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Environmental regulation of technically inefficient firms

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HIGHLIGHTS

- We present an externalities model with a technically inefficient polluting firm.
- Technical efficiency is the firm's private information.
- We study the control of emissions through two policy instruments, a tax and a quota.
- The paper derives second-best regulatory schemes.
- The choice of policy instrument is affected by the entire distribution of efficiency.

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ABSTRACT

This paper presents a model in which a technically inefficient firm is responsible for the emissions of pollutants. We derive second-best regulatory schemes (tax and quota) assuming that the firm's technical efficiency is unknown to the regulator.

1. Introduction

When external effects are present, the economic regulation of markets is important because competitive equilibrium is typically not socially optimal. When payoff functions are common knowledge, taxes and quotas are equivalent policy instruments that can be used to achieve optimal outcomes. Weitzman (1974) demonstrates that in the presence of asymmetrically held information these two traditional policy instruments are no longer perfect substitutes for one another.

This paper applies Weitzman's concepts to investigate a specific form of information asymmetry: unknown technical inefficiencies. We present a simple externalities model with two economic agents. The first is a technically inefficient firm that uses pollution as an input to produce an exporting good. The second is a household that receives negative utility from pollution. In the benchmark framework there is no environmental regulation in place and the firm freely chooses the amount of pollution to maximize profits, which leads to suboptimal social levels of pollution.

We study an environment in which the firm's technical efficiency is private information, hence unknown by the regulator. We examine two second-best policy instruments: taxes and quotas. Differently from Weitzman (1974), uncertainty affects marginal benefits of emissions in a multiplicative way. Multiplicative uncertainty has been recognized in the literature to have different consequences from additive uncertainty (see Muller (2011) and Carson and LaRiviere (2013)). Specifically, we show that the expected comparative advantage of a quota over a tax depends not only on the slopes of the marginal benefit and marginal cost functions, but also on the entire distribution of efficiency.

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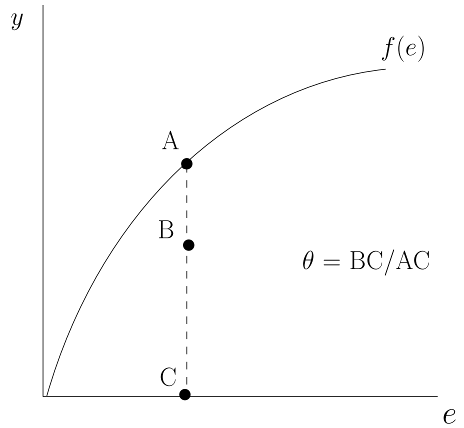

Fig. 1. Technical inefficiency.

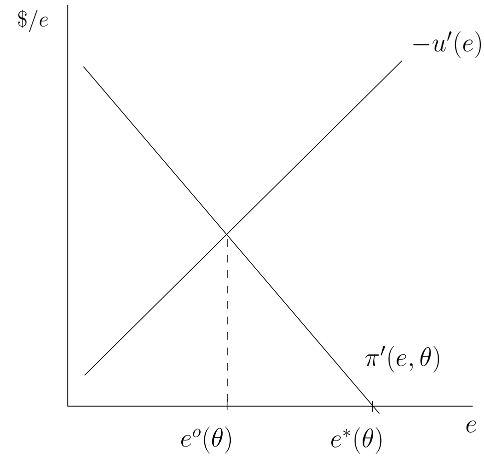

Fig. 2. Marginal profit and marginal utility of emissions.

2. The environment

Consider an environment with two agents: a firm and a household. The firm is engaged in a dirty production process in which the consumption of an essential input is associated with emissions of pollutants. The firm's production is exported and we assume a fixed foreign demand.[1] The household has preferences over the firm's emissions. Hence, the only connection between the firm's behavior and the household is the negative externality imposed to the household by the firm's activity.

The firm may or may not be technically efficient. Technical efficiency represents the firm's ability to transform emissions into output. The production process is expressed as follows:

$$y = f(e)\theta \tag{1}$$

where y is the output, e is the amount of emissions, f is a concave production function, and $\theta \in (0, 1]$ is the parameter that measures the firm's technical efficiency.[2]

Production process (1) is standard in the technical efficiency literature (see Aigner and Chu (1968), Afriat (1972), and Richmond (1974)). For any positive level of emissions, a technically inefficient firm has $\theta < 1$ and will produce lower output than an efficient firm with $\theta = 1$. Hence, an inefficient production plan lies below the production frontier $f(e)$. Fig. 1 illustrates the production process.

The function f in Fig. 1 delimits the feasible technology, i.e. the maximum output for a given level of emissions. Technical efficiency can be written as the ratio of observed output to the efficient (or maximum) output. Formally, $\theta = y/f(e)$. Notice that an efficient firm, with $\theta = 1$, operates on the production frontier (point A in Fig. 1). At point B the firm is technically inefficient, has $\theta < 1$, and hence does not produce the amount AB of feasible output.[3]

The efficiency parameter θ represents the firm's *type*. There is a continuum of types. Specifically, the firm's type θ is an element of the real interval (0, 1]. The firm draws its type θ from a cdf F with domain (0, 1]. We assume that θ is the firm's private information.

The firm draws its type and, conditioned on the realized θ, chooses emissions to maximize profits. Formally,

$$\max_e \pi(e, \theta) = Pf(e)\theta - we,$$

where P is the output price, and w is the firm's constant marginal cost of polluting. Denote by $e^*(\theta)$ the profit maximizing level of emissions. Note that the firm's optimum level of emissions is an increasing function of technical efficiency. Formally, $\frac{\partial e^*(\theta)}{\partial \theta} > 0$.[4]

The household has negative utility over emissions $u(e)$. Pollution lowers the household's utility at an increasing rate, i.e. $u' < 0$ and $u'' < 0$. In this unregulated environment, emissions provide the firm with profits $\pi(e^*, \theta)$ while the household obtains negative utility $u(e^*)$.

The Pareto optimality problem is

$$\max_e \pi(e, \theta) + u(e), \tag{2}$$

where the household utility u is measured in monetary terms. The first order condition is

$$\pi'(e^o, \theta) = -u'(e^o).\text{[5]} \tag{3}$$

Environmental regulation is necessary as $e^o(\theta) < e^*(\theta)$, i.e. the firm pollutes too much.[6] In our environment, emissions benefit the firm (because they are essential for the firm's operation) and harm the household (because of the negative utility over positive levels of emissions). Fig. 2 depicts the marginal benefit of pollution (i.e., the $\pi'(e, \theta)$ curve) and the marginal cost of pollution (i.e., the $-u'(e)$ curve). The Pareto optimum level of emissions is an increasing function of technical efficiency, capturing the intuition that efficiency gains incentivize the firm to increase production. Formally, $\frac{\partial e^o(\theta)}{\partial \theta} > 0$.[7]

3. Environmental regulation

3.1. Naive regulation

For simplicity, assume that there are only two possible levels of technical efficiency: (i) $\theta = 1$ denoting an efficient firm, and (ii) $\theta < 1$ denoting an inefficient firm. Consider the case in which the firm is inefficient and the regulator ignores the inefficiency acting as if regulating an efficient firm. The two traditional policy

[1] The firm is assumed to be a price taker in both output and input markets.

[2] Formally, the production frontier is defined by $y = g(x)$, where x represents the production input. We assume a technical relationship between emissions (e) and the input (x) described by $e = h(x)$. Solving for x and plugging the solution into the production function we obtain $y = f(e)$, where $f(e)$ is the composite function $(g \circ h^{-1})(e)$.

[3] This definition of efficiency corresponds to Farrell (1957)'s output-oriented measure of technical efficiency.

[4] $\frac{\partial e^*(\theta)}{\partial \theta} = \frac{-f'(e^*)}{f''(e^*)\theta} > 0$.

[5] The notation π' denotes the partial derivative of the function π w.r.t. e.

[6] To see this notice that $-u'(e^o)$ is a positive value while e^* solves $\pi'(e, \theta) = 0$. Since $\pi'(e, \theta)$ is decreasing in e, $e^o(\theta) < e^*(\theta)$.

[7] $\frac{\partial e^o(\theta)}{\partial \theta} = \frac{-Pf'(e^o)}{Pf''(e^o)\theta + u''(e^o)} > 0$.