Environmental Policy and the Size Distribution of Firms

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Abstract

In this paper we analyze the effects of environmental policies on the size distribution of firms. We model a stationary industry where the observed size distribution is a solution to the profit maximization problem of heterogeneous firms. We compare the equilibrium size distribution under emission taxes, non-tradable and performance standards. Our results indicate that each regulation affects differently firms of heterogeneous size and leads to different welfare levels.

1 Introduction

In recent years, several environmental regulations have been introduced to control emissions of local and global pollutants. These policies have a clear objective: to induce firms to reduce emissions by investing in cleaner/energy saving technologies and promoting industrial turnover by modifying, among other things, the possibility of entry of new firms, exit of incumbent firms, and the relative competitive advantage of active firms. Moreover, environmental regulations may also affect the distribution of market shares and the related size distribution of firms if compliance changes the optimal plant size or the range of optimal sizes. As pointed out by Evans (1986), the differential effect of regulation across firm size is important for at least three reasons. First, when there are scale economies in regulatory compliance, it might be optimal to exempt or impose lighter regulatory burden on smaller firms, or design regulations that are neutral across firm size to minimize the disproportionate impact of environmental regulatory requirements on small businesses (See Brock and Evans 1985). Second, society may have an interest in preserving small businesses because of antitrust or other noneconomic reasons. Third, the incidence of regulatory costs across firm size may tell us something about the interest of certain groups of businesses in supporting alternative regulatory policies.

While much of the existing literature assessing the impact of environmental regulation on market structure tends to focus on entry, exit, and the number of active firms (See for instance, Katsoulacos and Xepapadeas 1995, 1996; Lahiri and Ono 2007), the focus of this paper is on the effects of the choice of policy instruments on the size distribution of firms and the dynamics of growth of individual firms over time. In this regard, as mentioned above, one could argue that if there are some economies of scale in compliance, the minimum optimal firm size is larger under regulation. Thus, the market share of large firms should increase as small firms withdraw from the industry or expand and become larger. However, the effects of environmental policy will depend on the choice of policy instrument since different policy instruments redistribute intraindustry rents differently; if small firms are treated less harshly, regulation will increase the market share of small plants as large plants leave the industry or shrink in size. In this paper we analyze and compare the resulting size distribution under three policy instruments that differ in terms of their incidence across firm size, namely uniform emission standards, emission taxes and performance standards. Under performance standards, the intensity of emissions is fixed by policy and neutral across size. Instead, under emission standards, the regulatory goal is expressed as an absolute emission limit, which should tend to favor smaller firms as the limit might not bind their emissions. Finally, emission taxes raise the per unit cost of production for both small and large firms in an industry. However, if larger firms use the input that originates emissions more intensively, an emission tax should shift the supply curve of these firms to a greater extent than it shifts the supply curve of smaller firms.

The size distribution of firms has been extensively studied in the industrial organization literature[1]. Nevertheless, to the best of our knowledge, the dynamic effects of the choice of environmental policy instruments shaping the size distribution has not been studied previously. Perhaps the most closely related work in the environmental economics literature is Pashigian (1984), and Sengupta (2010). Pashigian (1984) measures the effects of environmental regulation under the 1970s Clean Air Act on the size distribution of plants and the distribution of factor shares in United States over the period 1958-1977. He finds that environmental regulation had a significant effect on plant structure indicating the existence of significant economies of scale on compliance; environmental regulation favored large plants relative to small plants and raised capital intensity. Sengupta (2010) investigates the links between environmental regulation and market structure by analyzing how regulation modifies the optimal scale of firms and the dynamic path of the industry. Nevertheless, unlike our paper, she

[1] Most of the literature deals with the distributional properties of firm size (see for instance, Cabral and Mata 2003 and Angelini and Generale 2008). However, more recent research has integrated the size distribution of firms into standard economic theory. Attempts to explain the size dynamics have investigated the effects of bad productivity shocks (Hopenhayn 1992 and Ericson and Pakes 1995), learning (Jovanovic 1982), inefficiencies in financial markets (Cabral and Mata 2002 and Clementi and Hopenhayn 2006), the exogenous distribution of managerial ability in the population (Lucas 1978 and Garicano and Rossi-Hansberg 2004) and the efficient accumulation and allocation of factors of production (Rossi-Hansberg and Wright 2007).

focuses on the case of a specific regulation, namely environmental taxes, comparing the equilibrium paths corresponding to different exogenous tax levels and outlining conditions under which industries with higher taxes are associated with higher investment in compliance cost reduction and higher shake-out of firms over time.

To study the effects of the choice of policy instruments on the size distribution of firms, we follow the seminal model by Lucas (1978) where the underlying distribution of firm's sizes in the industry is the result of the existence of a productive factor of heterogenous productivity.[2] In Lucas's model, such a factor is the managerial technology, while in ours, it is the energy efficiency of firms. In such a setting, we introduce different environmental policies and analyze the resulting size distributions, as well as the variations on size distribution that arise as a result of investments that reduce the cost of compliance with environmental regulations. We also compute the effects on welfare and illustrate our results through numerical examples. Hence, the paper is organized in five sections. The next section presents the model and the underlying distribution of firm's sizes in the absence of environmental policies. The third section analyzes how the choice of a policy instrument modifies the size distribution of firms. The forth section presents some numerical simulations and analyzes welfare implications. The final section concludes.

2 The Model

We consider a perfectly competitive stationary industry consisting of a continuum of risk-neutral polluting firms of mass 1. Firms produce a homogeneous good using two inputs, energy (e) and labor (l). Firms differ in terms of the parameter ϕ reflecting energy efficiency, which is assumed to be uniformly distributed on the interval $\left[\underline{\phi}, \overline{\phi}\right]$

Assuming a Cobb–Douglas technology, the production function of firm i is then characterized as:

$$q(\phi_i, e, l) = \theta \left[\phi_i e_i\right]^{\alpha} l_i^{\beta} \qquad \vee\, \alpha, \beta > 0,\ \alpha + \beta < 1, \tag{1}$$

where q is the amount of output produced by a firm using e units of energy and l units of labor, ϕ_i is the energy efficiency of firm i, and θ is a general productivity parameter. In the absence of environmental policy, firm i maximizes net profits π_i through the choice of inputs:

$$\max_{e,l} \pi_i = p\theta \left[\phi_i e_i\right]^{\alpha} l_i^{\beta} - wl_i - ze_i - F. \tag{2}$$

Where w and z are the equilibrium wage rate and energy price, and p rep-

[2] The heterogeneity of the available physical capital with respect to productivity and emission intensity is well established in the environmental literature. Changes in energy use and emissions profiles of an industry are the result of complex interrelationships among a multitude of time-varying technological and economic drivers (see Ruth et al. 2004 for discussion).

resents the output price. The first order conditions (FOCs) are given by:

$$p\alpha\theta\phi_i^{\alpha}e_i^{\alpha-1}l_i^{\beta} = z, \tag{3}$$

$$p\beta\theta\phi_i^{\alpha}{e_i}^{\alpha}l_i^{\beta-1} = w. \tag{4}$$

Dividing by parts and solving wrt l, we get:

$$l_i^{NR} = \frac{\beta}{\alpha}\frac{z}{w}e_i^{NR}. \tag{5}$$

Substituting equation (5) in the FOC, we can solve for e_i^{NR}, l_i^{NR} as:

$$e_i^{NR} = \left[p\theta\beta^{\beta}w^{-\beta}\alpha^{1-\beta}z^{-[1-\beta]}\phi_i^{\alpha}\right]^{\frac{1}{1-\alpha-\beta}}. \tag{6}$$

$$l_i^{NR} = \left[p\theta\beta^{1-\alpha}w^{-(1-\alpha)}\alpha^{\alpha}z^{-\alpha}\phi_i^{\alpha}\right]^{\frac{1}{1-\alpha-\beta}}. \tag{7}$$

Let $k_1 = \left[p\theta\beta^{\beta}w^{-\beta}\alpha^{1-\beta}z^{-[1-\beta]}\right]^{\frac{1}{1-\alpha-\beta}}$. We assume that $2\alpha+\beta<1$ analyzing the case where the optimal use of energy is a concave function of the energy efficiency (i.e., $\frac{\partial e_i^{NR}}{\partial\phi_i} = \frac{\alpha k_1}{1-\alpha-\beta}\phi_i^{\frac{2\alpha+\beta-1}{1-\alpha-\beta}} > 0$, and $\frac{\partial^2 e_i^{NR}}{\partial\phi_i^2} = \frac{\alpha[2\alpha+\beta-1]k_1}{[1-\alpha-\beta]^2}\phi_i^{\frac{3\alpha+2\beta-1}{1-\alpha-\beta}} < 0$).

Firm i would operate in this market as long as its profits are larger than the scrap value F, i.e., $\pi_i^{NR} \geq F$.[3] In the continuum of firms, the minimum energy efficiency consistent with this satisfies the condition $\pi^{NR}(\phi_0) = F$, or:

$$p\theta\phi_0^{\alpha}e_0^{\alpha}l_0^{\beta} - wl_0 - ze_0 = F \tag{8}$$

Substiting l_0^{NR} and e_0^{NR} in (8) yields to:

$$\phi_0^{NR} = \left[\frac{F^{1-\alpha-\beta}z^{\alpha}w^{\beta}}{p\theta\beta^{\beta}\alpha^{(1-\beta)}\left[\alpha^{-1}-\left(\frac{\alpha}{\beta}+1\right)\right]^{1-\alpha-\beta}}\right]^{\frac{1}{\alpha}} \tag{9}$$

Thus, the energy efficiency of the firms operating in the market is uniformly distributed on the interval $\left[\phi_0^{NR},\overline{\phi}\right]$. Note that ϕ_0^{NR} is an increasing funtion of the inputs' prices and a decreasing function of the output price p. Moreover, the existence of a fixed cost implies economies of scale as large firms can spread the fixed cost across more output units than small firms.

We can compute aggregate emissions in the absence of environmental regulation E^{NR} by integrating individual emissions in (6) over the range $\left[\phi_0^{NR},\bar{\phi}\right]$, which leads to:

$$E^{NR} = \int_{\phi_0^{NR}}^{\bar{\phi}}\left[p\theta\beta^{\beta}w^{-\beta}\alpha^{1-\beta}z^{-[1-\beta]}\phi_i^{\alpha}\right]^{\frac{1}{1-\alpha-\beta}}d\phi. \tag{10}$$

[3] In the current analysis, we assume that each firm has one plant. In this way we avoid comparing multi-plant firms with small firms which creates some problems, especially in the case of emission standards where firms with multiple units would be treated in the same way as one-unit firms.

Let $h = \frac{1-\beta}{1-\beta-\alpha} > 1$. The solution to equation (10) can be represented as:

$$E^{NR} = \frac{k_1}{h}\left[\bar{\phi}^h - \left[\phi_0^{NR}\right]^h\right]. \tag{11}$$

Finally, substituting equations (5) and (6) in (1), the output level of firm i is given by:

$$q_i^{NR} = \left[p^{\alpha+\beta}\theta\beta^\beta w^{-\beta}\alpha^\alpha z^{-\alpha}\right]^{\frac{1}{1-\alpha-\beta}} \phi_i^{\frac{\alpha}{1-\alpha-\beta}} \tag{12}$$

To compute total ouput with no regulation Q^{NR}, we integrate (12) over the interval $\left[\phi_0^{NR}, \bar{\phi}\right]$, which leads to:

$$Q^{NR} = \frac{z}{p\alpha}E^{NR}$$

Thus, the average emission's intensity in the industry in the absence of environmental regulations corresponds to $\frac{E^{NR}}{Q^{NR}} = \frac{\alpha p}{z}$. Note that it is a decreasing function of the price of energy and an increasing function of the share of energy in the production process.

3 Environmental Regulation

Let us analyze now the effects of environmental policies on the size distribution in equilibrium. We assume that each unit of energy used as an input in the production process generates one unit of emissions. Moreover, we assume that given the initial distribution of firms' size, the regulatory goal is to limit aggregate emissions at some exogenously given level $\overline{E}$ by means of one of the following three regulatory instruments: - a per-unit emission tax τ, - a uniform non-tradable emission quota $\bar{e}$, and - a uniform performance standard that defines the maximum intensity of emissions. Finally, we assume that the stringency of each policy remains unchanged regardless of the effects of the instruments on the initial distribution of firms' size.

3.1 Environmental taxes

In case of emissions taxes, firm i maximizes its profits:

$$\max_{e_i, l_i} \pi_i = p\theta\left[\phi_i e_i\right]^\alpha l_i^\beta - wl_i - \left[z+\tau\right]e_i - F,$$

where τ is the per unit tax of emissions.

The FOCs are:

$$p\alpha\theta\phi_i^\alpha e_i^{\alpha-1} l_i^\beta = z + \tau, \tag{13}$$

$$p\beta\theta\phi_i^\alpha e_i^\alpha l_i^{\beta-1} = w. \tag{14}$$

Dividing by parts, we get:

$$l_i^T = \frac{\beta}{\alpha}\frac{z+\tau}{w}e_i^T. \tag{15}$$

Substituting equation (15) in the FOC, we can solve for e_i^T, l_i^T as:

$$e_i^T = \left[p\theta\beta^{\beta}w^{-\beta}\alpha^{1-\beta}\left[z+\tau\right]^{-[1-\beta]}\phi_i^{\alpha}\right]^{\frac{1}{1-\alpha-\beta}}. \tag{16}$$

$$l_i^T = \left[p\theta\beta^{1-\alpha}w^{-(1-\alpha)}\alpha^{\alpha}(z+\tau)^{-\alpha}\phi_i^{\alpha}\right]^{\frac{1}{1-\alpha-\beta}}. \tag{17}$$

Let $k_2 = k_1\left[\frac{z}{z+\tau}\right]^h < k_1$. As in the previous case, the optimal use of energy is a concave function of the energy efficiency (i.e., $\frac{\partial e_i^T}{\partial\phi_i} = \left[\frac{z}{z+\tau}\right]^h\frac{\partial e_i^{NR}}{\partial\phi_i} > 0$, and $\frac{\partial^2 e_i^{NR}}{\partial\phi_i^2} = \left[\frac{z}{z+\tau}\right]^h\frac{\partial^2 e_i^{NR}}{\partial\phi_i^2} < 0$).

Individual output corresponds to:

$$q_i^T = \left[p^{\alpha+\beta}\theta\beta^{\beta}w^{-\beta}\alpha^{\alpha}\left[z+\tau\right]^{-\alpha}\right]^{\frac{1}{1-\alpha-\beta}}\phi_i^{\frac{\alpha}{1-\alpha-\beta}} \tag{18}$$

The cutoff value of the energy efficiency in the case of taxes ϕ_0^T satisfies the condition $\pi_0^T(\phi_0^T) = F$, or:

$$p\theta\left[\phi_0^T\right]^{\alpha}\left[e^T\right]^{\alpha}\left[l^T\right]^{\beta} = F + wl + \left[z+\tau\right]e^T \tag{19}$$

Substituting l_i^T and e_i^T in (19) yields to:

$$\phi_0^T = \left[\frac{F^{1-\alpha-\beta}(z+\tau)^{\alpha}w^{\beta}}{p\theta\beta^{\beta}\alpha^{(1-\beta)}\left[\alpha^{-1}-\left(\frac{\alpha}{\beta}+1\right)\right]^{1-\alpha-\beta}}\right]^{\frac{1}{\alpha}} \tag{20}$$

By simple inspection of equations (9) and (20), it is easy to see that $\vee\,\tau > 0$, $\phi_0^T > \phi_0^{NR}$. As in the previous case, we can compute aggregate emissions and output under taxes (E^T, Q^T) by integrating individual emissions and output over the range $\left[\phi_0^T, \bar{\phi}\right]$, which leads to:

$$E^T = k_2\int_{\phi_0^T}^{\bar{\phi}}\phi_i^{\frac{\alpha}{1-\alpha-\beta}}d\phi = \frac{k_2}{h}\left[\bar{\phi}^h - \left[\phi_0^T\right]^h\right]. \tag{21}$$

$$Q^T = \frac{\left[z+\tau\right]E^T}{p\alpha}$$

where the average emissions' intensity in the industry corresponds to $\frac{E^T}{Q^T} = \frac{p\alpha}{z+\tau}$. It is clear that with regards to the situation with no regulation, the average emissions' intensity of the industry is decreased under taxes. Moreover, $e_i^T = e_i^{NR}\left[\frac{z}{z+\tau}\right]^h < e_i^{NR}\ \forall i$. Hence, comparing equations (9) and (20), it is straightforward that with regards to the situation with no regulation, the average energy efficiency of the industry is increased under taxes since $\phi_0^T > \phi_0^{NR}$. Before the imposition of the regulation, firms whose energy efficiency was lower than ϕ_0^T earned positive profits, but they did not take the social externality cost into consideration. The tax on emissions corrects the divergence between private and social incentives by forcing firms whose energy efficiency belongs to the range $\left[\phi_0^{NR}, \phi_0^T\right]$ out of business.

3.2 Non-Tradable Uniform Emission Quotas

Under a non-tradable uniform emission quota, the government restricts the individual emissions generated during the production process to the level $\bar{e}$. In our setting, this restriction is equivalent to a restriction on the use of the energy input. Thus, firm i maximize profits given by the constraint $e_i \leq \bar{e}$, or:

$$\max_{e_i, l_i} \pi_i = p\theta\left[\phi_i e_i\right]^\alpha l_i^\beta - wl_i - ze_i - F \qquad s.t.\ \ e_i \leq \bar{e} \tag{22}$$

If the quota is not binding, the choice of inputs proceeds as in the case without regulation. Instead, if the quota is binding, the FOC wrt l_i is:

$$l_i^S = \left[\frac{p\beta\theta\phi_i^\alpha \bar{e}^\alpha}{w}\right]^{\frac{1}{1-\beta}} \tag{23}$$

Since aggregate emissions under the emission tax and non-tradable quotas are equivalent ex-ante, we can solve for the uniform non-tradable quota $\bar{e}$ by integrating equation (16) over the distribution $\left[\phi_0^T, \bar{\phi}\right]$, which leads to the following condition:

$$k_2 \int_{\phi_0^T}^{\bar{\phi}} \phi_i^{\frac{\alpha}{1-\alpha-\beta}} d\phi = \int_{\phi_0^{NR}}^{\bar{\phi}} \bar{e} d\phi,$$

$$k_2 \int_{\phi_0^T}^{\bar{\phi}} \phi_i^{h-1} = \bar{e}\left[\bar{\phi} - \phi_0^{NR}\right].$$

Therefore, the emission standard $\bar{e}$ can be represented as:

$$\bar{e} = \frac{k_2}{h}\left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}}\right]. \tag{24}$$

Since the standard is uniform and firms are heterogenous, we should expect it to be binding only for some firms. Taking the case without regulation as the baseline, we should expect the standard to be binding if $e_i^{NR} \geq \overline{e}$. By comparing equations (6) and (24), it is easy to show that there is a critical value $\widehat{\phi}_1$ that defines whether the emission standard is binding. The critical value $\widehat{\phi}_1$ corresponds to:

$$\widehat{\phi}_1 = \left[h \left[\frac{z}{z+\tau} \right] \left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}} \right] \right]^{\frac{1}{h-1}}$$

Note that $\frac{\partial \widehat{\phi}_1}{\partial h} < 0$, which implies that the larger the share of energy on the production process, the lower the critical value $\widehat{\phi}_1$. By analogy, the larger the share of labor on the production process, the larger the critical value $\widehat{\phi}_1$. Moreover, $\widehat{\phi}_1$ is positively related to the length of the energy efficiency distribution's interval $\left[\phi_0^{NR}, \bar{\phi}\right]$, meaning that the more heterogeneous the firms are in terms of the energy efficiency, the larger the critical value defining whether emission standards are binding.

If $\phi_i \in \left[\phi_0^{NR}, \widehat{\phi}_1\right]$, the emission standard is not binding and individual emissions and output are given by equations (6) and (12), respectively. Emission's intensity corresponds to $\frac{\alpha p}{z}$ as in the case with no regulation. Instead, if $\phi_i \in \left[\widehat{\phi}_1, \overline{\phi}\right]$, the emission standard is binding and individual emissions are equal to $\overline{e}$.

Integrating individual emissions over the range $\left[\widehat{\phi}_1, \bar{\phi}\right]$ leads to $E^S\lfloor_{[\widehat{\phi}_1, \bar{\phi}]} = \overline{e}\left[\overline{\phi} - \widehat{\phi}_1\right]$. Thus, aggregate emissions under the standard are equal to:

$$\begin{aligned} E^S &= k_1 \int_{\phi_0^{NR}}^{\widehat{\phi}_1} \phi_i^{\frac{\alpha}{1-\alpha-\beta}} d\phi + \overline{e}\left[\overline{\phi} - \widehat{\phi}_1\right], \qquad (25) \\ E^S &= \frac{k_1}{h}\left[\widehat{\phi}_1^h - \left[\phi_0^{NR}\right]^h\right] + \overline{e}\left[\overline{\phi} - \widehat{\phi}_1\right] \end{aligned}$$

Sustituting equation (24) in (25) yields to:

$$E^S = \frac{k_1}{h}\left[\left[\widehat{\phi}_1^h - \left[\phi_0^{NR}\right]^h\right] + \left[\frac{z}{z+\tau}\right]^h \left[\frac{\overline{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}}\right]\left[\overline{\phi} - \widehat{\phi}_1\right]\right].$$

On the other hand, individual ouput under binding standards is equal to:

$$q_i^S = \theta\left[\phi_i \overline{e}\right]^\alpha \left[l_i^S\right]^\beta$$

substituting l_i^S, we get:

$$q_i^S = \left[p^{\beta}\beta^{\beta}w^{-\beta}\theta\right]^{\frac{1}{1-\beta}} \bar{e}^{\frac{\alpha}{1-\beta}} \phi_i^{\frac{\alpha}{1-\beta}}. \quad (26)$$

Substituting $\bar{e}$ in equation (26) and aggregating over the range $\left[\widehat{\phi}_1, \bar{\phi}\right]$ yields to:

$$Q^S \lfloor_{\left[\widehat{\phi}_1,\bar{\phi}\right]} = \frac{zk_1}{\alpha p}\left[\frac{z}{z+\tau}\right]^{h-1}\left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}}\right]^{\frac{\alpha}{1-\beta}}\left[\frac{1-\beta}{1-\beta+\alpha}\right]\left[\bar{\phi}^{\frac{1-\beta+\alpha}{1-\beta}} - \widehat{\phi}_1^{\frac{1-\beta+\alpha}{1-\beta}}\right].$$

Thus, the emission intensity of the standard for the range where the standard is binding is equal to

$$\frac{E^S}{Q^S}\lfloor_{\left[\widehat{\phi}_1,\bar{\phi}\right]} = \frac{\alpha p}{z+\tau}\left[1 - \frac{\alpha^2}{\left[1-\beta\right]^2}\right]\left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}}\right]^{\frac{1}{h}}\left[\frac{\bar{\phi} - \widehat{\phi}_1}{\bar{\phi}^{\kappa} - \widehat{\phi}_1^{\kappa}}\right],$$

where $\kappa = \frac{1}{h} + \frac{2\alpha}{(1-\beta)}$.

Note that $\frac{E^S}{Q^S}\lfloor_{\left[\widehat{\phi}_1,\bar{\phi}\right]} < \frac{E^T}{Q^T}$ if and only if $\left[1 - \frac{\alpha^2}{\left[1-\beta\right]^2}\right]\left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}}\right]^{\frac{1}{h}}\left[\frac{\bar{\phi} - \widehat{\phi}_1}{\bar{\phi}^{\kappa} - \widehat{\phi}_1^{\kappa}}\right] < 1$.

Finally, integrating individual output over the range $\left[\phi_0^{NR}, \bar{\phi}\right]$ leads to:

$$Q^S = \frac{zk_1}{\alpha p h}\left[\left[\widehat{\phi}_1^h - \left[\phi_0^{NR}\right]^h\right] + h\left[\frac{1-\beta}{1-\beta+\alpha}\right]\left[\bar{\phi}^{\frac{1-\beta+\alpha}{1-\beta}} - \widehat{\phi}_1^{\frac{1-\beta+\alpha}{1-\beta}}\right]\right].$$

Hence, the average emission's intensity corresponds to:

$$\frac{E^S}{Q^S} = \frac{\alpha p}{z}\left[\frac{\left[\widehat{\phi}_1^h - \left[\phi_0^{NR}\right]^h\right] + \left[\frac{z}{z+\tau}\right]^h\left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}}\right]\left[\bar{\phi} - \widehat{\phi}_1\right]}{\left[\widehat{\phi}_1^h - \left[\phi_0^{NR}\right]^h\right] + h\left[\frac{z}{z+\tau}\right]^{h-1}\left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}}\right]^{\frac{\alpha}{1-\beta}}\left[\frac{1-\beta}{1-\beta+\alpha}\right]\left[\bar{\phi}^{\frac{1-\beta+\alpha}{1-\beta}} - \widehat{\phi}_1^{\frac{1-\beta+\alpha}{1-\beta}}\right]}\right].$$

3.2.1 Taxes vs. Quotas

From the comparison of equations (16) and (24), it can be shown that there is a critical value $\widehat{\phi}_2$ that defines whether the emission standard induces less emissions than taxes. The critical value $\widehat{\phi}_2$ corresponds to:

$$\widehat{\phi}_2 = \left[\frac{1}{h}\left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi} - \phi_0^{NR}}\right]\right]^{\frac{1}{h-1}}.$$

It is easy to see that $\widehat{\phi}_1 = \widehat{\phi}_2 \left[\frac{z}{z+\tau}\right]^{\frac{1}{h-1}} < \widehat{\phi}_2$. Hence, individual emissions under no-regulation, emission taxes and the emission standard $\overline{e}$ can be compared as:

$e_i^T = 0 < e_i^{NR} < \overline{e} \quad \text{if } \phi \in \left[\phi_0^{NR}, \phi_0^T\right]$

$0 < e_i^T < e_i^{NR} < \overline{e} \quad \text{if } \phi \in \left]\phi_0^T, \widehat{\phi}_1\right]$

$0 < e_i^T < \overline{e} < e_i^{NR} \quad \text{if } \phi \in \left]\widehat{\phi}_1, \widehat{\phi}_2\right]$

$0 < \overline{e} < e_i^T < e_i^{NR} \quad \text{if } \phi \in \left]\widehat{\phi}_2, \bar{\phi}\right]$

To compare aggregate emissions under taxation and under standards, we compare emissions in the different intervals defined before. Let ΔE^{TS} to denote the difference in emissions under these policies, i.e., $\Delta E^{TS} = E^T - E^S$. We have:

1. If $\phi \in [\phi_o^{NR}, \phi_o^T)$, firms operate under emission standards, but not under taxation. ΔE^{TS} in this case are given by:

$$\Delta E_1^{TS} = -k_1 \int_{\phi_o^{NR}}^{\phi_o^T} \phi_i^{h-1} d\phi = -\frac{k_1}{h}\left[\left(\phi_o^T\right)^h - \left(\phi_o^{NR}\right)^h\right].$$

2. If $\phi \in [\phi_o^T, \hat{\phi}_1]$, the emission standard is not binding for individual firms, firms generate the same amount of emissions as in the non-regulation case. As a result, emissions under standars are higher than emissions under taxation. The difference between the two levels is given by:

$$\Delta E_2^{TS} = k_1 \left[\left(\frac{z}{z+\tau}\right)^h \int_{\phi_o^T}^{\hat{\phi}_1} \phi_i^{h-1} d\phi - \int_{\phi_o^T}^{\hat{\phi}_1} \phi_i^{h-1} d\phi\right] = -\frac{k_1}{h}\left[1 - \left(\frac{z}{z+\tau}\right)^h\right]\left[\left(\hat{\phi}_1\right)^h - \left(\phi_o^T\right)^h\right].$$

3. If $\phi \in [\hat{\phi}_1, \hat{\phi}_2]$, the emission standards becomes binding for individual firms, but firms still generate more emissions compared to firms under taxation.

$$\Delta E_3^{TS} = k_1 \left(\frac{z}{z+\tau}\right)^h \int_{\hat{\phi}_1}^{\hat{\phi}_2} \phi_i^{h-1} d\phi - \int_{\hat{\phi}_1}^{\hat{\phi}_2} \bar{e} d\phi,$$

$$\Delta E_3^{TS} = -\frac{k_1}{h}\left(\frac{z}{z+\tau}\right)^h \left(\frac{\left[\left(\bar{\phi}\right)^h - \left(\phi_o^T\right)^h\right]}{\left(\bar{\phi}\right) - \left(\phi_o^{NR}\right)}\left[\hat{\phi}_2 - \hat{\phi}_1\right] - \left[\left(\hat{\phi}_2\right)^h - \left(\hat{\phi}_1\right)^h\right]\right).$$

4. Finally, if $\phi \in [\hat{\phi}_2, \bar{\phi}]$, emissions under taxation are higher than emissions under standards, and the difference is given by:

$$\Delta E_4^{TS} = \int_{\hat{\phi}_2}^{\bar{\phi}} \bar{e} d\phi - k_1 \left(\frac{z}{z+\tau}\right)^h \int_{\hat{\phi}_2}^{\bar{\phi}} \phi_i^{h-1} d\phi.$$

$$\Delta E_4^{TS} = \frac{k_1}{h}\left(\frac{z}{z+\tau}\right)^h \left(\frac{\left[(\bar{\phi})^h - \left(\phi_o^T\right)^h\right]}{(\bar{\phi}) - \left(\phi_o^{NR}\right)}\left[\bar{\phi} - \hat{\phi}_2\right] - \left[(\bar{\phi})^h - \left(\hat{\phi}_2\right)^h\right]\right).$$

Aggregate emissions under taxes are lower than under standards if:

$$\Delta E_1^{TS} + \Delta E_2^{TS} + \Delta E_3^{TS} + \Delta E_4^{TS} < 0.$$

After some manipulation the following proposition regarding aggregate emissions can be derived,

Proposition 1 *There is a critical ratio $\frac{z}{z+\tau}$ that defines whether aggregate emissions under emission taxes are higher or lower than under emission standards. If $\frac{z}{z+\tau} > (\frac{z}{z+\tau})^*$, aggregate emissions under taxes are higher than under emission taxes. If $\frac{z}{z+\tau} < (\frac{z}{z+\tau})^*$ the reverse holds.*

The critical ratio $(\frac{z}{z+\tau})^*$ corresponds to:

$$(\frac{z}{z+\tau})^* = \left[\frac{\left[\bar{\phi} - \phi_o^{NR}\right]\left[\left(\hat{\phi}_1\right)^h - \left(\phi_o^T\right)^h\right]}{(\bar{\phi})^h\left[\hat{\phi}_1 - \phi_o^{NR}\right] + (\phi_o^{NR})^h\left[\bar{\phi} - \hat{\phi}_1\right] - \left(\phi_o^T\right)^h\left[\bar{\phi} - \phi_o^{NR}\right]}\right]^{\frac{1}{h}}.$$

Note that the critical value depends strongly on the threshold $\hat{\phi}_1$, (i.e., the sooner the standard is binding, the smaller the critical value. At the limit, if $\hat{\phi}_1 \to \phi_o^{NR}$, $(\frac{z}{z+\tau})^* \to 1$.

3.3 Performance Standard

Under a performance standard, the average emissions intensity is fixed by policy. As in the case of the emission standard, we assume that aggregate emissions under the performance standard and the emission tax are equivalent ex-ante. Therefore, the performance standard is equal to the average emission's intensity under taxes and corresponds to $\frac{p\alpha}{z+\tau}$.Thus, firm i maximizes

$$\max_{e_i,l_i} p\theta(\phi_i e_i)^\alpha l_i^\beta - wl_i - ze_i - F \text{ s.t. } \frac{e_i}{q_i} \leq \frac{p\alpha}{z+\tau} \Longleftrightarrow e_i \leq \frac{p\alpha}{z+\tau} q_i.$$

Note that since the average intensity with no regulation is larger than under the tax (and hence, under the performance standard), the constraint is binding $\vee$ i, and thus individual emissions are equal to:

$$e_i = \frac{p\alpha}{z+\tau}\theta(\phi_i e_i)^\alpha l_i^\beta$$

or

$$e_i^{PS} = \left[\frac{p\alpha\theta\phi_i^{\alpha} l_i^{\beta}}{z+\tau}\right]^{\frac{1}{1-\alpha}}, \tag{27}$$

the profit maximization problem becomes:

$$\max_{l_i} p\theta(\phi_i e_i^{PS})^{\alpha} l_i^{\beta} - wl_i - ze_i^{PS}.$$

Solving the FOC wrt l_i we get:

$$\frac{\beta}{1-\alpha}\left[p\theta\left(\frac{\alpha}{z+\tau}\right)^{\alpha}\phi_i^{\alpha} l_i^{-(1-\alpha-\beta)}\right]^{1-\alpha} - w - \frac{\beta}{1-\alpha} z\left[\frac{p\theta\alpha}{z+\tau}\phi_i^{\alpha} l_i^{-(1-\alpha-\beta)}\right]^{1-\alpha} = 0$$

$$l_i^{PS} = \left[\frac{\beta^{1-\alpha} p\theta\alpha^{\alpha}\left[z\left[1-\alpha\right]+\tau\right]^{1-\alpha}}{(1-\alpha)^{1-\alpha}(z+\tau)\, w^{1-\alpha}}\phi_i^{\alpha}\right]^{\frac{1}{1-\alpha-\beta}}. \tag{28}$$

Substituting (28) into (27), we get:

$$e_i^{PS} = \left[\frac{p\theta\beta^{\beta}\alpha^{1-\beta}\left[z\left[1-\alpha\right]+\tau\right]^{\beta}\phi_i^{\alpha}}{\left[z+\tau\right]\left[1-\alpha\right]^{\beta} w^{\beta}}\right]^{\frac{1}{1-\alpha-\beta}}. \tag{29}$$

Note that $\frac{e_i^{PS}}{e_i^{T}} = \left[\frac{z[1-\alpha]+\tau}{[z+\tau][1-\alpha]}\right]^{\frac{\beta}{1-\alpha-\beta}}$, which means that $e_i^{PS} = e_i^{T}\left[\frac{z[1-\alpha]+\tau}{[z+\tau][1-\alpha]}\right]^{\frac{\beta}{1-\alpha-\beta}} > e_i^{T}\ \forall i$ since $\left[\frac{z[1-\alpha]+\tau}{[z+\tau][1-\alpha]}\right] > 1$.

More explicitly, we show that $e_i^{PS} > e_i^{T}$

$$\left[\frac{p\theta\beta^{\beta}\alpha^{1-\beta}\left[z\left[1-\alpha\right]+\tau\right]^{\beta}\phi_i^{\alpha}}{\left[z+\tau\right]\left[1-\alpha\right]^{\beta} w^{\beta}}\right]^{\frac{1}{1-\alpha-\beta}} > \left[\frac{p\theta\beta^{\beta}\alpha^{1-\beta}\phi_i^{\alpha}}{\left[z+\tau\right]^{1-\beta} w^{\beta}}\right]^{\frac{1}{1-\alpha-\beta}} \Rightarrow$$

$$\frac{\left[z\left[1-\alpha\right]+\tau\right]^{\beta}}{\left[z+\tau\right]\left[1-\alpha\right]^{\beta}} > \frac{1}{\left[z+\tau\right]^{1-\beta}} \Rightarrow$$

$$\frac{\left[z\left[1-\alpha\right]+\tau\right]^{\beta}}{\left[1-\alpha\right]^{\beta}} > \left[z+\tau\right]^{\beta} \Rightarrow$$

$$z+\tau-z\alpha > z+\tau-z\alpha-\tau\alpha \Rightarrow$$

$$0 > -\tau\alpha$$

which is true.

The cutoff value of the energy efficiency in the case of performance standards ϕ_0^{PS} satisfies the condition $\pi_0^{PS}(\phi_0^{PS}) = F$, or:

$$p\theta\left[\phi_0^{PS}\right]^{\alpha}\left[e^{PS}\right]^{\alpha}\left[l^{PS}\right]^{\beta} = F + wl^{PS} + ze^{PS}. \tag{30}$$

Substituting l_i^{PS} and e_i^{PS} in (30) yields to:

$$\phi_0^{PS} = \left[\frac{F^{1-\alpha-\beta} [z+\tau] w^{\beta} [1-\alpha]^{1-\alpha}}{p\theta\beta^{\beta}\alpha^{\alpha} [z[1-\alpha]+\tau]^{1-\alpha} [1-\beta[1-\alpha]]^{1-\alpha-\beta}} \right]^{\frac{1}{\alpha}}. \tag{31}$$

Comparing the cutt-off value in the case of PS with the one in the case of T:

$$\phi_0^T = \left[\frac{F^{1-\alpha-\beta} [z+\tau]^{\alpha} w^{\beta}}{p\theta\beta^{\beta}\alpha^{1-\beta} \left[\frac{\beta(1-\alpha)-\alpha^2}{\alpha\beta}\right]^{1-\alpha-\beta}} \right]^{\frac{1}{\alpha}}$$

We can show that:

$$\phi_0^{PS} < \phi_0^T$$

$$\frac{[z+\tau][1-\alpha]^{1-\alpha}}{[z[1-\alpha]+\tau]^{1-\alpha}[1-\beta[1-\alpha]]^{1-\alpha-\beta}} < \frac{[z+\tau]^{\alpha}}{\alpha^{1-\alpha-\beta}\left[\frac{\beta(1-\alpha)-\alpha^2}{\alpha\beta}\right]^{1-\alpha-\beta}}$$

$$\frac{[z+\tau][1-\alpha]^{1-\alpha}}{[z[1-\alpha]+\tau]^{1-\alpha}[1-\beta[1-\alpha]]^{1-\alpha-\beta}} < \frac{[z+\tau]^{\alpha}}{\left[\frac{\beta(1-\alpha)-\alpha^2}{\beta}\right]^{1-\alpha-\beta}}$$

$$\underbrace{[z[1-\alpha]+\tau[1-\alpha]]^{1-\alpha}}_{A}\underbrace{\left[1-\alpha\left[1+\frac{\alpha}{\beta}\right]\right]^{1-\alpha-\beta}}_{B} < \underbrace{[z[1-\alpha]+\tau]^{1-\alpha}}_{C}\underbrace{[1-\beta[1-\alpha]]^{1-\alpha-\beta}}_{D}$$

We can show that $C < A$ and $B < D$, which implies that $\phi_0^{PS} < \phi_0^T$. Since taxes impose stricter restrictions on firms, making them reduce their individual emissions even more than in the case of performance standards, the marginal firm in the case of taxation should be more energy efficient that the corresponding one in the case of performance standards.

Aggregate emissions under performance standard E^{PS} are calculated by integrating individual emissions over the range $\left[\phi_0^{PS}, \bar{\phi}\right]$, which leads to:

$$E^{PS} = \left[\frac{z[1-\alpha]+\tau}{[z+\tau][1-\alpha]}\right]^{\frac{\beta}{1-\alpha-\beta}} \int_{\phi_0^{PS}}^{\bar{\phi}} e_i^T = \frac{k_2}{h}\left[\frac{z[1-\alpha]+\tau}{[z+\tau][1-\alpha]}\right]^{\frac{\beta}{1-\alpha-\beta}} \left[\bar{\phi}^h - \left[\phi_0^{PS}\right]^h\right]. \tag{32}$$

3.3.1 Performance Standards vs. Taxes and. Quotas

From the comparison of equations (16),(24) and (29), it can be shown that there is a critical value $\widehat{\phi}_3$ that defines whether performance standards induce less emissions than emission standards. This critical value is equal to:

$$\hat{\phi}_3 = \left[\frac{z+\tau}{z[1-\alpha]+\tau}\right]^{\frac{\beta}{\alpha}} \left[h\left[\frac{\bar{\phi}^h - \left[\phi_0^T\right]^h}{\bar{\phi}-\phi_0^{NR}}\right]\right]^{\frac{1}{h-1}}.$$

Moreover, $\hat{\phi}_3 = \hat{\phi}_2 \left[\frac{(z+\tau)(1-\alpha)}{z[1-\alpha]+\tau}\right]^{\frac{\beta}{\alpha}} < \hat{\phi}_2$. Thus, as mentioned above, $e_i^{PS} > e_i^T \ \vee i$.

Individual emissions under no-regulation e_i^{NR}, emission taxes e_i^T, emission standard $\overline{e}$ and performance standard e_i^{PS} can now be ranked as:

$e_i^{PS} = e_i^T = 0 < e_i^{NR} < \overline{e}$ if $\phi \in \left[\phi_0^{NR}, \phi_0^{PS}\right]$

$e_i^T = 0 < e_i^{PS} < e_i^{NR} < \overline{e}$ if $\phi \in \left]\phi_0^{PS}, \phi_0^T\right]$

$0 < e_i^T < e_i^{PS} < e_i^{NR} < \overline{e}$ if $\phi \in \left]\phi_0^T, \widehat{\phi}_1\right]$

$0 < e_i^T < e_i^{PS} < \overline{e} < e_i^{NR}$ if $\phi \in \left]\widehat{\phi}_1, \widehat{\phi}_3\right]$

$0 < e_i^T < \overline{e} < e_i^{PS} < e_i^{NR}$ if $\phi \in \left]\widehat{\phi}_3, \widehat{\phi}_2\right]$

$0 < \overline{e} < e_i^T < e_i^{PS} < e_i^{NR}$ if $\phi \in \left]\widehat{\phi}_2, \bar{\phi}\right]$

From this ranking, the following propositions can be derived,

Proposition 2 *Aggregate emissions under emission taxes are lower than under performance standards.*

The intuition behind this proposition is straightforward; with regards to emission taxes, performance standards induce more emissions for all firms, and a lower cutoff value consistent with non-negative profits.

Proposition 3 *There is a critical ratio $\frac{z}{z+\tau}$ that defines whether aggregate emissions under performance standards are higher or lower than under emission standards. If $\frac{z}{z+\tau} > (\frac{z}{z+\tau})^{**}$, aggregate emissions under performance standards are higher than under emission standards. If $\frac{z}{z+\tau} < (\frac{z}{z+\tau})^{**}$ the reverse holds.*

The critical ratio $(\frac{z}{z+\tau})^{**}$ corresponds to:

$$(\frac{z}{z+\tau})^{**} = \left[\frac{\left(\left[\frac{(z[1-\alpha]+\tau)^{\beta}}{(z+\tau)(1-\alpha)^{\beta}}\right]^{\frac{1}{1-\alpha-\beta}}\left[(\bar{\phi})^h - (\phi_0^{PS})^h\right] - z^{-\frac{1-\beta}{1-\alpha-\beta}}\left[(\hat{\phi}_1)^h - (\phi_0^{NR})^h\right]\right)\left[\bar{\phi} - \phi_o^{NR}\right]}{z^{-\frac{1-\beta}{1-\alpha-\beta}}\left[(\bar{\phi})^h - (\phi_0^T)^h\right]}\right]^{\frac{1}{h}}.$$

We can show that $(\frac{z}{z+\tau})^{*} > (\frac{z}{z+\tau})^{**}$. This means that compared to taxes, aggregate emissions under performance standards are more likely to exceed the aggregate emissions under emission standards.

4 Numerical Example

In this section we present some numerical examples of the size distribution induced by the different policies under analysis. For such a purpose, we provide values for some of our key parameters and calculate the resulting choice of inputs, profits, and aggregate emissions and output.

Table 1: Parameter Values

a	β	θ	p	w	z	τ	F	N	$\bar{\phi}$	$\underline{\phi}$
0.2	0.5	2	5	1	1.6	0.2	21	30	1	0

The production elasticity of emissions and labor is set at $a = 0.2$ and $\beta = 0.5$ respectively. The genaral productivity parameter, θ, is equal to 2. The price of the output is set at $p = 5$, while the wages and the price of energy are also set at $w = 1$ and $z = 1.6$ respectively. We set the emission tax $\tau = 0.2$ and the fixed entry cost of firms $F = 21$. Finally, we assume that the initial number of firms is 30 (N), and these firms are uniformely distributed in the interval $[0, 1]$, which means that the upper bound of the distribution is given by $\bar{\phi} = 1$ and the lower bound $\underline{\phi} = 0$.

Using the parameter values presented in Table 1, we study the size distribution of firms before and after the implementation of the environmental regulation. Table 2 summarizes the main results. If no policy is enforced, 7 out of 30 firms cannot operate due to the fixed entry cost which makes them non profitable. This means that firms with low energy efficiency $[0, 0.267)$ will not be active, even in case of no regulation.

Firms need to be more energy efficient in order to survive if environmental taxes are imposed. The cutt-off value in this specific numerical example is 0.3. The consideration of the social cost of emissions made firms belonging to the interval $[0.267, 0.3)$ exit the market. The case of standards is different. For the firms lying on the left hand side of the distribution ($[0.267, 0.43]$), the emissions standard seems not to be binding. Those firms produce the same amount of output and solve the same maximization problem as in the non regulation case. The firms that have to comply with the rule are those lying on the right hand side of the distribution, i.e. $[0.43, 1]$ in this particular numerical example. Those firms produce less than before, as it is illustrated in Figure 1. To make the comparison with taxes, small firms ($[0.267, 0.57]$) produce more output in the case of the emission standard, while large firms ($[0.57, 1]$) produce more in the case where taxes are chosen as an instrument to reduce pollution. The point 0.57 is the one where the two curves (qT, qS) cross each other. In the same graph, we can also observe the output distribution in the case of performance standards (PS). It is very clear that output under trandable permits is higher than output under taxation, which is easily explained if we take into account that firms pay taxes for the total of the emissions they generate, while in the case of performance standards, they are restricted by the regulation, but there is no extra, monetary cost that they have to pay in order to comply with this. Using the specific parameter values assumed here, we can rank the four regimes as follows, $Q^{NR} > Q^{PS} > Q^{T} > Q^{S}$. This ranking is in line with the predictions of our theoretical model.

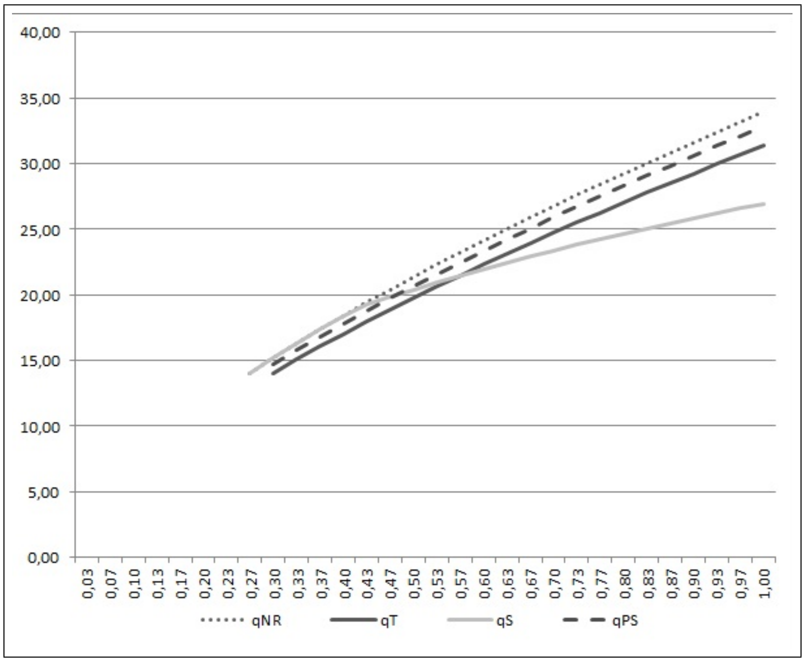

Figure 1: Distribution of Output across the Different Types of Firms (NR: Non-regulation, T:taxes, S:standards, PS: performance standards.

Table 2: Static Case, Numerical Results

	ϕ_0	$\widehat{\phi}_1$	E	Q	E/Q	WI
Non Regulation	0.267		355	567	0.63	368
Taxes	0.3		284	511	0.56	361
Standards	0.267	0.43	265	502	0.52	349
Performance Standard	0.3		297	535	0.56	363

Table 2 also shows the total emission level in each case, while Figure 2 presents the emissions generated by each type of firms. To start with the aggregate amount, the higher the output, the higher the total amount of emissions, which means, $E^{NR} > E^{PS} > E^{T} > E^{S}$. So, under no regulation, we observe an increasing amount of emissions, as we move to the right of the distribution, which is highly connected to the higher output levels and the implied size of the firms. Taxes and PS result in lower levels of emissions (still higher in the case of PS, where firms do not pay a tax per unit of emissions they generate). Finally, the enforcement of emission standard leads to the same emission levels as in the non regulation case for the firms lying on the left hand side of the distribution, but there is a significant decrease in the emissions generated by the rest of the firms. This decrease also affects the emissions-output ratio, which has been calculated in Table 2 for all the cases under study. More specifically, in this table we can see that $(E/Q)^S < (E/Q)^T = (E/Q)^{TP} < (E/Q)^{NR}$.

The last column of Table 2 provides the values of a welfare indicator for each policy instrument. This indicator is equal to aggregate profits of active firms in the different policy senarios. Two factors determine the observed differences in the welfare values: (i) the cost of compliance with the different environmental policies and (ii) the different number of firms exiting the market after the implementation of each environmental policy. The formulas for each welfare indicator (WI) are given below:

$$WI^{NR} = \int_{\phi_0^{NR}}^{\bar{\phi}} \left[pq_i^{NR}(\phi_i) - wl_i^{NR}(\phi_i) - ze_i^{NR}(\phi_i) - F \right] d\phi \tag{33}$$

$$WI^T = \int_{\phi_0^T}^{\bar{\phi}} \left[pq_i^T(\phi_i) - wl_i^T(\phi_i) - (z+\tau)e_i^T(\phi_i) - F \right] d\phi_i + (\bar{\phi} - \phi_0^T) \left[\frac{\int_{\phi_0^T}^{\bar{\phi}} \tau e_i^T(\phi_i) d\phi_i}{(\bar{\phi} - \phi_0^T)} \right] \tag{34}$$

$$WI^S = \int_{\phi_0^{NR}}^{\hat{\phi}_1} \left[pq_i^{NR}(\phi_i) - wl_i^{NR}(\phi_i) - ze_i^{NR}(\phi_i) - F \right] d\phi + \int_{\hat{\phi}_1}^{\bar{\phi}} \left[pq_i^S(\phi_i) - wl_i^S(\phi_i) - z\,\bar{e} - F \right] d\phi \tag{35}$$

$$WI^{PS} = \int_{\phi_0^{PS}}^{\bar{\phi}} \left[pq_i^{PS}(\phi_i) - wl_i^{PS}(\phi_i) - ze_i^{PS}(\phi_i) - F \right] d\phi \tag{36}$$

Note that in equation (34) that presents the welfare indicator in the case of environmental tax, there are two additive parts. The first part shows the aggregate profits of active firms after having paid the cost of taxation. The second part shows that these money are returned to the firms in the form of a lump-sum subsidy which is equal for every firm. This is a only policy that implies an actual, monetary cost for the firms and this should be taken into account by the social planner. Equations (35) shows the aggregate profits in the case of emissions standards. More specifically, the first part presents the derived profits when the standard is not binding, while the second integral term shows the aggregate profits of active firms that find the imposed standard binding. The results based on our numerical experiments provide the following ranking: $WI_{NR} > WI_{PS} > WI_T > WI_S$. This welfare ranking is in line with the analysis and the comparison of the different policies above and can be used to provide some policy implications for the environmental tools under study. In this context, performance standards are not only considered to be the most neutral policy among the three, but it is shown to lead to higher welfare levels. Environmental taxes lead to lower welfare levels compared to performance standards, while emissions standards are proved to be the worst instrument in terms of welfare. This could be explained by the fact that they impose strict restrictions not only to emission levels but also to the level of the output. In general, policies that favor significantly either small or large firms (e.g. emissions standars, environmental taxes) lead to lower welfare levels compared to

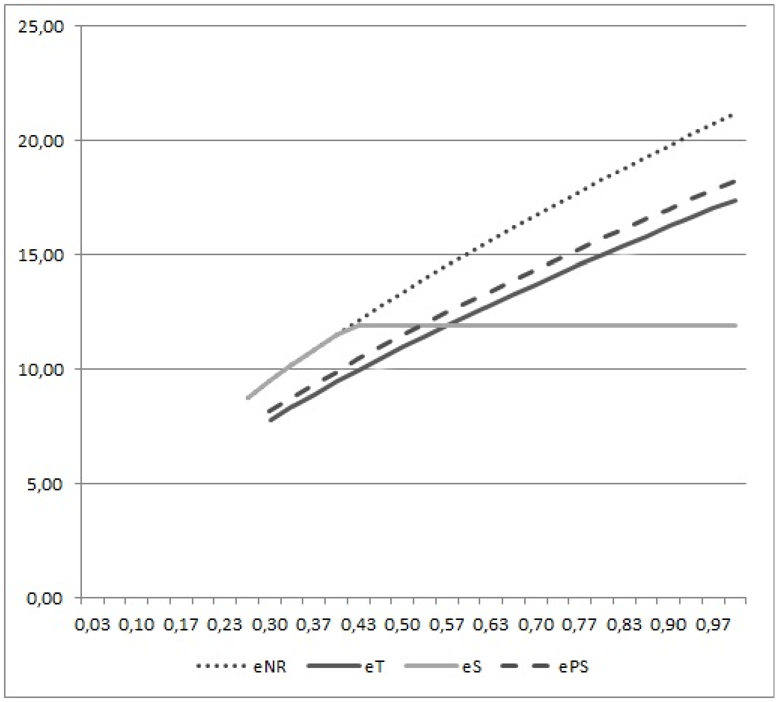

Figure 2: Distribution of Emissions across the Different Types of Firms (NR: Non-regulation, T:taxes, S:standards, PS: performance standards.

policies that are cosidered to impose relatively the same restrictions to firms of different sizes (e.g. performance standards).

In order to evaluate the different kinds of environmental policy and and see how they affect firms of different sizes, we calculate the absolute and the percentage change in the profits shares of individual firms after the implementation of the policy instruments under study. As we can see in Figures 3 and 4, emission standards are much more stringent for larger firms, while they have a positive effect on small firms which seem to increase their profits share. Performance standards are considered to be a neutral policy that imposes relatively more constraints to smaller firms which, due to their smaller output, have to face stricter environmental constraints. This kind of policy is somehow equivalent to a differentiated emission standard, where the lower the output, the more restrictive is the emission standard. Under performance standards, small firms lose a small part of their profits while larger firms increase marginally their profits shares. Taxes clearly impose a higher cost to smaller firms, which do not have high surpluses, leading to the exiting of the firms that were closer to the lower boundary of the distribution. On the contrary, environmental taxes favor larger firms increasing their profits shares.

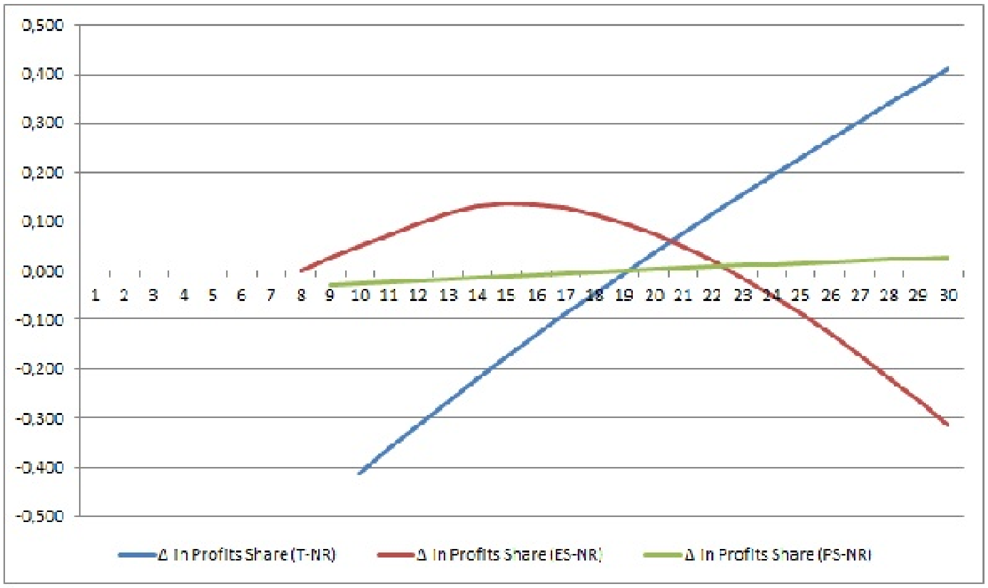

Figure 3: Change in Profits Shares of Individual Firms

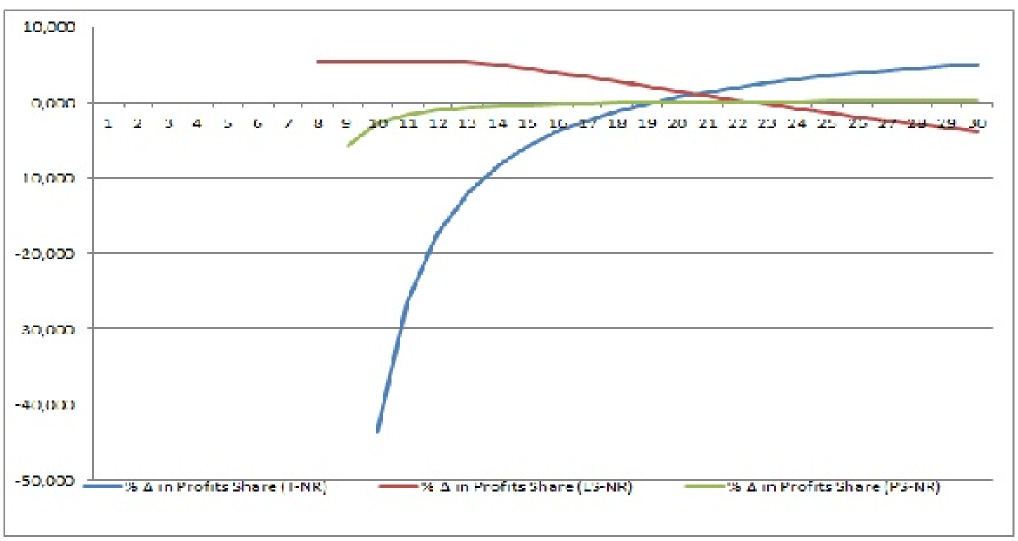

Figure 4: % Change in Profits Shares of Individual Firms.

5 Conclusions

In this paper we study the effects of the choice of policy instruments on the size distribution of firms. We have shown that each regulation affects differently firms of heterogeneous size, favoring either small or large firms. For instance, compared to taxes, uniform emission standards are much more stringent for larger firms - that emit in absolute terms more than small firms. Moreover, the fact that a different number of firms goes out of business under different policy instruments provides some implications for their level of strigency. In the current study, the implied heterogeneity among firms differentiates the effects of the alternative policies studied here.

To sum up, the internalization of the social cost, coming from the polluting activity of firms, leads to lower production levels for each "type" of firm. More specifically, emission taxes will affect more small firms with significantly low surpluses as the use of energy now becomes more expensive. The result here is equivalent to an increase in the price of energy. Emission standards, as stated above, affect only the large firms who have to comply with the new regulation. Small firms keep producing the same amount of output, using the same amount of energy, since the constraint is not binding in their case. Finally, performance standars favor marginally large firms that produce high levels of output and do not find the regulation so restrictive. However, compared to the other two policy instruments, performance standards do not affect profits shares significantly, while at the same time, they lead to higher welfare levels.

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