The Common Tragedy of Regulations

Jean-Marc Bourgeon

Paper prepared for presentation at the X[th] EAAE Congress
'Exploring Diversity in the European Agri-Food System',
Zaragoza (Spain), 28-31 August 2002

The common tragedy of regulations[*]

Jean-Marc Bourgeon[†]

Rough draft. Do not quote

This paper considers the optimal regulation of extraction of a common resource by multiple extractors under conditions of asymmetric information between the regulator and the extractors and costly monitoring of extraction. Extractors are assumed to use the extracted resource for productive purposes. A classical example is the problem of optimal groundwater extraction by a group of nonidentical farmers with differing use values, which is the source of the asymmetric information between the regulator and the extractor, for the extracted groundwater. One might think intuitively that such problems of asymmetric information may be circumvented rather easily by simply requiring each farmer to pay the marginal social cost of extraction for each unit of groundwater extracted if the marginal social cost of extraction is identical across firms. This, of course, is the standard Pigouvian solution. However, the literature on implementation of the standard Pigouvian solution typically assumes that the ability to monitor extraction is costless. If nonnegligible costs of monitoring extraction are present, then it will generally be optimal for the regulator not to monitor completely and instead to monitor on a probabilistic basis. Monitoring on a probabilistic basis, however, turns the regulator's problem into a compliance game where the extractor's benefit from noncompliance is dependent upon its own use value of the extracted resource. If this use value is private information, then the presence of costly monitoring re-introduces problems of adverse selection which must be addressed.

[*]File: common0325.tex. Date: March 27, 2002

[†]Jean-Marc Bourgeon is Maître de conférences in the Department of Economics at the Université Paris X, Nanterre, France. I am indebted to Robert G. Chambers for useful comments and suggestions. All remaining errors are mine.

Most analyses of optimal groundwater regulation (Burt and Provencher; Negri) take an explicitly dynamic approach. For purposes of tractability, however, this approach is static. Thus, my results are most appropriately interpreted in terms of optimal steady-state regulation and not in terms of dynamic adjustment paths. The reason for adopting a static approach does not reflect a belief on my part that issues of dynamics are secondary. Indeed, I would argue that they are of primary importance. However, a number of excellent studies that focus on these issues already exist, while to my knowledge no studies have addressed the informational problems that I consider. Thus, this analysis is perhaps best viewed as a precis of the type of issues that should be addressed in a more complex informational and dynamic setting.

In what follows, I first outline our model. The modelling framework draws on the recent work of Bontems and Bourgeon. I then consider the optimal regulation of groundwater extraction assuming that the regulator's objective is social surplus from groundwater extraction. After that, however, I consider optimal regulation of groundwater extraction that is further constrained by the government having minimum-income objectives for farmers. The paper then concludes.

The model

Consider a group of N farms exploiting a common groundwater resource. Denote by $B_i(q; q_{-i})$ the benefit of farm i using a quantity q of the groundwater when the $N-1$ others are extracting $q_{-i} \equiv (q_j)_{j \neq i}$. Assume that

$$B_i(q; q_{-i}) = \pi_i(q) - dQ_{-i}$$

where $\pi_i(q)$ is the profit farm i would obtain with an amount q of the groundwater resource if no other farm exploits this groundwater resource and dQ_{-i} the supplementary cost due to the extraction of the quantity $Q_{-i} \equiv \sum_{j \neq i} q_j$ by the $N-1$ other farms. I suppose that unless the resource allocation is nil, in which case $\pi_i(0) = 0$ for all i, these farms are heterogeneous in the sense that they obtain different gross benefits π_i from the same amount of the groundwater resource. More specifically, the productivity of farm i depends on its productivity level θ_i according to the relation $\pi_i(q) = \pi(q; \theta_i)$. This productivity level is the private information of each farm (the type of farm i). The government knows the distribution of productivity levels, denoted by $p(\theta)$ with $\sum_\theta p(\theta) = N$, but it cannot identify a farm's type without prohibitively costly monitoring of the purposes activities. I restrict attention to the case where farms are of two types only, i.e., $\theta_i \in \Theta = \{\underline{\theta}; \bar{\theta}\}$ with $\underline{\theta} < \bar{\theta}$ and I assume that farms are ranked according to their marginal productivity of groundwater. More specifically, denoting by $\Delta(q)$ the difference of gross benefits from a resource allocation q, i.e.; $\Delta(q) \equiv \pi\left(q; \bar{\theta}\right) - \pi(q; \underline{\theta})$, I assume that[1]

$$\Delta'(q) > 0: \tag{1}$$

If the regulator knew the private information of each farm of the sector and could costlessly monitor extraction of groundwater, she would implement the first-best assignment rule q_i^{FB}, i.e., the production levels that maximize the social welfare given by

$$W = -sQ + \sum_i B_i(q_i; q_{-i}) \tag{2}$$

where $-sQ$ is the social damage corresponding to a total extraction $Q \equiv \sum_i q_i$ of the groundwater resource by the N farmers. These first-best assignments satisfy

$$\pi_i'(q_i^{FB}) = s + (N - 1)d$$

for all $i = 1; ::: ; N$. These levels are equivalent to assigning to each farm i one of the two different levels $q^{FB}(\underline{\theta})$ or $q^{FB}(\bar{\theta})$ given by

$$\partial_q \pi(q^{FB}(\theta); \theta) = s + (N - 1)d$$

for $\theta \in \Theta$, where ∂_x denotes the partial derivative with respect to x. The first-best assignment of farm i is different from its private choice, given by $\pi_i'(q_i^*) = 0$ or equivalently $\partial_q \pi(q^*(\theta_i); \theta_i) = 0$, which yields the selfish gross profit level $\pi^*(\theta_i) \equiv \pi(q^*(\theta_i); \theta_i)$.

In the presence of asymmetric information, it is doubtful that the regulator is able to implement a given quantity assignment without resorting to a reward and/or threat system, that I assume to be monetary (a tax-subsidy and/or fine system). Absent redistributional and fiscal concerns, it would be possible to implement the first-best allocation via a Pigouvian tax (or subsidy) with constant marginal rate equal to the marginal damage $s + (N - 1)d$, assuming the agency is able to control without cost the amount of groundwater resource extracted by each farm.

No farm would willingly comply, however, with such a rule if they are not controlled by the regulator. Hence, every tax or subsidy scheme must be augmented by a monitoring system. A public policy is thus a scheme, a (non-linear) relationship between quantities q, monetary amounts t and f, and a probability of control or monitoring ρ, where q is the amounts of groundwater resource that the farm can extract, t is a tax or licence fee paid by the farm for this amount and f the fine paid in case of a monitoring revealing that an effective level of groundwater resource y greater than the one permitted q.[2]

In designing such a scheme, it is easier to consider the "game-form" of the regulation problem. Indeed, this problem is mathematically equivalent to the problem of having to design an "announcement game" or "mechanism" where the farms truthfully announce their private information to the regulator. To obtain truthful announcements, however, the regulator must be able to commit to an assignment rule $q(\theta)$, payment rules $t(\theta)$ and $f(y;\theta)$, and monitoring probability $\rho(\theta)$ $(0 \leq \rho(\theta) \leq 1)$ that satisfy incentive compatibility constraints given by

$$\text{(IC)} \qquad B_i(q(\theta_i); q_{-i}) - t(\theta_i) - \rho(\theta_i) f(q(\theta_i);\theta_i) \geq \max_{y;\tilde{\theta}} B_i(y; q_{-i}) - t(\tilde{\theta}) - \rho(\tilde{\theta}) f(y;\tilde{\theta})$$

for all $\theta_i \in \Theta$.[3] Constraints (IC) require that a type-θ_i farm is never worse-off announcing truthfully its type and following the policy requirements than choosing any other announcement $\tilde{\theta}$ and production level y. Because the cost dQ_{-i} due to the extraction of the other farms does not change the incentive constraint of the farm i, it can be removed from each side of (IC). The incentive constraints can be thus expressed equivalently in term of gross profits.

With a control that reveals only the effective amount y and not the farm's type θ, two types of misbehavior are possible: The farm may choose to 'mimic' another farm's type, or it may try to 'evade' the policy by not complying with its intended allocation. The first type of cheating is the standard adverse-selection problem investigated in the regulation literature (Guesnerie and Laffont). The evasion problem was first investigated by Becker and then developed by Towsend, Mookherjee and Png and Chandler and Wilde. In the following, we assume that fines are constrained by

$$\bar{F} \geq f(y;\theta) \geq 0$$

where $\bar{F}$, for example, may corresponds to the limited liability of farms. It is common in the taxation literature to assume that the maximum fine can be farm-specific (e.g., Chandler and Wilde). However, because monitoring does not permit the regulator to assess the farm's profit in case of evasion, the maximum fine cannot be farm-specific.

By the incentive constraints (IC), one must have for all θ; $f(q(\theta);\theta) = 0$ and $f(y;\theta) = \bar{F}$ for all $y \neq q(\theta)$. Indeed, for any payment schedule $t(\cdot)$, setting the fine to 0 in case of compliance increases the left-hand side of (IC), while imposing the maximum fine in case of evasion at least weakly decreases the right-hand side of (IC).[4] This very simple fine schedule allows us to separate the two incentive problems of the administration. Let $U(\theta) \equiv \pi(q(\theta);\theta) - t(\theta)$ denote the gross profit of a compliant type-θ farm. The inefficient mimicking problem is addressed by the usual adverse-selection constraints

$$U(\theta) \geq \max_{\tilde{\theta}} \pi(q(\tilde{\theta});\theta) - t(\tilde{\theta}); \tag{3}$$

which require that regulation must be designed so that mimicking behavior cannot improve the farm's profit. Evasion is deterred if

$$U(\theta_i) \geq \pi^*(\theta_i) - \min_{\tilde{\theta}} \{t(\tilde{\theta}) + \mu(\tilde{\theta})\bar{F}\} \tag{4}$$

which states that a farm is worse off being selfish while declaring to be of a type that minimizes its expected payment (fine in case of control included) than by complying with the groundwater regulation.

Simple manipulations of (3) give

$$\Delta(q(\bar{\theta})) \geq U(\bar{\theta}) - U(\underline{\theta}) \geq \Delta(q(\underline{\theta})) \tag{ASC}$$

implying

$$\Delta(q(\bar{\theta})) \geq \Delta(q(\underline{\theta}))$$

or

$$\int_{q(\underline{\theta})}^{q(\bar\theta)} \Delta'(q)dq \geq 0.$$

By this last expression and (1), it follows that the only incentive compatible contracts are ones with $q\left(\bar\theta\right) \geq q(\underline{\theta})$.

Denote by $K \equiv \min_{\tilde\theta}\{t(\tilde\theta) + \mu(\tilde\theta)\bar F\}$. The constraints (4) can be written equivalently as

$$K \geq \pi^*(\theta) - U(\theta)$$

for all θ. Using the first inequality of (ASC), we have

$$\begin{aligned}
\pi^*(\bar\theta) - U(\bar\theta) - (\pi^*(\underline{\theta}) - U(\underline{\theta})) &\geq -\Delta(q(\bar\theta)) - (\pi^*(\underline{\theta}) - \pi^*(\bar\theta)) \\
&\geq -\Delta(q(\bar\theta)) - (\pi(q^*(\bar\theta);\underline{\theta}) - \pi^*(\bar\theta)) \\
&= \int_{q(\bar\theta)}^{q^*(\bar\theta)} \Delta'(q)dq.
\end{aligned}$$

The second inequality comes from the fact that $\pi^*(\underline{\theta}) \geq \pi(q;\underline{\theta})$ for all q. Under the reasonable assumption that the regulator never wants to implement a level of extraction by the $\bar\theta$-type farmer that is higher than what he or she would extract privately, i.e., $q^*(\bar\theta) \geq q(\bar\theta)$, this last expression is positive. It then follows that deterring the $\bar\theta$-type farmer from evading the allocation regulation is also sufficient to deter the less productive from evasion. Mathematically, this observation implies that a single constraint is required to ensure that the contracts deter evasion:

(EC) $$K \geq \pi^*(\bar\theta) - U(\bar\theta)$$

Finally, by the definitions of K and $U(\theta)$,

$$\begin{aligned}
K &\leq t(\theta) + \mu(\theta)\bar F \\
&= \pi(q(\theta);\theta) - U(\theta) + \mu(\theta)\bar F
\end{aligned}$$

which implies that the inspection effort is bounded below by

(CTR) $$\mu(\theta) \geq (U(\theta) - \pi(q(\theta);\theta) + K)/\bar F \geq 0$$

where the last inequality comes from (4), using $\pi^*(\theta) \geq \pi(q(\theta);\theta)$. The meaning of (CTR) is straightforward: the agency has to inspect farms with positive probability to enforce an assignment level lower than the selfish one.

The preceding arguments establish that the government's groundwater allocation problem is given mathematically by

$$(5) \qquad \max_{\substack{q(\Theta);U(\Theta);K \\ \mu(\Theta)\leq 1}} \sum_{\theta\in\Theta} \{\pi(q(\theta);\theta) - [s + (N-1)d]q(\theta) - c\mu(\theta)\}p(\theta) : \text{(ASC),(EC),(CTR)}$$

where $c\mu$ denotes the cost of an audit μ incurred by the agency. Before solving the program, observe that since the audit is costly, the constraints (CTR) are binding at the optimum; i.e.; the optimal solution involves $K = t(\theta) + \mu(\theta)F$ for all θ, which means that the expected payment in case of evasion is the same for both type of farms. This implies a negative relationship between the tax and the probability of control: The more a farm has to pay, the less it is inspected. Since tax payment and groundwater allocations must be positively related to satisfy (3) constraints, it then follows from this observation that the higher is the farm's allocation, the lower will be the optimal inspection probability for that farm type.

Characterizing the Optimal Extraction Policy with No Redistributional Concerns

In solving program (5), it is analytically convenient to adopt a two-step solution procedure suggested originally by Weymark and later developed more fully by Chambers and Bourgeon and Chambers. The solution strategy is to first solve the adverse selection and evasion problems given a particular groundwater assignment $q(\Theta)$ and then to pick the optimal groundwater assignment. Let us consider the case of an interior solution for μ first. With binding constraints (CTR), the groundwater allocation problem (5) can be rewritten as

$$(6) \qquad \max_{q(\Theta)} \sum_{\theta\in\Theta} \{(1 + c/F)\pi(q(\theta);\theta) - [s + (N-1)d]q(\theta)\}p(\theta) - C(q(\Theta))$$

where

$$(7) \qquad C(q(\Theta)) \equiv \frac{c}{F} \min_{U(\Theta);K} \left\{ NK + \sum_{\theta\in\Theta} U(\theta)p(\theta) : \text{(ASC),(EC)} \right\}.$$

$C(q(\Theta))$ can be interpreted as the cost of the adverse-selection and evasion problem for a given groundwater resource assignments $q(\Theta)$. Since I assume that there is no social gain associated to the amount of tax collected, the cost of the policy comes solely from the inspection effort that the regulation of the groundwater extraction necessitates. Using the fact that $t = \pi - U$, a decrease of $U(\theta)$ for the θ-type farm corresponds to an increase of its tax payment, which from binding (CTR) allows to monitor less intensively this farm. Still from binding (CTR), a decrease in the expected evasion payment K allows the agency to reduce inspection effort on all farms.

Figure 1 illustrates problem (7) for a given K in gross profit level ($U(\Theta)$) space. The straight lines parallel to the bisector (the 45^0 degree line emanating from the origin) correspond to the binding incentive constraints (ASC). The incentive-compatible profit pairs are thus located between these two lines. The horizontal line with intercept $\pi^*(\bar{\theta}) - K$ corresponds to the evasion constraint (EC), and the relevant profit values are located above this line. Finally, the lines with intercepts $C - K$ and $C^* - K$ with the same negative slope correspond to the agency's iso-cost lines. Cost is decreasing downward as indicated. Observe that the incentive area delimited by the (ASC) lines does not depend on K, whereas iso-cost lines and the evasion line (EC) do. Consequently, for any $q(\Theta)$, there are three possible situations depending on the value of K. We either have

$$\pi^*(\bar{\theta}) - K \qquad \Delta(q(\underline{\theta}))$$

which corresponds to an intercept of the (EC) line located below the intercepts of the (ASC) lines (e.g.; at point D), or

$$\Delta(q(\bar{\theta})) < \pi^*(\bar{\theta}) - K < \Delta(q(\underline{\theta}))$$

which corresponds pictorially to an intercept of the (EC) line located between the intercepts of the two (ASC) lines (e.g.; at point B), and finally

$$\pi^*(\bar{\theta}) - K \geq \Delta(q(\bar{\theta}))$$

which is the case depicted. These cases correspond to decreasing values of K, and given (7), we intuitively infer that the later situation of a "small" K is the optimal one. This intuition is easily verified. Consider that the first case is the optimal situation, i.e.; that the optimal solution is such that

$$\pi^*(\bar\theta) - K \quad \Delta(q(\underline\theta))$$

The optimal point is at the intercept of the $\bar\theta$-type incentive constraint (ASC), which gives

$$U(\bar\theta) = \Delta(q(\underline\theta))$$
$$U(\underline\theta) = 0$$

whence

$$C(q(\Theta)) = \frac{c}{\bar F}\min_K\{N K + p(\bar\theta)\Delta(q(\underline\theta))\}$$

Minimizing with respect to K increases the intercept of the (EC) line which would eventually be higher than the intercept of the $\bar\theta$-type (ASC) line since $\pi^*(\bar\theta) > \Delta(q(\underline\theta))$, hence a contradiction. Same reasoning applies in the second case, i.e.;

$$\Delta(q(\bar\theta)) < \pi^*(\bar\theta) - K < \Delta(q(\underline\theta))$$

In that case, the optimal point solution is at B, which gives

$$U(\bar\theta) = \pi^*(\bar\theta) - K$$
$$U(\underline\theta) = 0$$

hence

$$C(q(\Theta)) = \frac{c}{\bar F}\min_K\{p(\underline\theta)K + p(\bar\theta)\pi^*(\bar\theta)\}$$

Again, minimizing the right hand side with respect to K increases the intercept of the (EC) line which would eventually be higher than the intercept of the $\underline\theta$-type (ASC) line since $\pi^*(\bar\theta) \geq \pi(q(\bar\theta);\bar\theta)$, hence a contradiction.

We thus must have

(8) $$K < \pi^*(\bar\theta) - \Delta(q(\bar\theta))$$

at the optimum of the program, which is the situation depicted Fig. 1. The optimal point solution is thus at point A which yields a cost equal to C^*. The optimal solution is located where the $\underline{\theta}$-type incentive constraint (ASC) and the evasion constraint (EC) intersect. Indeed, we then have

$$\text{(9)} \qquad \begin{aligned} U(\bar{\theta}) &= \pi^*(\bar{\theta}) - K \\ U(\underline{\theta}) &= U(\bar{\theta}) - \Delta(q(\bar{\theta})) \end{aligned}$$

whence

$$\text{(10)} \qquad C(q(\Theta)) = \frac{c}{\bar{F}}\{N\pi^*(\bar{\theta}) - p(\underline{\theta})\Delta(q(\bar{\theta}))\}.$$

Observe that the constant K disappears from the expression of the cost. Consequently, as long as (8) is satisfied, optimal tax levels are defined up to a constant. Indeed, because the regulator has no redistributive concerns, only marginal tax rates matter. However, the condition (8) on K imposes that total tax payments $t(\cdot)$ must be sufficiently small to reduce inspection efforts. Also notice that

$$dC(q(\Theta))/dq(\bar{\theta}) = -p(\underline{\theta})\Delta'(q(\bar{\theta}))c/\bar{F} < 0$$

so that under (1) an increase in the allocation to the $\bar{\theta}$-type of farmer reduces the cost of implementing the groundwater assignment. The reason that this happens is clear from Figure 1. The binding incentive constraint for the regulator is the one which makes it at least weakly optimal for the less productive farmer not to mimic the extraction practices of the more productive farmer. Hence, a marginal increase in $q(\bar{\theta})$, which brings a relatively low return to the low productivity farmer, makes the contract intended for the more productive farmer even less attractive. As we shall see below, this leads to a 'spreading' effect of the type noticed by Chambers.

Substituting (10) in (6) and solving for $q(\cdot)$ give the following first-order conditions for an interior solution,

$$\text{(11)} \qquad \partial_q \pi(\hat{q}(\bar{\theta}); \bar{\theta}) = \frac{s + (N-1)d}{1 + c/\bar{F}} - \frac{c/\bar{F}}{1 + c/\bar{F}} \frac{p(\underline{\theta})}{p(\bar{\theta})} \Delta'(\hat{q}(\bar{\theta}))$$

and

$$\partial_q \pi(\hat{q}(\underline{\theta}); \underline{\theta}) = \frac{s + (N - 1)d}{1 + c/\bar{F}} \tag{12}$$

and it is easy to show that

$$q^{FB}(\underline{\theta}) < \hat{q}(\underline{\theta}) < q^{*}(\underline{\theta})$$

$$q^{FB}(\bar{\theta}) < \hat{q}(\bar{\theta})$$

and

$$\hat{q}(\underline{\theta}) < \hat{q}(\bar{\theta})$$

Because the marginal tax rates defined by the right-hand sides of (11) and (12) are lower than the Pigouvian tax, $s + (N - 1)d$, the optimal groundwater allocation induces over-extraction of groundwater as compared to the first best. Notice, however, that the marginal tax presented to the $\bar{\theta}$-type farmer is lower than the marginal tax presented to the lower productivity firms. Thus, when compared with the first best, the more productive farmers have a higher marginal incentive to over-extract than the less productive farmers. The last result (no bunching at the optimum) is deduced from (1) and the fact that using (12) and (11) we have

$$\partial_q \pi(\hat{q}(\bar{\theta}); \bar{\theta}) < \partial_q \pi(\hat{q}(\underline{\theta}); \underline{\theta})$$

To understand the intuition behind these results recall that there are two incentive problems that the groundwater regulator is trying to address. One is the existence of information asymmetries between the regulator and the extracting farmers, and the other is the existence of a costly monitoring mechanism. Consider the latter problem first. Generally, it is not optimal to monitor completely (set $\mu(\theta) = 1$). Without complete monitoring, even if the Pigouvian tax is charged, farmers will optimally depart from first-best extraction practices. Thus, some over extraction, relative to the first best, emerges from the presence of costly monitoring.

Now consider the former informational effect. As we have seen above, $C(q(\cdot))$ is decreasing in $q(\bar{\theta})$ because raising $q(\bar{\theta})$ makes it less attractive for the less productive farmer to mimic the extraction practices of the more efficient farmer. Put another way, there is a reduction in the informational cost of implementing an extraction assignment if $q(\bar{\theta})$ is higher. Hence, because of the presence of the information asymmetries the more productive farmer receives an extra incentive to over-extract groundwater when compared with the less productive farmer. This additional over-extraction effect depends on the extent of the difference between firms types, their relative proportions and the monitoring cost. Rearranging terms in (11) give

$$\partial_q \pi(\hat{q}(\bar{\theta});\bar{\theta}) = \frac{p(\bar{\theta})}{p(\bar{\theta}) + N(c/\bar{F})}\left(s + (N-1)d + \frac{c}{\bar{F}}\frac{p(\underline{\theta})}{p(\bar{\theta})}\partial_q \pi(\hat{q}(\bar{\theta});\underline{\theta}) \right)$$

and we have $\hat{q}(\bar{\theta}) < q^*(\bar{\theta})$ if

$$\partial_q \pi(q^*(\bar{\theta});\underline{\theta}) > -\frac{p(\bar{\theta})}{p(\underline{\theta})}\frac{\bar{F}}{c}[s + (N-1)d]$$

Consequently, a high monitoring cost compared to the maximal fine, or a large number of type-$\underline{\theta}$ firms, may induce the agency to give up reducing the resource extraction of the type-$\bar{\theta}$ firms to reduce monitoring costs.

As mentioned above, optimal tax payments are defined up to a constant. This is not the case for inspection probabilities, which are completely determined by the resource allocation pair $\hat{q}(\cdot)$. Indeed, using binding (CTR) constraints and (9), we obtain

$$\begin{aligned} \nu(\bar{\theta}) &= [\pi^*(\bar{\theta}) - \pi(\hat{q}(\bar{\theta});\bar{\theta})]/\bar{F} \\ \nu(\underline{\theta}) &= \nu(\bar{\theta}) + [\pi(\hat{q}(\bar{\theta});\underline{\theta}) - \pi(\hat{q}(\underline{\theta});\underline{\theta})]/\bar{F} \end{aligned}$$

This is easily understood. Inspection probabilities must deter type-$\bar{\theta}$ producers from evading the regulation. The agency has to design a regulation such that whatever type-$\bar{\theta}$ farmers' announcements, expected benefits in case of evasion are the same, and are lower than their revenues when complying. Observe that even if producers do not comply with their extraction assignments, they do have paid the tax payment corresponding to their announcements. Consequently, if they have announced their true type, the tax payment do not matter, and the inspection probability is deduced from the binding evasion constraint (EC): $\pi(\hat{q}(\bar{\theta});\bar{\theta}) - t(\bar{\theta}) = \pi^*(\bar{\theta}) - [t(\bar{\theta}) + \nu(\bar{\theta})\bar{F}]$: (Since the tax payment of type-$\bar{\theta}$ producers appears on both sides of this equation, the agency inspection effort is the same whatever the tax level.) If they have paid the type-$\underline{\theta}$ tax amount, we must have $t(\underline{\theta}) + \mu(\underline{\theta})\bar{F} = t(\bar{\theta}) + \mu(\bar{\theta})\bar{F}$ to maintain the same expected payment in case of evasion. Since the same constant affects both tax payments, it cancels out, and the supplementary effort of inspection on the less efficient producers depends only on the difference between tax levels.

The case where $\mu(\underline{\theta}) = 1$ at the optimum is straightforward. Because there is no possibility to save on the monitoring costs of type-$\underline{\theta}$, arising from the information asymmetry, we have

$$\partial_q \pi(\hat{q}(\underline{\theta}); \underline{\theta}) = s + (N - 1)d$$

and

$$\partial_q \pi(\hat{q}(\bar{\theta}); \bar{\theta}) = \frac{s + (N - 1)d}{1 + c/\bar{F}}$$

i.e.; only the type-$\bar{\theta}$ groundwater resource level is increased, and this distortion is limited to the direct monitoring effect.

It is worth to summarize the results obtained in this section. The cost minimization stage allowed us to deduce that at the optimum, more productive farms are tempted to evade from the regulation (they are indifferent at the optimum). Low productive producers are not tempted to evade, but they are inclined to mimic more productive farms to increase their resource extraction. From the second stage, we have obtained that the optimal resource extraction levels are greater than Pigovian levels. This over-extraction allows the agency to reduce its monitoring cost on all farms. For more productive producers, this over-extraction effect is exacerbated by the incentive of less productive farmers to choose the resource extraction - tax payment pair designed for the more productive farmers. Over-extraction of the more productive farmers allows the agency to increase the tax payment of the less productive farmers, thus to decrease monitoring efforts on these farms.

Maintaining farm incomes

We observed previously that since the government has no redistributive concerns, the tax schedule is only defined up to a constant. However, it is common for agricultural policy makers to have minimal income targets for their farm programs most obviously manifested in the form of parity incomes. Suppose that the regulation of groundwater exploitation is tempered by a farm-income goal. Because the reduction of the resource extraction diminishes farms profits, the optimal regulation characterized above may lead the agency to actually subsidize farms (negative tax payments). This is the case when the marginal social damage s is large and the number of farms N is important. The agency would follow these policy requirements if they do not encounter a budget constraint. This is obviously not a reasonable assumption, and in the following I will assume that the agency's program is affected by terms reflecting the cost of public funds and the preference of the agency for tax revenues. More precisely, taking into account the cost of raising funds to finance public programs, the agency's objective is given by

$$(13) \qquad \sum_{\theta\in\Theta}\{\pi(q(\theta);\theta) - [s+(N-1)d]q(\theta) - (1+\lambda)c^{1}(\theta) + \lambda t(\theta)\}p(\theta)$$

where $\lambda > 0$ is the per monetary unit deadweight loss incurred by distortionary taxation systems.[5]

Denote by $\bar{R}$ the minimum farm revenue that the government wants to guarantee. The agency problem possesses an additional constraint

$$U(\theta_i) - dQ_{-i} \geq \bar{R}$$

for all θ_i, or

$$(\text{PI}) \qquad U(\underline{\theta}) \geq \bar{R} + d[Q - q(\underline{\theta})]$$

and

$$U(\bar{\theta}) \geq \bar{R} + d[Q - q(\bar{\theta})]$$

Because the incentive constraints (ASC) imply $U(\bar{\theta}) \geq U(\underline{\theta})$ and $q(\bar{\theta}) \geq q(\underline{\theta})$, only constraint (PI) is relevant at the optimum.

The agency problem is now given by

$$(14) \qquad \max_{q(\Theta)} \sum_{\theta\in\Theta}\{(1+\lambda)(1+c/\bar{F})\pi(q(\theta);\theta) - [s+(N-1)d]q(\theta)\}p(\theta) - \mathcal{C}(q(\Theta))$$

where

(15)
$$\mathcal{C}(q(\Theta)) \equiv \min_{U(\Theta);K} \left\{ (1+\lambda)c/\bar{F} N K + [(1+\lambda)c/\bar{F} + \lambda] \sum_{\theta \in \Theta} U(\theta)p(\theta) : (ASC),(EC),(PI) \right\}.$$

A strictly positive λ and the constraint (PI) change the optimal solution of program (15) as depicted Fig. 2. Compared to Fig. 1, the constraint (PI) limits the available gross profit pairs to the right of the vertical line going trough the x-axis at the point $\bar{R} + d[Q - q(\underline{\theta})]$. With $\lambda > 0$, point A can no longer be the optimal solution. Indeed, we would have

$$\mathcal{C}(q(\Theta)) = \min_{K} -\lambda N K + [(1+\lambda)c/\bar{F} + \lambda)][N\pi^*(\bar{\theta}) - p(\underline{\theta})\Delta(q(\bar{\theta}))]:$$

Minimizing with respect to K decreases the intercept of the (EC) line, which can no longer cross the (ASC) constraint of the type-$\underline{\theta}$ farmers at point A, hence a contradiction. This result reflects the fact that the agency places a positive weight on tax revenues, and thus will arrange that incomes of (at least) the less productive farmers do not exceed the minimal income requirement. Pictorially, this implies that the optimal solution is located on the (PI) line between points B' and D'. Consequently, three type of situations are possible candidates for an optimum: Along the vertical segment between points B' and D', where both incentive constraint (ASC) are lenient, at point B', where the type-$\underline{\theta}$ (ASC) is binding, and finally at point D', where the type-$\bar{\theta}$ (ASC) is binding.

Before examining the different possibilities, it is convenient to define

$$\bar{\lambda} \equiv \frac{p(\underline{\theta})c/\bar{F}}{p(\bar{\theta}) - p(\underline{\theta})c/\bar{F}}$$

which is positive if $p(\bar{\theta})/p(\underline{\theta}) > c/\bar{F}$ and is a threshold level for the deadweight loss of public funds. Indeed, for given extraction levels, the agency has to balance two effects when defining the tax payment of the type-$\bar{\theta}$ farmers. Since $t = \pi - U$, a decrease dU of their gross profit allows the agency to raise an additional tax revenue $dt = -dU$ per farm, inducing a social gross benefit equal to $-\lambda p(\bar{\theta})dU$. Moreover, with an increased tax payment, pretending to be a type-$\bar{\theta}$ farmer is less attractive for type-$\underline{\theta}$ producers. This allows the agency to monitor less intensively type-$\bar{\theta}$ farms while satisfying their (CTR) constraint, leading to an additional benefit $-(1+\lambda)p(\bar{\theta})c/\bar{F}dU$. However, to avoid tax evasion of type-$\bar{\theta}$ farmers, the agency will have to increase K, the expected payment in case of evasion, as indicated by (EC). This involve to monitor more intensively all farms, as indicated by (CTR). This second monitoring effect annihilates the former one and induces an additional social cost on type-$\underline{\theta}$ producers equal to $(1+\lambda)p(\underline{\theta})c/\bar{F}dU$. As a result, adding \$1 to the tax payment of the type-$\bar{\theta}$ farmers induces a social net benefit equal to

$$\lambda p(\bar{\theta}) - (1+\lambda)p(\underline{\theta})c/\bar{F} = [p(\bar{\theta}) - p(\underline{\theta})c/\bar{F}](\lambda - \tfrac{\mu}{\lambda})$$

Consequently, when the number of type-$\bar{\theta}$ farmers and the deadweight cost of public funds are large (i.e.; $p(\bar{\theta})/p(\underline{\theta}) > c/\bar{F}$ and $\lambda > \frac{\mu}{\lambda}$) the agency is induced to raise as much tax revenue as possible on type-$\bar{\theta}$ farmers. Otherwise, the primary concern of the agency is to reduce the monitoring cost of enforcing the groundwater allocation schedule.

We can now proceed to the examination of the possible optimal situations. Assume first that the optimal point belongs to the vertical segment between points B' and D'. At such a point, the vertical (PI) line crosses the horizontal (EC) line and none of the (ASC) is binding at the optimum. The optimal solution would be given by

$$\begin{aligned} U(\underline{\theta}) &= \bar{R} + d[Q - q(\underline{\theta})] \\ U(\bar{\theta}) &= \pi^*(\bar{\theta}) - K \end{aligned}$$

whence

$$\text{(16)} \qquad \begin{aligned} C(q(\Theta)) = \min_K [p(\bar{\theta}) - p(\underline{\theta})c/\bar{F}](\tfrac{\mu}{\lambda} - \lambda)K \\ +[(1+\lambda)c/\bar{F} + \lambda]\{p(\bar{\theta})\pi^*(\bar{\theta}) + p(\underline{\theta})(\bar{R} + d[Q - q(\underline{\theta})])\}. \end{aligned}$$

Unless $\lambda = \frac{\mu}{\lambda}$, minimizing with respect to K changes the intercept of the (EC) line, which can no longer cross the (PI) line at the intended point, hence a contradiction. However, such a situation is optimal when $\lambda = \frac{\mu}{\lambda}$ (which implies that $p(\bar{\theta})/p(\underline{\theta}) > c/\bar{F}$). In that case, the agency is indifferent to the tax payment of the more productive farmers (tax payment of the less productive farmers is deduced from the parity income constraint), since an increase of their tax payment induces social costs due to monitoring of the less productive farmers that offset marginal social benefits. Their tax payment is thus defined up to a constant depending on K, the expected cost of evasion. However, since none of the (ASC) constraints is binding, we must have

$$\bar{R} + d[Q - q(\underline{\theta})] + \Delta(q(\bar{\theta})) > \pi^*(\bar{\theta}) - K > \bar{R} + d[Q - q(\underline{\theta})] + \Delta(q(\underline{\theta}))$$

which, for given $q(\cdot)$, limits the range of available values for K.

Observe that (16) increases with the allocations of all farms. Indeed, an increase of the resource extracted decreases the net benefit from the resource of the less productive farms due to the supplementary cost of extraction (equal to $dp(\bar{\theta})$ for a marginal increase of the more productive farms and $d[p(\underline{\theta}) - 1]$ for the less productive farms). This leads the agency to decrease the type-$\underline{\theta}$ tax payment to reach the parity income, and to monitor more intensively the less productive farms to deter tax-evasion. For each \$ lost by a type-$\underline{\theta}$ farms, the marginal social cost is thus equal to $(1 + \lambda)c/\bar{F} + \lambda$.

Taking into account these effects, the optimal extraction level $\bar{q}(\cdot)$ satisfies

$$\partial_q \pi(\bar{q}(\bar{\theta}); \bar{\theta}) = \frac{s + d[p(\bar{\theta}) - 1]}{(1 + \lambda)(1 + c/\bar{F})} + dp(\underline{\theta})$$

and

$$\partial_q \pi(\bar{q}(\underline{\theta}); \underline{\theta}) = \frac{s + dp(\bar{\theta})}{(1 + \lambda)(1 + c/\bar{F})} + d[p(\underline{\theta}) - 1]$$

and are attainable only in the improbable case where $\lambda = \bar{\lambda}$.

When $\lambda \neq \bar{\lambda}$, it is easy to deduce from (16) which situation of the two remaining possibilities B' and D' is optimal. If $p(\bar{\theta})/p(\underline{\theta}) < c/\bar{F}$ (which implies $\bar{\lambda} < 0$) or if $\bar{\lambda} > \lambda$, then reducing K allows to decrease (16). The optimal solution is thus located point B'. At this point, the horizontal (EC) line crosses the vertical (PI) line and the type-$\underline{\theta}$ (ASC) line. We thus have an additional equation that allows to determine the optimal value for K, given by

$$K^* = \pi^*(\bar{\theta}) - \bar{R} - d[Q - q(\underline{\theta})] - \Delta(q(\bar{\theta}))$$

The cost of a resource extraction pair $q(\cdot)$ is then given by

$$C(q(\cdot)) = (1 + \lambda)c/\bar{F} N \pi^*(\bar{\theta}) + \lambda N \{\bar{R} + d[Q - q(\underline{\theta})]\} + (\lambda - \bar{\lambda})[p(\bar{\theta}) - c/\bar{F} p(\underline{\theta})] \Delta(q(\bar{\theta}))$$

Observe that if the second term of $C(q(\cdot))$ is still increasing with the resource extracted, the last term decreases with $q(\bar{\theta})$. As explained above, when there is only a small number of more productive farms, or when the deadweight loss λ is low, the primary concern of the agency is still to reduce the cost of auditing farms. This situation thus parallels the one explained in the previous section where asymmetric information leads to an increase of the resource extraction of the more productive farmers. Indeed, denoting by $q^B(\Theta)$ the optimal extraction schedule, we have

$$\begin{aligned}\partial_q\pi(q^B(\bar\theta);\bar\theta) - \partial_q\pi(\bar q(\bar\theta);\bar\theta) &= \frac{(\lambda - \bar\lambda)[p(\bar\theta) - c/\bar F\, p(\underline\theta)]}{(1+\lambda)(1+c/\bar F)}[dp(\underline\theta) + \Delta'(q^B(\bar\theta))] \\ &< 0\end{aligned}$$

and

$$\begin{aligned}\partial_q\pi(q^B(\underline\theta);\underline\theta) - \partial_q\pi(\bar q(\underline\theta);\underline\theta) &= \frac{(\lambda - \bar\lambda)[p(\bar\theta) - c/\bar F\, p(\underline\theta)]}{(1+\lambda)(1+c/\bar F)}d[p(\underline\theta) - 1] \\ &< 0\end{aligned}$$

Compared to the preceding case, we thus have over-extraction for all farms due to the agency's objective to reduce monitoring costs. As in the previous section, this over-extraction effect is exacerbated for the more productive farmers to reduce the incentive of the less productive farmers to choose their extraction - tax payment pair.

When $\lambda > \bar\lambda > 0$, increasing K allows to reduce (16). The optimal solution is thus located point D', as depicted Fig. 2. Type-$\bar\theta$ farmers (ASC) constraint is binding which gives

$$K^* = \pi^*(\bar\theta) - \bar R - d[Q - q(\underline\theta)] - \Delta(q(\underline\theta))$$

hence

$$\begin{aligned}\mathbf{C}(q(\Theta)) &= (1+\lambda)c/\bar F N\pi^*(\bar\theta) + \lambda N\{\bar R + d[Q - q(\underline\theta)]\} \\ &\quad + (\lambda - \bar\lambda)[p(\bar\theta) - c/\bar F\, p(\underline\theta)]\Delta(q(\underline\theta));\end{aligned}$$

The last term of $\mathbf{C}$ is now increasing in $q(\underline\theta)$. As above, this arises from informational concerns. However, in that case, it is the incentive constraint (ASC) for the type-$\bar\theta$ farmers that binds at the optimum. The more productive farmers are thus (weakly) induced to mimic less productive farmers in order to receive compensation payments. A decrease of the resource extraction of the less productive farmers $q(\underline\theta)$ makes this mimicking less attractive by reducing the gross profit of the more productive farmers. More specifically, denoting by $q^C(\cdot)$ the optimal extraction schedule, it is easily shown that

$$\begin{aligned}
\partial_q \pi(q^C(\bar\theta);\bar\theta) - \partial_q \pi(\bar q(\bar\theta);\bar\theta) &= \frac{(\lambda - \bar\lambda)[p(\bar\theta) - c/\bar F\, p(\underline\theta)]}{(1+\lambda)(1+c/\bar F)} dp(\underline\theta) \\
&> 0
\end{aligned}$$

and

$$\begin{aligned}
\partial_q \pi(q^B(\underline\theta);\underline\theta) - \partial_q \pi(\bar q(\underline\theta);\underline\theta) &= \frac{(\lambda - \bar\lambda)[p(\bar\theta) - c/\bar F\, p(\underline\theta)]}{(1+\lambda)(1+c/\bar F)} \{d[p(\underline\theta) - 1] + C'(q^C(\underline\theta))\} \\
&> 0
\end{aligned}$$

Compared to the case $\lambda = \bar\lambda$, extraction is reduced for all farms. This effect is exacerbated for the less productive farm. The primary goal of the agency is now to increase tax revenues while maintaining the income of the less productive farmers to its minimum level. The regulator, if he could, would capture the more productive farmers revenues above the minimum income level. If the planner attempts to do so, however, he gives the more productive farmers an incentive to mimic the behavior of the less productive farmers. The incentive problem is now on the other foot. To deter this type of mimicking behavior, the regulator optimally raises the cost to the more productive farmers of mimicking the less productive farmers by adjusting the groundwater allocation intended for the less productive farmers downward.

Conclusion

This paper addresses the optimal regulation of groundwater extraction under two assumptions not usually maintained in the literature on groundwater regulation: positive costs of monitoring the rate of extraction and the presence of asymmetric information between the regulator and the farmer on the use-value of the extracted groundwater. In such a situation, the presence of costly monitoring prevents the regulator from using the Pigouvian solution to achieve what is first best. It is shown that the presence of these twin problems thus leads to over-extraction of the resource as compared to the first best. When there are no redistributional concerns, the more productive type of farmer has a greater marginal incentive to extract than the less productive farmer. When there are redistributional concerns, the primary objective of the agency depends on the cost of public funds. When this cost is low, reducing monitoring cost is still the primary objective of the regulator, and we have over-extraction compared to the second-best situation. When raising tax revenues is the primary concern, this relationship is turned on its head, and farmers have lower marginal incentive to extract.

Notes

[1]Since ¼(0; µ) = 0 for all type µ, (1) implies ¢(q) > 0 for all stricly positive allocation q.

[2]Monitoring, if it occurs, is assumed to be perfectly informative.

[3]I assume commitment is possible on the part of the regulator.

[4]If f(q(µ); µ) were di¤erent from 0, we could replace t(¢) by the schedule t̂(¢) ´ t(¢) + ¹(¢)f(q(¢); ¢) with a …ne equal to 0 in case of compliance to obtain the same set of inequalities.

[5]¸ re‡ects the so-called "double dividend" of environmental taxation policies. The term 1 + ¸ a¤ecting the agency's cost is the per monetary unit "shadow cost" of public funds.

References

[1] Becker, G. (1968), "Crime and Punishment: An Economic Approach", Journal of Political Economy, 76, 169-217.

[2] Bontems, P., Bourgeon J.-M. (2001), "Optimal Environmental Taxation and Enforcement Policy", Working paper THEMA.

[3] Border K.C., Sobel J. (1987), "Samurai Accountant: A Theory of Auditing and Plunder", Review of Economic Studies, 54, 525-540.

[4] Bourgeon J.-M., Chambers, R. G. (2000), "Stop-and-Go Agricultural Policies", American Journal of Agricultural Economics, 82, 1-13.

[5] Burt O., Provencher, B. (1993), "The externalities associated with the common property exploitation of groundwater", Journal of Environmental Economics and Management, 24(2), 139-159.

[6] Chambers, R. (1997) "Information, Incentives, and the Design of Agricultural Policies", University of Maryland, Working Paper.

[7] Chander P., Wilde L.L. (1998), "A General Characterization of Optimal Income Tax Enforcement", Review of Economic Studies, 65, 165-183.

[8] Guesnerie R., La¤ont J.J. (1984), "A Complete Solution to a Class of Principal-Agent Problems with an Application to the Control of a Self-Managed Firm", Journal of Public Economics, 25, 329-369.

[9] Mookherjee D., Png I.P.L. (1989) : "Optimal auditing, insurance and redistribution", The Quaterly Journal of Economics, May 1989, 399-415.

[10] Mookherjee D., Png I.P.L. (1994) : "Marginal Deterrence in Enforcement of Law", Journal of Political Economy, 102, 1039-1066.

[11] Negri, D. H. (1989), "The Common Property Aquifer As a Di¤erential Game", Water Ressouces Research, 25(1), 9-15.

[12] Townsend, R. (1979) : "Optimal Contraccts and Competitive Markets with Costly State Veri…cation", Journal of Economic Theory, 22, 265-93.

[13] Weymark, J. (1986), "A reduced-Form Optimal Income Tax Problem." Journal of Public Economics, 30, 199-217.

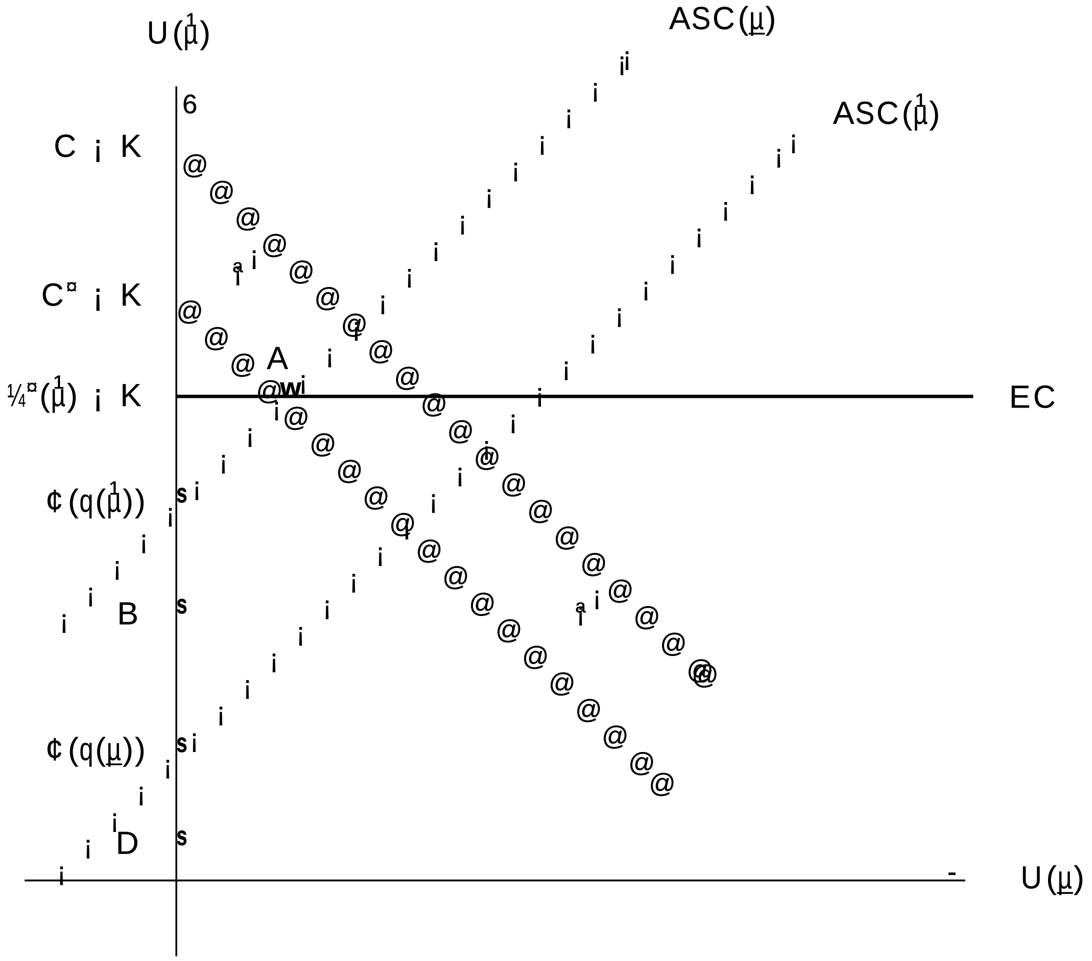

Figure 1: Enforcement costs and incentives.

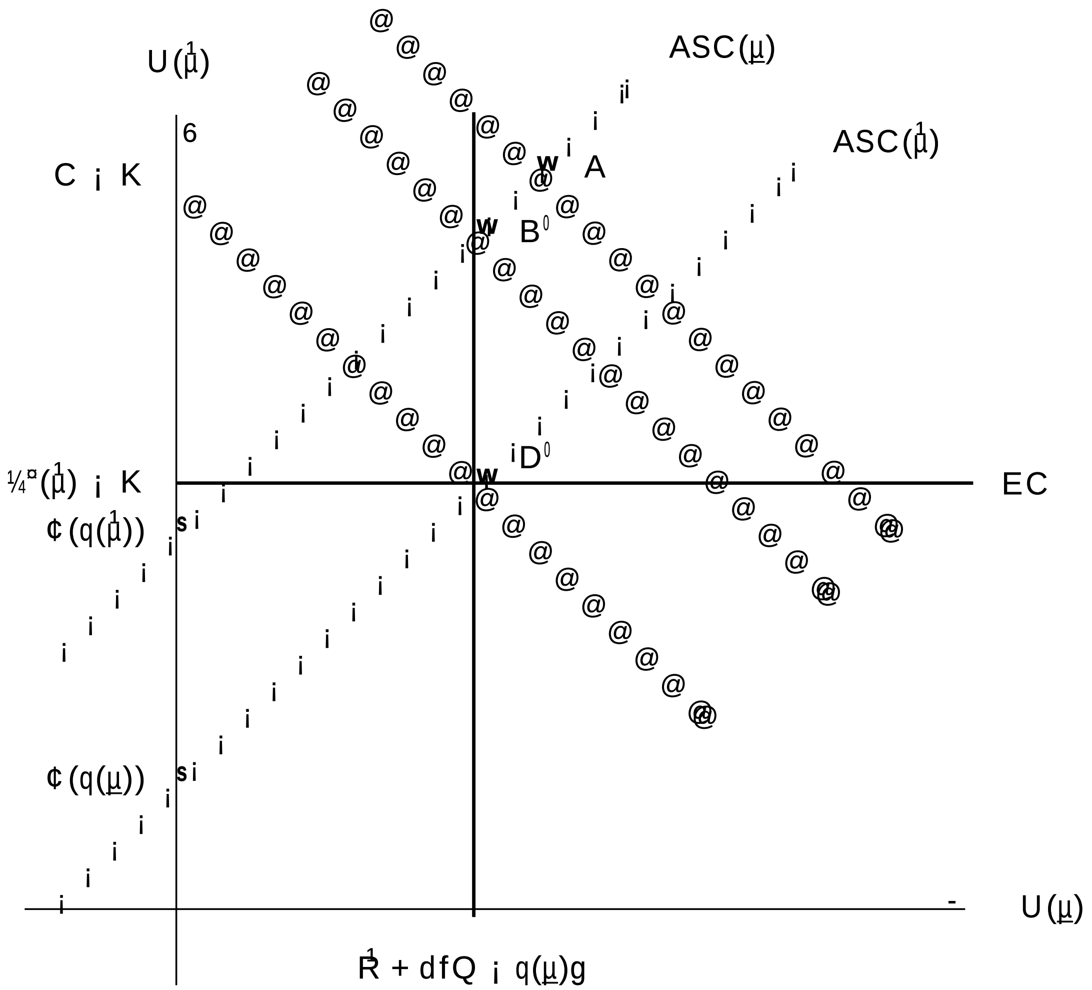

Figure 2: Redistribution, incentives and enforcement costs.