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On pigouvian taxes and implementability: information, monitoring and efficiency

Acerca de los impuestos pigouvianos y su implementabilidad: información, monitoreo y eficiencia

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SOBRE LOS IMPUESTOS PIGOUVIANOS Y LA IMPLEMENTABILIDAD: INFORMACIÓN, MONITOREO Y EFICIENCIA

RESUMEN

Carlos Mario Gómez Gómez

El objetivo de este artículo es contribuir a estrechar la distancia entre la teoría formal y el entorno práctico del diseño de política. Se formula un modelo teórico general y comprensivo para tomar en cuenta los distintos problemas, tecnológicos y de informacion, que caracterizan la definición y la implementación de los impuestos pigouvianos. Después de formalizar estos problemas, se presenta un modelo general que nos permite hablar de la existencia tanto de objetivos de calidad ambiental como de instrumentos de política, que sean eficientes e implementables, y analizar muchos casos particulares. La teoría general que se desarrolla en este trabajo también se utiliza para sustentar las siguientes conclusiones importantes: Primero, ninguno de los problemas de implementación considerados nos permite llegar a la conclusión que se debe abandonar los impuestos pigouvianos o reemplazarlos con otros, supuestamente más prácticos, incentivos alternativos. Segundo, el único problema de implementación que se puede considerar como una condición necesaria y suficiente y que no permite la implementación de impuestos pigouvianos eficientes es la existencia de los objetivos de ingresos impositivos por parte de la agencia reguladora.

On Pigouvian Taxes and Implementability: Information, Monitoring and Efficiency

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1. Introduction

Standard microeconomic theory proves that when an externality occurs, the solution of the social cost problem requires that the producers face an additional cost identical to the marginal damage caused by them at the efficient level of the externality. Pigouvian taxes and adequately designed property rights markets, are both political instruments to put this theory into practice. Nevertheless, although Pigouvian taxes are convincing in the context of general theory, they are rare, if they do exist, in the real world. In common practice, command and control rather than markets and incentives are the preferred devices of public agencies seeking to cope with externality problems.

The relative failure of economists in proposing and gaining an audience for practical environmental policy instruments is largely a consequence of the wide distance from abstract theory, from which normative policy is derived, to concrete markets, where policy recommendations must be applied. In other words, although Pigouvian taxes may be rational in the context of general equilibrium analysis they could be unimplementable in the context of real markets. In great part all this is due to informational and technological problems that, by reducing the power of public regulators, create perverse incentives that allow firms to successfully avoid compliance with the environmental objectives.

The purpose of this paper is to contribute to narrowing the gap between formal theory and practical policy design[1]. For this we take into account the different implementation problems which are defined in the next section of the paper. All of these problems are well known in the literature and, rather than analyzing each one on his own, we will try to incorporate all of them in a general and comprehensive model. On the other hand, we also want to show that none of these problems justifies the conclusion that Pigouvian taxes must be abandoned or replaced by other presumably more effective instruments such as deposit-refund systems, subsidies or rewards for good behavior. These differences with the previous literature are presented in the next section of the paper.

Our target is not the search for perfect Pigouvian taxes but for the best implementable ones [2]. This also means that we cannot follow the commonly used two stage path consisting of, firstly, defining the optimum externality level and, secondly, choosing the proper mixture of policy instruments (such as taxes, inspection policies, non compliance fines, etc.). In our case, the environmental agency can only choose among implementable objectives. For this reason, after presenting our basic regulation model (in section 3), we start by asking what policy objectives are implementable given the information and technological constraints (section 4), and continue by identifying the optimal instruments that allow for the application of any implementable objective (section 5). All these implementable targets and their related best instruments are used to identify the best implementable policy (section 6) and to discuss different polar cases and the inefficiencies resulting from the implementation constraints. The main conclusions are presented in section 7 and the necessary and sufficient conditions for implementability of a given objective are formally proved in the appendix.

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[1] By policy we mean a set formed by both an objective and some policy instruments that allow for the realization of that objective. An objective is an overall pollution level and, more exactly, a pollution profile defining the emission level expected by each of the polluting firms. Policy instruments are, for example, taxes, inspections of the firms, non-compliance fines, etc.

instruments (e.g. Dasgupta et al., 1980, and Spulber, 1988). This context is also well suited for studying the trade-off between revenue and efficiency objectives; this is due to the fact that the presence of private information allows the regulatory agency to "extract" informational rents from the firms (see: Laffont and Tirole, 1992, chap. 10). It is worth mentioning that in this paper we also prove that private information or implementation problems are not a sufficient condition to discard first best solutions; for this to occur it is also necessary that the agency give a positive value to the rents collected from pollution taxes and fines.

If design of environmental policy instruments is a difficult matter, implementation is no less complicated, and the following four problems are of the most importance:

- First, it is evident that to observe the behavior of firms, the agency must incur costly monitoring and enforcement.

- Second, without enforcement effort, incentives for truth telling can be weak. Monitoring is an obvious option at hand for the agency but, given the "fugitive" nature of emissions[3], it cannot normally be carried out *ex-post*. The only way to measure effective emissions is by self-reporting of the firms, by direct on-going monitoring, or by a combination of both.

- Third, in most cases the existing monitoring technology is rather primitive. Up to now, there is not any available filter or end of pipe device which is able to report unambiguously the quantity and composition of effluents going through it. In fact, monitoring must rely on raft experiments or limited sample techniques, whose results must be interpreted (and not just read) by the environmental agency, giving rise to well

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discussed in section 6.

mechanism, or contract menu, consisting of different emission levels that firms can choose and one the corresponding tax they must pay; (b) at the second stage, firms decide whether to play or not and, in case they do, they declare their emission levels for the following period and pay in advance the corresponding tax; (c) at the third stage, the agency inspects firms with a known probability function, which depends on the declared emission level, and fines firms with unfavorable auditing.

In what follows it is assumed that only a single agent (the firm) interacts with the principal (the environmental agency). However, as is well known, all the results can be generalized to a situation with multiple independent agents (see e.g., Laffont and Tirole, 1992, and Fudenberg and Tirole, 1991, chap. 7).

a. Production and abatement cost as private information:

For the basic model we consider an individual firm whose production cost ($c\ (x,\theta)$)[8] depends negatively on the emission level (x) and positively on a parameter (θ), which stands for the firm's private information. For simplicity, θ is assumed to be a positive number; its value is known by the firm but cannot be observed by the agency. Among the factors that determine the value of θ are input prices, the demand for final products, the setting up and maintenance costs of abatement equipment, etc. Such factors are highly variable across the time and, consequently, the environmental agency has a limited learning ability. Abatement cost is decreasing and

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[7] Xepapades (1992) offers an alternative approach in which the environmental agency controls just environmental quality and renounces the monitoring of firms.

[8] Apart from mathematical easiness, this function is compatible with an overall cost function that is separable in emissions. This function is common in the literature, and additional explanations can be found in, e.g.: Swierzbinsky (1994), Russell (1990), Spulber (1988) and Nichols (1984).

b. A tax, or direct transfer function, $t\ (x';(\theta))$, which specifies what the firm has to pay in advance according to the declared emission level for the next period $(x';)$;

c. A function $\lambda(x';(\theta))$ specifying the inspection probability depending on the declared emission level; and

d. A monetary sanction, $m(x';(\theta))$, to be applied when the firm is monitored with an unfavorable result.

c. Compliance costs for a regulated firm:

In a regulated institutional framework firm costs can come from direct production cost, from taxes and from fines. The first two concepts are defined above and we need now a proper definition for fines. As mentioned above, imperfect-monitoring technology implies that the agency can judge incorrectly the fulfilment of an inspected firm with a positive probability z $(0<z<1)$[10].

We assume the firm is risk-neutral and, therefore, the expected cost function is quasi-linear in the expected transfer. The expected cost function of a firm that declares and meets an emission level $x';$ is defined as:

$$\psi(x',\theta) = c(x'(\theta),\theta) + t\,(x'(\theta)) + \lambda(x'(\theta))mz$$

A violation of environmental regulation occurs when the firm declares an emission level $(x';)$ and emits a greater one. In this case, the firm's rational behavior is to emit the maximum level (thus

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the emission level and not emission reduction over a maximum permitted level. It is also easy to verify that the above cost function is compatible with the standard assumption of increasing marginal abatement costs.

[10] Monitoring technology can induce two types of mistakes: first, there are some measurement errors which occur with a certain probability (1-a) and, second, the agency can accept (with a certain probability b) the measurement obtained by its instruments. Then z, the probability of erroneously judging the firm behavior, will be equal to $z=a(1-b)+(1-b)a$. In a different context, probability z was defined by Laffont and Tirole (1992) to study the cost mark-up

Finally, expression [3.c] represents a rationality or participation condition meaning that the firm has a *reservation cost* (ϕ^M) (which, for simplicity, is assumed independent from the firm type), above which it decides not to produce. In most of the paper it is assumed that this constraint is not binding and it will be only introduced as a particular case in the discussion of optimal policies.

In the following two sections we solve the regulation problem by sequentially solving three related questions. First: what kind of environmental objectives (or decision functions) are implementable? Second, for any implementable objective, what policy instruments (taxes, inspection probabilities, and fines) allow the objective to be obtained with the minimum cost? And third, among the possible outcomes and the best instruments to obtain each one of them: what policy (that is, what objective with its respective instruments) is the most efficient?.

4. Implementable Policies: what are the possible outcomes?

From the incentive-compatibility condition [3.a], we can deduce that a decision profile ($x(\theta)$) is implementable if and only if it is nondecreasing in θ. This result comes from the application of the Mirlees *sorting condition* to the environmental regulation problem. In the basic model, this necessary condition is also sufficient for implementability because the marginal rate of substitution between costs and expected transfers is equal to one (see Guesnerie and Laffont, 1984). This condition, known as *monotonicity* of the decision function, together with the fact that the direct cost function is increasing in θ, allows the conclusion that the expected cost function must be increasing in θ. The formal demonstration of this fundamental result is given in the Appendix. Nevertheless, in what follows we give an intuitive version of the conditions to be met by an incentive-compatible decision function in the simple discrete case when the firm can be only one of two different types.

compliance fine are related as follows:

$$\lambda(\theta) \geq \frac{c(x(\theta),\theta)}{m(\theta)(1-2z)}$$

Then, for a given fine (m), the monitoring probability has to be at least equal to the relation between the saving in production cost (from emitting the maximum level), and the fine multiplied by the effective probability of it being charged. As monitoring is costly, the agency will prefer to keep probability λ at its minimum possible value. In theory, this means that there always exists a fine high enough to make any monitoring probability incentive compatible for each firm type. In other words, the rational agency will always prefer a higher non-compliance fine to consuming resources in monitoring the firm. However, this is not very realistic; in practice, it is reasonable to assume that there exists a maximal (credible and applicable) non-compliance fine and that the agency will always prefer to impose such a fine to punish any deviation by the firm. Therefore, the rational agency must choose the minimal monitoring probability that guarantees the firm's full compliance, given the maximal fine allowed by law or credibility. As a result, the optimal monitoring policy is given by:

$$\lambda^*(\theta) = \frac{c(x(\theta),\theta)}{\bar{m}(1-2z)} \qquad [4]$$

The monitoring policy objective is to guarantee that the emission level is adjusted to that declared by the firm. However, as the monitoring technology is imperfect, even when the firm behaves honestly, it faces a positive probability of being punished. The monitoring policy implies the imposition and collection of unfair penalties. It could be though that these penalties should not be enforced; however, the designed mechanism requires that fines be a credible threat and their diminution or elimination would only weaken the incentives for revealing private information and increase the public costs. The solution to this apparent contradiction of firms

$$\varphi(\theta) \equiv \underset{\theta}{MIN}\; c(\bullet) + t(\theta') + m\,\lambda(\theta')z \equiv C(\theta,\theta) \equiv C(\theta) \qquad [6]$$

And, according to the envelope theorem:

$$\frac{\partial \varphi(\theta)}{\partial \theta} = \frac{\partial C(\theta)}{\partial \theta} \qquad [7]$$

which implies:

$$C(\theta) = c(\underline{\theta}) + \int_{\underline{\theta}}^{\theta} \frac{\partial C}{\partial \theta}\, d\theta \qquad [8]$$

By substituting this optimal tax profile (*[8]*) and the optimal monitoring probability (*[4]*) into the total expected cost (*[5]*), we obtain the optimal tax function for a feasible objective when the rationality condition is not binding, as follows:

$$t(\theta) = c(\underline{\theta}) - c(x(\theta),\theta)\left(\frac{1-z}{1-2z}\right) + \int_{\underline{\theta}}^{\theta} \frac{\partial C}{\partial \theta}\, d\theta \qquad [9]$$

According to this equation, the aggregated cost of the most efficient firm type (with the lower value of $\theta = \theta$) can be established independently from the incentive compatibility. From this starting value, a tax function has to be designed such that the other firm types cannot get positive benefits by claiming to belong to a lower θ -type. The resulting optimal program, which is analysed in the next section, does not introduce distortions at the bottom of the distribution function, but it does at all higher levels.

c. An illustration

The previous two firm type examples can be used to illustrate the optimal policy instruments defined by [4] and [9]. Let us assume in Figure 1 that the agency wants type 2 firms emission level to be x_2. A possible incentive-compatible solution is the contract *B*. However, this solution

Once feasible decision profiles and optimal instruments are defined, we can deal with the problem of selecting the optimal environmental policy. For this purpose, our first step is to define the objective function of the environmental agency.

a. The objective of the agency:

Among the implementable policies, the environmental agency must choose that which imposes the minimum social cost. This social cost is the sum of the private production cost, the public application and enforcement cost and the damage from the resulting pollution. Social cost must be considered net of the benefits coming from the rents obtained from pollution sources. The elements of this objective function are the following:

- First, we define a damage function associated with the firm's emission level. For mathematical simplicity, we assume a damage function ($D(\theta)= D(x(\theta),\theta)$) increasing in emissions, and increasing and convex in firm types. If the regulator is risk neutral, the expected environmental damage can be defined as:

$$D=\int_{\underline{\theta}}^{\bar{\theta}} D(x(\theta),\theta)\, f(\theta)d\theta \qquad [11]$$

- Second, given the agency's uncertainty about the firm's characteristics, we can define the expected private production cost function as:

$$C=\int_{\underline{\theta}}^{\bar{\theta}} C(x(\theta),\theta)f(\theta)d\theta \qquad [12]$$

- Third, if we define γ as the shadow price of an additional unit of public revenue and v as the unit cost of monitoring, we obtain the following expressions for the monitoring cost:

The first order condition, which characterises the optimal decision profile, is:

$$\frac{\partial D}{\partial x} = -\frac{\partial c}{\partial x} - \nu\frac{\partial \lambda}{\partial x} - \frac{\partial c}{\partial x}\left[\gamma\left(\frac{\nu}{m(1-2z)} + 1\right)\right] + \gamma\frac{1-F(\theta)}{f(\theta)}\frac{\partial^2 c}{\partial \theta \partial x} \qquad [16]$$

This expression is the main result from this paper, and defines the best implementable environmental policy. In other words, equation [16] establishes the best implementable decision for each firm type as a function of the private information it has. Policy instruments like taxes and monitoring probability functions can be derived directly from the implementable decision for each firm type.

The best way to interpret the proposed solution is to compare it with the *first best* solution: marginal damage equal to marginal abatement cost for all possible firm types. That is, $\partial D/\partial x = -\partial c/\partial x$; both the marginal damage and the marginal private cost appear in equation [16], in which all other terms denote the inefficiencies resulting from the informational structure of the problem, the budget constraint and (imperfect) monitoring cost and technology. The right side of the equation is the sum of two positive terms, and the expression that multiplies the marginal cost in the first term is strictly higher than to one. This means that in the *second best* solution the marginal abatement cost is inferior to the marginal damage caused by pollution, and, therefore, the emission level is greater than in the first best solution.

It is also worth mentioning that the many problems we have considered (such as asymmetric information, bounded penalties and imperfect or costly monitoring) are not sufficient conditions to exclude the implementability of first best solutions. On the contrary, the only necessary and sufficient condition for that is that the government assigns a positive value to its revenues. Again we can check in [16] that a "benevolent" regulator, or neutral with respect to income distribution, will obtain the first best solution despite the informational structure of the problem since, in such

It is clear that when the agency has complete information, informational rents disappear and the marginal abatement cost gets closer to the marginal damage from residual pollution. Due to the positive value of public revenue, the emission level is superior to that which characterizes the first best policy. Such an emission level will be greater as the maximum implementable policy is lesser, the monitoring cost is higher and the monitoring technology is more imperfect.

We can deal now with the case in which the rationality (or participation) constraint is binding for the less efficient firm type (or that with the maximum θ). Then, the solution is built by using equation [13] to redefine the value of the expected tax revenues (i.e., equation [15]) and, thereby, to reformulate the agency's problem. The optimal emission decision function obtained from this procedure is described by:

$$\frac{\partial D}{\partial x} = -\frac{\partial c}{\partial x} - v\frac{\partial \lambda}{\partial x} - \frac{\partial c}{\partial x}\left[\gamma\left(\frac{v}{m(1-2z)}+1\right)\right] + \gamma\frac{F(\theta)}{f(\theta)}\frac{\partial^2 c}{\partial \theta \partial x} \qquad [16.c]$$

The only relevant difference with respect to the basic situation is a change in the informational rents that the agency can obtain from each firm type (i.e., the second term in the right side). Such rents are necessarily lower, although the difference between the two depends on the particular form of the distribution function $F(\theta)$. However, there are important differences with regard to the rents each firm type must pay. The most inefficient types, with higher emissions, will pay greater pollution taxes. Therefore, the informational rents from them will have a higher relative weight (if θ is too high, $F(\theta)$ will be greater than $1-F(\theta)$), while the most efficient firms will pay less pollution taxes (in such a case $F(\theta)<1-F(\theta)$). In this case, the environmental policy is determined by the taxes the environmental agency can collect from the most inefficient firms. And, the possibility that most polluting firms can pay greater taxes is very limited if, as is highly probable, those firms are on or below the rentability threshold. If this occurs, the most efficient

Appendix

In this section the following proposition is demonstrated:

> Necessary condition for implementability: *A decision function $x(\theta)$ is incentive-compatible, or implementable through expected transfers, if it is nondecreasing in θ.*

The proof is derived from the necessary and sufficient conditions of the cost minimizing problem for each firm type.

- Let us define, for a simplified exposition, the following expected transfer function:

$$\zeta(\theta') = t(\theta') + \lambda(\theta')mz \qquad [1.A]$$

- The cost minimizing problem of firm type θ can be described as:

$$\underset{\theta'}{Min}\ \phi(\theta', \theta) = \phi(x(\theta'), \zeta(\theta'), \theta) \qquad [2.A]$$

- The necessary and sufficient conditions for truth telling (that is, $\theta'=\theta$) are:

$$\frac{\partial \phi}{\partial \theta'}(\theta, \theta) = \frac{\partial \phi}{\partial x}\frac{\partial x}{\partial \theta'} + \frac{\partial \phi}{\partial \zeta}\frac{\partial \zeta}{\partial \theta'} = 0 \qquad [3.A]$$

$$\frac{\partial^2 \phi}{\partial \theta'^2}(\theta, \theta) > 0 \qquad [4.A]$$

The sufficient condition for a decision to be implementable can be deduced as follows:

- Differentiating necessary condition [3.A] with respect to its two arguments yields:

$$\frac{\partial^2 \phi}{\partial \theta'^2}(\theta, \theta) = -\frac{\partial^2 \phi}{\partial \theta' \partial \theta}(\theta, \theta) \qquad [5.A]$$

- Which allows one to rewrite the second-order condition as:

$$\frac{\partial^2 \phi}{\partial \theta' \partial \theta}(\theta, \theta) = \frac{\partial}{\partial \theta}\frac{\partial \phi}{\partial x}\frac{\partial x}{\partial \theta'} + \frac{\partial}{\partial \theta}\frac{\partial \phi}{\partial \zeta}\frac{\partial \zeta}{\partial \theta'} < 0 \qquad [6.A]$$

- The necessary condition to be fulfilled by the expected transfer function can be obtained by using the first order condition:

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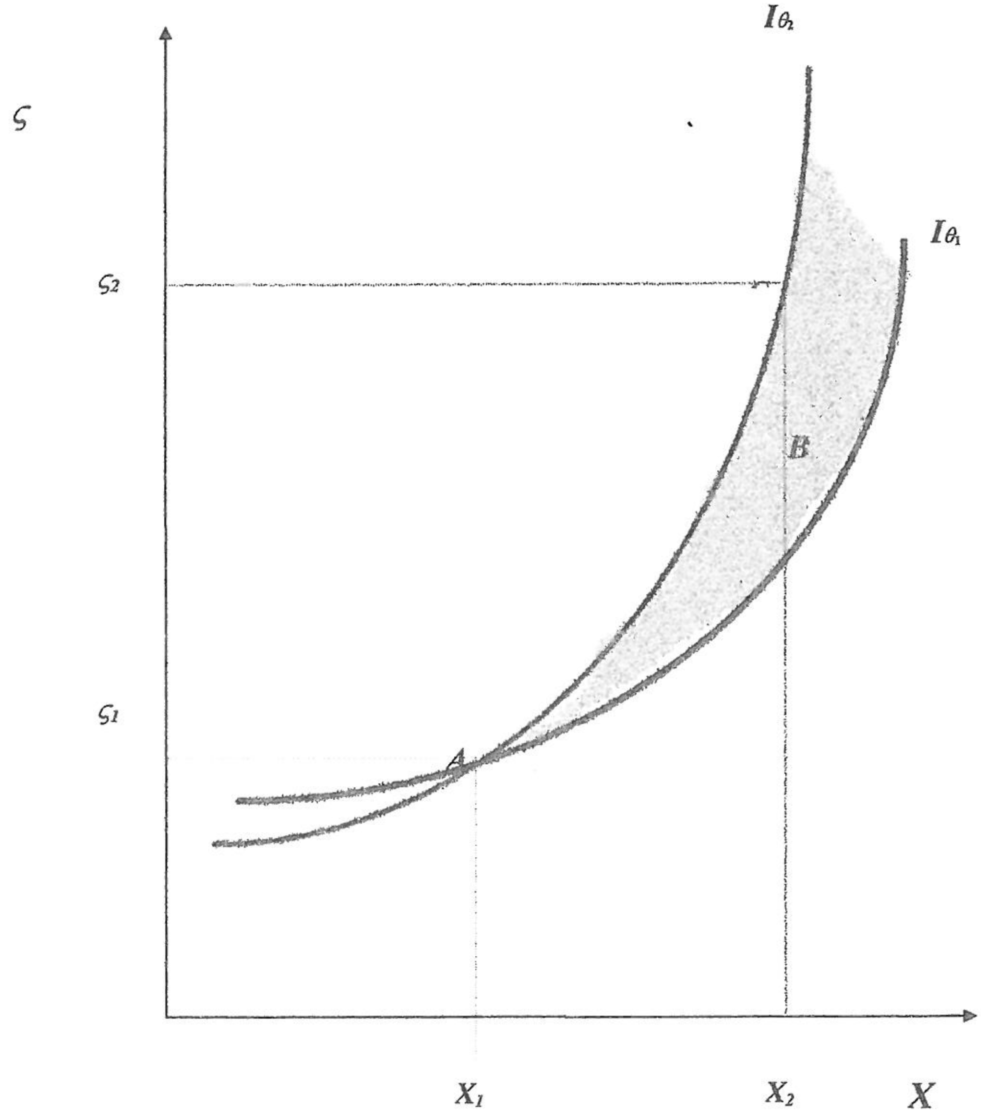
FIGURE 1: Incentive compatible policies



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