^{\overline{e}} d_P(P,s^{-j})f(e)de = 0 \tag{18}$$

The third term is equal to the public good effect. The private first order condition for an agent that distorts probabilities is given by (11). An integration by parts yields:

$$-u'(w-a_j^p)+b'(A)\left(d_P(\overline{P},s^j)-Y\int_{\underline{e}}^{\overline{e}}d_{PP}(P,s^j)H(F(e),\theta^k)de\right)=0\quad i=(j,k);j=h,l;k=o,O \tag{19}$$

Substracting (19) from (18), both being evaluated at a_j^*, gives after simplification

$$-b'(A)\left(Y\int_{\underline{e}}^{\overline{e}}d_{PP}(P,s^j)(F(e)-H(F(e),\theta^k))de\right)+b'(A)\int_{\underline{e}}^{\overline{e}}d_P(P,s^{-j})f(e)de,$$

which is positive. Indeed by assumption $F(e)<H(F(e),\theta^k)\quad\forall k$, and $b'(A)\int_{\underline{e}}^{\overline{e}}d_P(P,s^{-j})f(e)de$ is positive as a product of positive functions. And finally $a_{(k,j)}^p<a_j^*\quad\forall j,\forall k$.

ii) Considering (19) for individuals (O,l) and (o,l) and substracting the former from the latter, both being evaluated at $a_{o,l}^p$, gives after simplification

$$-b'(A)Y\int_{\underline{e}}^{\overline{e}}d_{PP}(P)(H(F(e),\theta^o)-H(F(e),\theta^O))de,$$

which is positive. Indeed by assumption $H(F(e),\theta^o)<H(F(e),\theta^O)$, and $d_{PPs_j}=0$, that is to say $d_{PP}(P,s^j)\equiv d_{PP}(P)\quad\forall j$. And finally $a_{O,l}^p<a_{o,l}^p$.

Besides, substracting the first order condition of individual (o,h) from the first order condition of individual (o,l), both being evaluated at $a_{o,l}^p$, gives after simplification:

$$b'(A)\left(d_P(\overline{P},s^l)-d_P(\overline{P},s^h)\right)$$

which is negative. Indeed by assumption $d_{Ps^j}(\overline{P},s^j)>0$. And finally $a_{o,l}^p<a_{o,h}^p$.

The proof of $a_{O,l}^p<a_{O,h}^p<a_{o,h}^p$ is straightforward when following the steps of the previous proof.

Finally, still using the same steps for $a_{o,l}^p$ and $a_{O,h}^p$, we are not able to rank them against each other.

iii) Under private information, the regulator considers a mean sensitivity $\mu = 0,5.s^l + 0,5.s^h$ for each individual. Here, the regulator has no idea of the likelihood to face h or l when considering a given individual. His program becomes

$$\max_{a_i} \sum_{i=1}^{2} \int_{\underline{e}}^{\overline{e}} \left(u(w-a_i) - d(P,\mu)\right) f(e)de$$

By denoting $a^*_{\overline{s}}$ the social individual optimum, the first order condition is:

$$-u'(w-a^*_{\overline{s}}) + 2b'(A) \int_{\underline{e}}^{\overline{e}} d_P(P,\mu) f(e)de = 0$$

Or:

$$-u'(w-a^*_{\overline{s}}) + b'(A) \left(d_P(\overline{P},\mu) - Y \int_{\underline{e}}^{\overline{e}} d_{PP}(P)F(e)de \right) + b'(A) \int_{\underline{e}}^{\overline{e}} d_P(P,\mu) f(e)de = 0 \tag{20}$$

Consider now an individual with a sensitivity s^h and type θ^k, $k = o, O$. Her first order condition is given by (19) with $j = h$.

Substracting (19) from (20), both being evaluated at $a^*_{\overline{s}}$, gives after simplification

$$b'(A) \left(d_P(\overline{P},\mu) - d_P(\overline{P},s^h) - Y \int_{\underline{e}}^{\overline{e}} d_{PP}(P)(F(e) - H(F(e),\theta^k))de \right) + b'(A) \int_{\underline{e}}^{\overline{e}} d_P(P,\mu) f(e)de,$$

or,

$$b'(A) \left(d_P(\overline{P},\mu) - d_P(\overline{P},s^h)\right) + b'(A) \left(\int_{\underline{e}}^{\overline{e}} d_P(P,\mu) f(e)de - Y \int_{\underline{e}}^{\overline{e}} d_{PP}(P)(F(e) - H(F(e),\theta^k))de \right), \tag{21}$$

the first term in (21) is negative since $d_{Ps^j} > 0$ and $b'(A) > 0$. The second term is positive knowing that $d_P > 0$, $d_{PP} > 0$ and $H(F(e),\theta^k) > F(e)$ by assumption. And finally, the sign of (21) is undetermined.

Proof of Proposition 2

i) The first order condition for individual (θ^k, s^j) in the initial problem is given by (19). When a tax is considered it becomes, thanks to an integration by parts on (13):

$$-(1+t'(a_i^t))\cdot u'(w-a_i^p-t(a_i^t))+b'(A)\left(d_P(\overline{P},s^j)-Y\int_{\underline{e}}^{\overline{e}} d_{PP}(P,s^j)H(F(e),\theta^k)de\right)=0 \tag{22}$$

Substracting (22) from (19), both being evaluated at a_i^p, gives after simplification

$$-u'(w-a_i^p)+(1+t'(a_i^p))u'(w-a_i^p-t(a_i^p))$$

Recall that $t'(.) \leq 0$. Individuals increase their level of individual contributions if this difference is negative, that is to say if

$$t'(a_i^p) < \frac{u'(w-a_i^p)}{u'(w-a_i^p-t(a_i^p))}-1$$

The right-hand-side term is negative knowing that $u''(.) \leq 0$. Notice that

$$\lim_{t\to 0}\frac{u'(w-a_i^p)}{u'(w-a_i^p-t(a_i^p))}=1,$$

knowing that $u'(.)$ and $t'(.)$ are continuous functions by assumption, any negative tax rate $t'(a_i)$ induces higher contributions.

ii) Assume that individuals (O,h) and (o,l) contribute the same level of individual contributions in the initial setting (it is possible according to the point ii) of Proposition1). The first order condition under the tax is given by (22). Let us denote as $Cm(a)$ the first term in (19) and as $Bm(a)$ the second term.

If both individuals contributed the same in the initial setting, ie $a_{O,h}^p = a_{o,l}^p$, we have $Cm(a_{O,h}) = Cm(a_{o,l})$.

Now, consider the respective benefits $Bm(a_{O,h})$ and $Bm(a_{o,l})$. Because individuals differ in both their type θ^k and in their sensitivity s^j, it is possible to have $Bm(a_{O,h}) =$

$Bm(a_{o,l})$. In other words, a high sensitivity can counterbalance a high optimism. Formally, we have $d_{Ps^j} > 0$ while $H_\theta < 0$.

We conclude that there must exist a τ such that both individuals contribute the same in the initial problem, and after the implementation of a tax.

Proof of Proposition 3

i) The first order condition for individual (θ^k, s^j) in the initial setting is given by (19). When a nudge is used it becomes, after an integration by parts on (15),

$$-u'(w - a_i^n) + b'(A)\left(d_P(\overline{P}, s^j) - Y\int_{\underline{e}}^{\overline{e}} d_{PP}(P, s^j)H(F(e), \theta^k)de\right) - g_{a_i}(a_i^n - a_i^*|s^j) = 0 \tag{23}$$

Substracting (23) from (19), both being evaluated at a_i^p, gives after simplification

$$g_{a_i}(a_i^n - a_i^*|s^j)$$

which is negative. Indeed by assumption $g_{a_i}(a_{\theta^k,j}^n - a_i^*|s^j) < 0$. Finally $a_i^n > a_i^p$.

ii) Assume that individuals (O, h) and (o, l) contribute the same level of contributions, ie $a_{O,h}^p = a_{o,l}^p = a^p$, in the initial setting and in the setting with the tax (this is possible according to point ii) of Proposition2). From the previous proof, we have that the difference between the first order condition of the initial setting and the one with the nudge is $g_{a_i}(a_{O,h}^n - a_i^*|s^h)$ for individual (O, h), and $g_{a_i}(a_{o,l}^n - a_i^*|s^l)$ for individual (o, l).

We have that $g_{a_i}(a_{o,l}^n - a_i^*|s^l) < g_{a_i}(a_{O,h}^n - a_i^*|s^h)$ because, by assumption, $\eta(\hat{a}|s^h) > \eta(\hat{a}|s^l)$ for the same level of contributions. And finally, $a_{O,h}^n > a_{o,l}^p = a^n$.

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