Environmental Policy and Tournaments: A Theoretical Formulation with Over-compliance

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Abstract
In this paper the concept of rank-order tournament is illustrated as an incentive mechanism targeting potential over-compliant polluters - those already complying with existing environmental regulations but can further develop the capacity to exceed such regulatory requirements. Employing partial equilibria in a game theoretic framework it is demonstrated that (1) participants have the tendency to over-invest in pollution abatement, contrary to the standard result in principal-agent problems where the principal's choice of contract fails to induce an agent's efficient level of effort; (2) higher expected returns from the game induce lower emissions for each player; and (3) emissions with high risks of negative impacts, or emissions reductions with the most benefits should be accorded high prizes in the game; (4) low cost firms achieve a higher environmental improvement than high-cost firms for any given standard and prize structure. A scheme of the nature presented here is attractive in several ways: the cost of emissions reductions from 'losers' in the game are incurred privately but the benefits of these emissions reduction are a public good; it provides firms with a reason to over-comply, without which they have no incentive to exceed regulatory requirements.
Keywords: environmental regulation, incentives, over-compliance, tournaments

A common criticism of command and control approach to environmental regulation, such as emissions or technology standards is that regulated firms have little or no incentive to over-comply – that is, to perform beyond the requirements of the standard. Over-compliance has the potential to produce significant benefits in the form of reduced pollution and its associated negative impacts. With the exception of the United States Environmental Protection Agency (EPA) there has been little concerted regulatory effort to specifically target and promote over-compliance as a policy objective, by designing and/or implementing policies tailored to firms and facilities with the desire and capability to over-comply with established standards. Over-compliance as a policy objective is important given that there is substantial evidence of over-compliance; either through environmental performance over and above the standard or by adopting and voluntarily complying with specific requirements (for examples of voluntary programs, see EPA's 33/50, WasteWi$e and Green Lights). Several reasons have been advanced for over-compliance. The most relevant one to this paper is the desire for firms to distinguish themselves from the rest of their peers and therefore benefit from the growing numbers of 'green' consumers and/or investors. Self-distinction is clearly the target of voluntary approaches to environmental regulation, since they serve as a channel to transmit important environmental performance to the public – for example, through the use of an eco-label. Leaving aside the significant shortcomings of voluntary compliance as over-compliance, what about over-compliance with mandatory standards? Should we encourage over-compliance with mandatory standards? How can this be done? These are important questions for environmental policy; especially with the prime objective of achieving aggregate emissions reductions. It is important to target potential over-compliant firms and provide them with some incentives to reduce their emissions beyond the legal requirements. We do observe voluntary over-compliance with mandatory standards, which is easier to measure but has received little policy attention in the debate on environmental regulation. In this paper, an incentive scheme in the form of a tournament is proposed as one possible, simple and market-oriented approach to promote over-compliance. The idea is to design a scheme which separate firms with a strong environmental record from the rest of the regulated firms and offer them incentives (prizes in this case) to compete against each other. Their over-compliance performance is ranked on an ordinal scale to determine winners and losers.
The obvious questions are what would motivate firms to join such a scheme? As a participant in the scheme how would a firm make its pollution abatement investment decisions? What is the optimal prize structure that maximizes returns from the contest? What would be an optimal environmental standard? What would be the optimal level of environmental performance? To answer these questions a simple model of a rank order tournament, with partial equilibrium analysis is employed.

1.2 Importance of Targeting Over-compliance as a Policy Objective

If reducing aggregate emissions is the goal of policy, then over-compliance with a mandatory standard plays an important role in achieving aggregate emissions reduction. Over-compliance also has the potential to compensate for violations of the standard by firms and facilities either with low abatement efforts or inferior technology such that emissions reduction targets would still be achieved if the mandatory standard is not achieved by every regulated entity. Also, targeting over-compliance as a policy variable has the capacity to motivate polluters to undertake new investments in research to develop advanced abatement technologies, and this could have positive externalities within regulated industries. Over-compliance as a policy objective can also be used to help firms distinguish themselves among its peers. This has the tendency to enable over-compliant firms to attract a share of the 'green' consumers and/or investors. An example of a program with a built-in mechanism of this nature is the now defunct The National Performance Track (NEPT); a public-private partnership program that operated under the EPA's National Center for Environmental Innovation (NCEI). It was aimed at encouraging facilities with strong environmental records to go above and beyond their legal requirements. Members set typically four public, measurable three-year goals for continuous improvements in environmental performance beyond their legal requirements in areas such as air, water, and land. Members included major corporations, small businesses, and public facilities that were steering a course toward environmental excellence. Membership had grown to more than 450 facilities in 46 states and Puerto Rico, with more than 1,500 commitments by the time the program was shut down in 2010. The shutdown of the program was motivated by significant abuses and inconsistencies (Hassell et al, 2010). Design failures transformed it into an inefficient bureaucracy.

Despite its shortcomings, the popularity of the program suggests a desire or race to over-comply among best performing facilities. "From newspaper headlines to the covers of Fortune 500 reports, we are reading about more and more companies working to outdo each other in 'going green'"[3]. What did facilities gain by joining Performance Track?

The EPA provided incentives to these facilities in several ways. There were regulatory and administrative incentives; for example a reduction in the frequency of reports required under the Maximum Available Control Technology (MACT) provisions of the Clean Air Act such that semi-annual reports may be submitted annually, expedite the review of National Pollutant Discharge Elimination System (NPDES) permit application renewals or modifications held by Performance Track members, Reduced Self-Inspections for Performance Track Members, and low priority for routine inspections. Regulatory and administrative incentives were designed to reduce a facility's transaction costs without causing harm to the environment.

This paper is motivated by two incentives that NEPT provided to members: (1) 'recognition' - the program recognized best formers in various ways. First, Performance Track gave special awards to a select few members who achieved particularly outstanding results in environmental performance (who were also admitted into Performance Track Hall of Fame), letters were sent to elected representatives at the local, state, and national levels announcing the facility's acceptance in the program, articles about many of its members were placed in trade association journals. (2) 'green investing' – NEPT data was readily available to investment research and advisory firms who consider environmental and social performance as an indicator to evaluate and rate companies. This practice benefits top-performing publicly traded companies that included many Performance Track members, by making them more attractive to investors and increasing their brand recognition.

In this paper performance (or recognition) awards are treated as a rank order tournament. A rank order tournament refers to a compensation scheme in which the rewards to contestants are solely based on their (ordinal) position and not on the actual size of their output (or contribution). Earnings are dependent on the rank order of contestants and not on the output of a particular contestant or the entire game, since prizes are determined or fixed in advance. Hence, performance incentives are set by attempts to win the contest. Unlike in marginal analysis, prices (winner and loser prizes in the case of many players) awarded may or may not be worth the value of outputs.

In tournaments, winners receive prizes but in the model to be explored here, the recognition awards and brand recognition are treated as prizes. This is particularly important because member facilities recognized the market/business value of their efforts as can be identified in some of their testimonials:

"In terms of bottom line impact, we really weren't looking for a monetary payback from the program. But we have seen monetary payback, certainly, from reduced energy usage and water usage, for example." Jack Blackmer Coordinator, Novozymes North America"

Treating recognition and market value (or brand recognition) as prizes is similar to contests in innovation races where the winner of an innovation contest takes the prize in the form of a patent to appropriate the benefits of its discovery. Only that in this case increasing 'green' market share is the benefit. An important advantage with a scheme of this nature is that the cost of emissions reductions from 'losers' are incurred privately but the benefits are a public good. Another advantage of the scheme is that it provides an incentive to over-compliant firms to undertake pollution abatement that would otherwise not be pursued.

1.3 Related Literature

There is significant literature on the reasons for over-compliance. Arora and Cason (1995, 1996); Arora and Gangopadhyay (1995); Videras and Alberini, (2000); Khanna and Damon (1999) provide evidence on self-

[3] Press Release (05/09/2007) on: The Performance Track Fifth Annual Progress Report quoting EPA Administrator Stephen L. Johnson.

distinction in search of 'green' public recognition. Barett, 1991; Salop and Scheffman, 1983 argue that firms use over-compliance as a means to establish barriers to entry by signaling to the regulator that a higher standard is achievable, but at a high cost. While Fri, (1992) argues that over-compliance is used to influence the regulatory process or regulation itself, Maxwell, Lyon and Hackett, (1995) show that over-compliance can be used to pre-empt or even delay regulation. Also, Arora and Cason (1996), suggest that over-compliance may simply be a result of lumpy investment in abatement with substantial long run cost savings. The missing piece in the literature has been the question of what over-compliance means for policy. It is important to consider how the ability and willingness of polluters to over-comply with legal requirements can be leveraged to further reduce emissions beyond aggregate achievable emissions reduction goals. The seminal work of Lazear and Rosen (1981) provides a useful guide for motivating potentially over-compliant facilities to invest more on pollution abatement. This motivation takes the form of a rank-order tournament – compensation in a game theoretic scheme in which the rewards to contestants are solely based on their ordinal position and not the actual size of their output or contribution. While there exist sizable empirical and experimental work (for example, see Vulina & Zheng (2007); Bull, Schotter, and Weigelt (1987); Camerer and Lovallo (1999); Bull et al (1987); Eriksson et al (2008)) on rank-order tournament, applications exploring their usefulness for environmental problems have not been pursued. This paper is an attempt to investigate the importance of rank-order tournaments in environmental policy.

2. Method

In this paper, a simple model of a rank order tournament with partial equilibrium analysis is employed, in a game theoretic framework. The general form of the model is presented and simplified for convenience and ease of analysis to a two-player tournament.

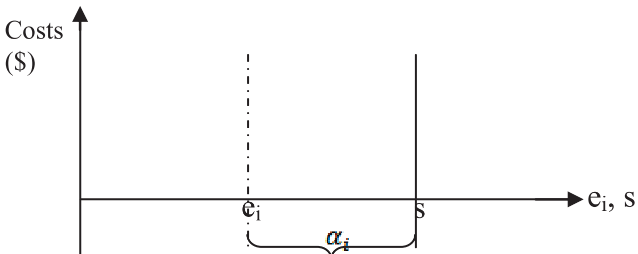
2.1 Model and Results

Consider a non-cooperative two-stage game with complete but imperfect information. In the first stage, compliant firms decide whether or not to expend resources on additional pollution abatement investments that qualify them to join the contest. In the second stage, they choose their over-compliance efforts to compete for a prize. The model mostly focuses on the second stage of the game, assuming self-selection in the first stage. Facilities over-comply relative to some fixed standard, s. Hence, a facility's over-compliance can be defined by

$$\alpha_i = s - e_i$$

Where e_i is the choice of emissions[4]; $\alpha_i > 0$ for every firm *i* in the second stage ($\alpha_i \leq 0$ in the first stage of the game and any facility with $\alpha_i \leq 0$ is not qualified to compete in the game). Over-compliance can be graphically illustrated as follows:

Figure 1: Over-Compliance



Assume a performance level (function), G_i of firm i with α_i and some error ε_i as its argument. G_i can be expressed as:

$$G_i = g_i(\alpha_i) + \varepsilon_i$$

Where $g_i(\alpha_i)$ is a concave function of α_i. That is, $g_i^{/}(\alpha_i) > 0$, $g_i^{//}(\alpha_i) < 0$. ε_i is an error term common to all firms. The performance level suggests that firms may not necessarily have full control over their emissions, such that emissions could be higher or lower than their proposed or planned goal. Brannlund and Lofgren (1996) explore this randomness in firms' emissions. This randomness in performance can also be viewed as error in measurement of performance on the part of the regulator. Furthermore, including ε_i is consistent with observation of the data on the defunct NEPT, which shows facilities did not always meet their stated goals. The standard assumption that the random component is identically and independently distributed, (i.i.d.) across individual firms is considered here. That is,

$$\varepsilon_i \text{ is } i.i.d.\, N(0, \sigma_\varepsilon^2)$$

[4] e_i can also be assumed to be a class or multiple class of emissions. A single class of emissions makes the determination of best performance straight forward, compared to a multiple class of emissions

2.2 Prizes and Choice of Pollution Abatement Investments: Two-firm Case, One Fixed Winner-Take-All Prize:

Consider there are only two firms and suppose there is, for simplicity purpose, only one fixed winner-take-all prize, Z. The regulator independently selects the prize and facilities compete to win (the selection of an optimal prize is addressed in the next section). It can be argued that a more complete prize structure would be endogenous in order to account for the benefits of brand recognition from increased exposure (facilitated by winning the contest) – this issue is addressed in an extension to this paper. Even an endogenous prize structure would depend on the reach of the competition – the ability of the competition and prize to influence the winner's market share. By assuming a fixed prize, it is considered that the effect of competing is stronger than winning; such that simply competing distinguishes a facility from a non-participating facility.

Firms incur over-compliance costs $C_i(s-e_i)=C_i(\alpha_i), i=1{,}2$. In a study of plant level data on actual and permitted levels of water pollution emissions for the pulp and paper industry, McClelland and Horowitz (1999) show that plants do incur substantial costs to over-comply. These costs may be different for different firms because both $C_i(s)$ and $C_i(e_i)$ may differ across individual firms and facilities. It is assumed $C_i(s)$ is same across firms and $C_i(\alpha_i)$ is an increasing function of α_i. That is, $C_i^{/}(\alpha_i)>0, C_i^{//}(\alpha_i)>0$. However, for costs of abatement $C_i^{/}(e_i)<0, C_i^{//}(e_i)>0$.

Firm 1's utility is defined as:

$$U_i=\begin{cases} Z-C_1(\alpha_1)\ if\ \alpha_1>\alpha_2 \\ -C_1(\alpha_1)\ if\ \alpha_1<\ \alpha_2 \end{cases} \tag{1}$$

Firm 2's utility is defined in a similar way. The firm or facility with the best performance wins the prize. Hence, firm 1 wins the contest if and only if

$$G_1(\alpha_1)>G_2(\alpha_2)\ \ or\ g_1(\alpha_1)+\varepsilon_1>g_2(\alpha_2)+\varepsilon_2 \tag{2}$$

The probability of winning takes the probit form, a special form of probabilities used in models of discrete choice where outcomes embody elements of noise[5]. Equation (2) can be re-written as

$g_1(\alpha_1)-g_2(\alpha_2)>\varepsilon_2-\varepsilon_1$

Hence, using the cumulative distribution function of $\varepsilon_j-\varepsilon_i$; the probability of winning the contest becomes:

$P(\alpha_1,\alpha_2)=F[g_1(\alpha_1)-g_2(\alpha_2)]$

Note that the probability that firm 1 wins the contest depends not only on its performance, α_1 but also on the performance of firm 2. It is assumed here that a firm's choice of performance goals has a positive but diminishing effect on its probability of winning the contest[6]. In the two-firm case, we can write this as:

$$\frac{\partial P(g_1(\alpha_1),g_2(\alpha_2))}{\partial g_1(\alpha_1)}>0 \text{ and } \frac{\partial^2(g_1(\alpha_1),g_2(\alpha_2))}{\partial g_1^2(\alpha_1)}<0$$

Also note that in terms of actual emissions, individual firms increase abatement (low emissions) to increase their probability of winning. That is,

$$\frac{\partial P(.)}{\partial e_1}=\frac{\partial P}{\partial g_1}.\frac{\partial g_1}{\partial \alpha_1}.\frac{\partial \alpha_1}{\partial e_1}=-\frac{\partial P}{\partial g_1}.\frac{\partial g_1}{\partial \alpha_1}<0$$

In a winner-take-all contest, a firm's expected prize or net payoff from the game is

$$EU_i=P\big(g_1(\alpha_1),g_2(\alpha_2)\big)[Z-C_i(\alpha_1)]+\big[1-P\big(g_1(\alpha_1),g_2(\alpha_2)\big)\big][-C_i(\alpha_i);i=1{,}2$$

$$=F[g_1(\alpha_1),g_2(\alpha_2)]Z-C_i(\alpha_1)$$

A risk-neutral firm chooses its performance, α_i at e_i for a given standard (*s*) to maximize its expected payoff from the contest. A firm's objective function is given by

$$\max_{\alpha_i} EU_i=\max_{\alpha_i} F[g_1(\alpha_1),g_2(\alpha_2)]Z-C_i(\alpha_1);i=1{,}2 \tag{3}$$

The firm's objective function is concave in $\alpha_1\ or\ \alpha_2$ to guarantee that there exists an interior Nash equilibrium

[5] An alternative form is the logit form – where randomness in performance is absent. But the probit is well appropriate because a great deal of randomness features in many firms' compliance and over-compliance efforts. Also, as indicated earlier, there is evidence that facilities in the NEPT did not always meet their goals.

[6] Dixit (1987) makes the similar assumption in a tournament context with multiple players.

(α_1, α_2). That is, for firm 1:

$$\frac{\partial EU_1}{\partial \alpha_1} = \frac{\partial F[.]}{\partial g_1(\alpha_1)} . \frac{\partial g_1(\alpha_1)}{\partial \alpha_1} . Z - C_1^{/}(\alpha_1) \equiv f\big(g_1(\alpha_1) - g_2(\alpha_2)\big) . g_1^{/}(\alpha_1) . Z - C_1^{/}(\alpha_1) > 0$$

$$\frac{\partial^2 EU_1}{\partial \alpha_1^2} = \frac{\partial^2 F[.]}{\partial g_1^2(\alpha_1)} Z - C_1^{//}(\alpha_1) \equiv f^{/}\big(g_1(\alpha_1) - g_2(\alpha_2)\big) . g_1^{//}(\alpha_1) . Z - C_1^{//}(\alpha_1) < 0$$

For all $\alpha_1, \alpha_2 \geq 0$; $C_1^{/}(\alpha_1) > 0$; $C_1^{//}(\alpha_1) > 0$; $g_1^{/}(\alpha_1) > 0$; $g_1^{//}(\alpha_1) < 0$; $f\big(g_1(\alpha_1) - g_2(\alpha_2)\big) > 0$; $Z > 0$. $F[g_1(\alpha_1) - g_2(\alpha_2)]$ defines the randomness of performance. Hence, it is required that $f^{/}\big(g_1(\alpha_1) - g_2(\alpha_2)\big) \leq 0$ for interior solutions to exist. This means that $f^{/}\big(g_1(\alpha_1) - g_2(\alpha_2)\big)$ is sufficiently flat; large increases in firm's environmental quality improvement goals result in its performance being completely random. The weaker case that; $f^{/}\big(g_1(\alpha_1) - g_2(\alpha_2)\big) = 0$ satisfies the two conditions for the concavity of the firm's objective function. In terms of actual emissions, setting goals for distinctively low emissions may not be achievable and facilities undertaking such risks to improve their chances of winning the contest may experience increased randomness in their performance.

Remark 1: As standard in the literature, firms choose performance goals to equalize marginal abatement expenditures and returns on those expenditures, the expected prize from winning the contest.

The F.O.C in (3) is

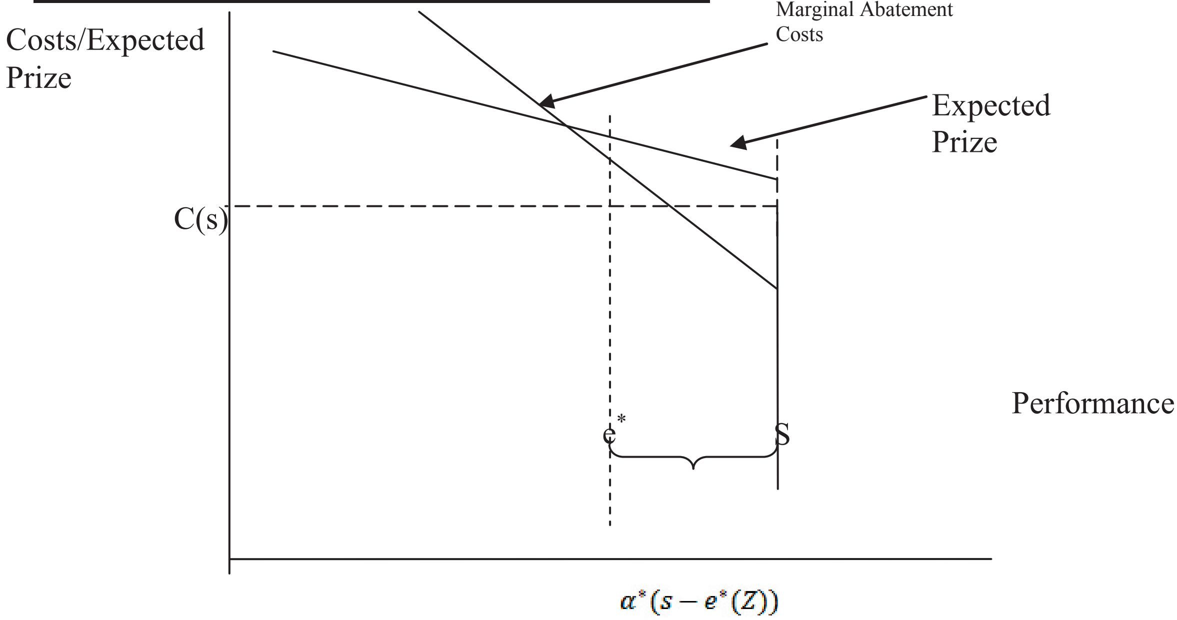
$$\frac{\partial EU_1}{\partial \alpha_1} = \frac{\partial F[.]}{\partial g_1(\alpha_1)} . \frac{\partial g_1(\alpha_1)}{\partial \alpha_1} . Z - C_1^{/}(\alpha_1) = 0$$

$$\equiv f\big(g_1(\alpha_1) - g_2(\alpha_2)\big) . g_1^{/}(\alpha_1) . Z - C_1^{/}(\alpha_1) = 0 \tag{4}$$

Equation (4) implies that a firm's investments on extra pollution abatement depend on both the prize and their ability to affect their chance of winning the contest. Firms invest in over-compliance up to the point where each additional dollar invested equals the expected prize from the contest. Firms affect their chance of winning the contest by investing more on pollution abatement. This implies that the regulator can always increase over-compliance and/or attract new entrants into the game by increasing the prize. A bigger prize induces more investments on pollution abatement, either through increased investment by existing firms or increased number of firms.

It is plausible to assume Nash equilibrium conditions in this game. Each firm will then maximize its payoff from the competition against the optimum investment decisions of its competitors. In other words, in the determination of its pollution abatement investments firm 1 takes α_2 as given. Firm 2 behaves the same way. In this sense, equation (4) is also a symmetrical reaction function for the individual firms. Symmetry implies that for a Nash solution, $\alpha_1 = \alpha_2 \; and \; g_1(\alpha_1) = g_2(\alpha_2) = g(\alpha)$. Symmetry also implies that the probability of winning the contest is the same for every contestant; $P(\alpha_1, \alpha_2) \equiv F[g_1(\alpha_1) - g_2(\alpha_2)] \equiv F(0) \equiv 1/2$. Hence, the outcome of the game in Nash equilibrium is completely random. At Nash equilibrium, equation (4) can be written as $f(0). g(\alpha) Z - C_i^{/}(\alpha_i) = 0; i = 1,2.$ The expected prize from the contest should be large enough to balance the costs of pollution abatement to induce participation in the game. We can graphically illustrate the choice facing the firms as follows:

Figure 2: Firm's Choice of Pollution Abatement Investment



The expected prize function has a negative slope[7] – a higher prize is associated with lower emissions. At the standard, *s*, where the expected prize is higher than extra abatement costs to firms, there exist efficiency losses associated with the lack of incentive on the part of the firms to over-comply without a reasonable expectation of a fair return on the additional abatement effort. Therefore, there exist opportunities to improve through further emissions reductions away from the standard. On the graph, firms will increase their performance because the expected prize from the contest exceeds the abatement costs incurred. At α*, the expected prize equals extra abatement costs. Below α*, firms increase their performance goals but will cut back on these goals for any performance levels above α* because they would have overinvested in relation to their expected payoffs from those investments.

Another implication here is that low cost firms achieve a higher environmental improvement than high-cost firms for any given standard and prize structure. To see this, rotate the abatement cost curve downwards (anti-clockwise) – it intersects the expected prize curve at a lower level of emissions or higher performance α. A steeper prize function yields a similar result, as shown in the following remark:

Remark 2: The regulator can induce high environmental quality improvement from firms by awarding a larger prize.

Consider how individual firms respond to the prize, z. Equation (4) implicitly defines firm 1's choice of performance. The first-best efficient level of performance can be written as:

$$\alpha = \alpha^*(Z) = s - e^*(Z) \tag{5}$$

Substitute (5) into (4):

$$f[g_1(\alpha^*(Z)) - g_2(\alpha^*(Z))].g_1^{/}(\alpha^*(Z)).Z - C_1^{/}(\alpha^*(Z)) \equiv 0 \tag{6}$$

Differentiate (6) with respect to z.

$$\left[f^{/}(.)g_1^{/}\frac{\partial\alpha}{\partial Z}g_1^{/} + f(.)g_1^{//}\frac{\partial\alpha}{\partial Z}\right]Z + f(.)g_1^{/}(.) - C_1^{//}(.)\frac{\partial\alpha}{\partial Z} = 0$$

$$\Rightarrow \frac{\partial\alpha}{\partial z} = \frac{-fg_1^{/}}{\{f^{/}[g_1^{/}]^2 + f(.)g_1^{//}\}.Z - C_1^{//}} > 0 \tag{7}$$

Equation (7) holds because $g_1^{/} > 0, f^{/} \leq 0, f > 0, g_1^{//} < 0$, and $C_1^{//} > 0$. Hence, equation (7) suggests that the regulator can set a bigger prize to induce greater environmental improvement from firms. In other words,

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[7] To see this, differentiate the expected prize with respect to e. That is, $\frac{\partial[F(.)z]}{\partial e} = f(.)g^{/}(.)\frac{\partial\alpha}{\partial e}$ $= -f(.)g^{/}(.) < 0$, where $\frac{\partial\alpha}{\partial e} = -1$

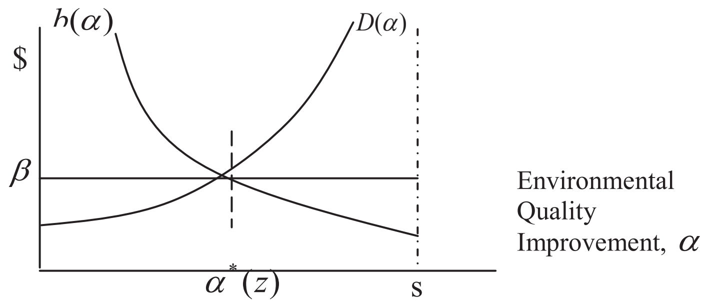
increasing the prize provides an incentive for firms to further reduce emissions. However, note that increasing the prize is costly.

2.3 Optimal Prize and Firm's Performance

With the knowledge of how firms would respond to prizes in (4), the regulator can determine an optimal prize. To examine how the regulator determines an optimal prize, we first analyze her problem. The subscripts are dropped here because the analyses are based on Nash equilibrium outcomes.

Define a social value function of a level of environmental improvement[8], $b(\alpha)$ which is increasing and convex in α, (but is bounded at some performance level beyond which there are a little or no benefits). That is, $b^{/}(\alpha) > 0$, $b^{//}(\alpha) > 0$, but $b(\alpha) = b(s) = \beta$; where β is the benefit from a level of environmental quality improvement achieved by the standard. In terms of actual emissions, $b_e(\alpha) < 0$, and $b_{ee}(\alpha) > 0$. The regulator determines an optimal prize by maximizing the difference between the benefits and costs at the level of environmental quality α. The costs include damage and abatement investment costs. That is, total damage is $D(\alpha) = d(\alpha) + C(\alpha)$, with $D^{/}(\alpha) < 0$, $D^{//}(\alpha) < 0$ This can be graphically illustrated as follows:

<u>Figure 3: Optimum Environmental Performance</u>



The regulator's objective function then is:

$$b(\alpha) - [d(\alpha) + C(\alpha)] \quad (8)$$

The regulator chooses a prize, z by maximizing (8) subject to

$$F(.)Z - C(\alpha) \geq R \quad (8a)$$

$$\alpha = \alpha^*(Z) = s - e^*(Z) \quad (8b)$$

Equation (8a) is the firm's participation constraint. R is the firm's fallback position; the payoff from simply being in the game and not actively competing for the prize – the equivalent of a consolation prize. This constraint must be binding for a firm to enter the contest. Equation (8b) is the firm's incentive compatibility.

Remark 3: Firms respond by choosing environmental quality improvements above the first-best efficient level; over-investing in pollution abatement and hence over performing.

Substitute (8a) and (8b) into (8) to obtain;

$$b(\alpha^*(Z)) - [d(\alpha^*(Z)) + F(.)Z + R] \quad (9)$$

Assuming equation (8a) is binding, the first-order condition in (9) is

$$b^{/}(.)\frac{\partial\alpha}{\partial Z} - d^{/}(.)\frac{\partial\alpha}{\partial Z} - f(.)g^{/}(.)\frac{\partial\alpha}{\partial Z}Z - F(.) = 0$$

$$\Rightarrow \frac{\partial\alpha}{\partial Z} = \frac{F(.)}{b^{/}(.) - d^{/}(.) - f(.)g^{/}(.)Z} > 0 \quad (10)$$

Note that $f(.)g^{/}(.)Z = C^{/}(.)$ according to (4). An efficient level of performance (α) requires $b^{/}(\alpha^*) - [d^{/}(\alpha^*) + C^{/}(\alpha^*)] = 0$. But since $F(.) > 0$, equation (10) is true if and only if $b^{/}(.) - d^{/}(.) - f(.)g^{/}(.)Z$
$= b^{/}(.) - [d^{/}(.) + C^{/}(.)] > 0$.

It can then be concluded here that (8b) ($\alpha = \alpha^*(Z) = s - e^*(Z)$) exceeds the efficient level of environmental quality. The prize, *Z* chosen by the regulator does induce the firm to choose a level of environment quality beyond the first-best efficient level of performance. Firms choose emissions below the first-best level. That is, $\alpha > \alpha^*(Z)$ implying that $e(Z) < e^*$.

This over performance arises from the desire to win the contest. Firms make abatement choices according to (4), in which the regulator determines z but the firm chooses lower emissions or a higher α to

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[8] Similarly, think of $b(\alpha)$ as benefits of emissions/pollution control.

increase its probability of winning the contest. This conclusion is contrary to the standard result in principal-agent problems where the principal's choice of contract does not induce the agent to choose an efficient level of effort; a problem that arises from information asymmetry; particularly incomplete information.

Tournaments solve this problem of incomplete information by removing the need for principal to have knowledge of the agent's choice of action. A tournament allows the firm to choose abatement investments according to (4). Its ability to win the contest depends on its choice of performance, α and its associated costs. Unlike in standard principal-agent problems, it suffices that a firm observe z and set performance level and costs to win the contest. The regulator is not obliged to know $C(\alpha)$ before setting the prize, z.

Remark 4: The optimal prize is increasing in both the benefit of, and damage caused by a level of environmental quality $\alpha = \alpha^*(Z) = s - e^*(Z)$*)*

To see this, note that optimal z requires that the first-order condition in (9) equals zero. That is,

$$b^{/}(.)\frac{\partial\alpha}{\partial Z} - d^{/}(.)\frac{\partial\alpha}{\partial Z} - f(.)g^{/}(.)\frac{\partial\alpha}{\partial Z}Z - F(.) = 0$$

$$\Rightarrow Z^* = \frac{1}{fg^{/}}[b^{/} - d^{/} - \frac{F}{\frac{\partial\alpha}{\partial Z}}]$$

Differentiate Z^* with respect to $b^{/}(.)$ and $d^{/}(.)$.

$$\frac{\partial Z^*}{\partial b(.)} = \frac{b^{//}}{fg^{/}} > 0$$

$$\frac{\partial Z^*}{\partial d(.)} = -\frac{d^{//}}{fg^{/}} > 0$$

These conditions hold because $b^{//}(\alpha) > 0$, $d^{//}(\alpha) < 0$, $f > 0$, and $g^{/}(.) > 0$. Hence, the optimal prize is increasing in both the benefit of, and damage caused by a level of environmental quality. This conclusion has important policy implications; it suggests that pollution activities with higher potential benefits of environmental improvement or with higher risks of pollution effects should be allocated higher prizes in the contest.

3. Conclusions and Discussion

In this paper, a rank-order tournament scheme has been proposed as an incentive mechanism to target those firms that are believed to better position to deploy additional resources to exceed regulatory requirements and achieve better levels of environmental quality. This type of a scheme is very suitable for pollutants that are difficult to control but that have significant impacts on the environment. The firm's response to the optimal prize structure instituted by the regulator in a simple tournament has been examined and the results indicate that participants have the tendency to over-invest in pollution abatement.

We have examined firms' abatement decisions and the results show that individual participants make abatement decisions by balancing abatement cost against expected returns from winning the contest. Furthermore, higher expected returns from the game induce lower emissions for each player. The effect of the optimal prize on environmental quality has been analyzed. The result is that missions with high risks of negative impacts, or emissions reductions with the most benefits should be accorded high prizes in the game. A scheme of the nature presented here is attractive in several ways: the cost of emissions reductions from 'losers' in the game are incurred privately but the benefits of these emissions reduction are a public good.

The key message here may not necessarily be that only lump sum cash prizes be used as an environmental policy tool. In a more realistic approach, similar results can be achieved if various categories of investors are given the tools and incentives to influence the abatements choices of firms. For example, tax credits on "green" investments can have direct effects on investment decisions. Firms would "compete" for these ("Green") investments from potential investors - the prize in this case. An important advantage with a scheme of this nature is that the cost emissions reductions from 'losers' are incurred privately but the benefits are a public good. Another advantage of the scheme is that it provides an incentive to over-compliant firms to undertake pollution abatement that would otherwise not be pursued.

A further area for research on the scheme presented here includes the effect of a prize structure that is endogenous. It is apparent from the literature on over-compliance that facilities are increasingly adopting and exceeding regulatory requirements in ways that build added value to their business. This value added, intuitively, qualifies as a prize. Furthermore, the model developed here assumes that facilities are not monitored. It may be worth examining the effect of enforcement (and enforcement costs) on optimal performance.

Acknowledgements
I would like to thank my research assistant, Peter Standbridge (Economics Department, Gettysburg College) for his assistance. I am also grateful for the additional funding the Economics Department. I would also like to acknowledge the helpful advice and encouragements from colleagues.

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