# 1 Introduction

There has been considerable debate on whether government regulations and firms' efforts to protect the environment harm or benefit firms. A traditional view is that tighter environmental policies impose significant costs on firms and thereby have negative impacts on their productivity and competitiveness. This suggests resistance to environmental regulations from interest groups that represent a polluting industry's benefits. However, according to the literature, there is some evidence that industry interest groups do not necessarily oppose, or may even support, strict environmental policies.[1] In fact, there are an increasing number of firms and industries that actively work on environmental protection and conservation to practice corporate social responsibility.[2]

An economic explanation for why stricter environmental regulation can benefit firms can be found in the "Porter hypothesis", which claims that "well-designed environmental regulations might lead to improved competitiveness" (Porter and van der Linde, 1995, p.115). The basic idea is that properly designed environmental regulation may spur technological innovation, the benefits from which can offset the additional regulatory costs. A considerable number of studies have identified more detailed mechanisms that cause the Porter hypothesis and have also examined the empirical validity of the hypothesis.[3]

This article presents another channel, namely, a *general equilibrium effect*, whereby tighter environmental policy may have a beneficial effect on polluting firms. For this purpose, we develop a simple model of general oligopolistic equilibrium (GOLE) in which firms are large in their own markets but small in the economy as a whole (Neary, 2003).[4] Unlike conventional oligopoly models, factor prices are endogenously determined in the GOLE model, and we show that this general equilibrium response in the factor market works in the opposite direction as the environmental policy on the firms' production costs.[5] Some sectors experience the general equilibrium effect offsetting the increase in regulatory costs, and thus, production is enhanced. We identify which industries can be such ones. We also show that despite the possibility of stricter environmental policy enhancing production in some industries, the total pollution in the economy unambiguously decreases.

[1] See Kelsey (2018) and the references therein.

[2] See, for example, Kolk (2016).

[3] See Ambec et al. (2013) and Dechezleprêtre and Sato (2017) for a survey of the literature.

[4] See Colacicco (2015) for a survey of the GOLE literature. Colacicco (2021) introduces transboundary pollution into a two-country GOLE model and analyzes optimal environmental policies.

[5] The general equilibrium response of factor prices to environmental policy has already been discussed in the literature, using the framework of perfect competition. From the seminal work by Yohe (1979) to recent studies of Fullerton and Heutel (2007, 2010), the literature focuses on the difference in factor intensities and elasticity of substitution across sectors. However, the competitive models assume constant-returns technology, and thus, firms earn zero profit, meaning that the effect of environmental regulation on firms' profitability cannot be examined. There are also studies using general equilibrium models of monopolistic competition with firm heterogeneity, including Egger et al. (2021). However, this line of research focuses on the technology difference among firms within an industry rather than the technology difference across industries, as we do in this paper.

# 2 The model

We consider a closed economy in which there is a continuum of industries in a unit interval. In each industry $z \in [0,1]$, there are $n(z)$ firms producing a homogeneous product by employing labor as a single factor of production. The production process generates pollution, which can be mitigated by firms' pollution abatement activities.

The preferences of a representative consumer are represented by the following utility function:

$$u = \int_0^1 \left[ a - \frac{b}{2} x(z) \right] x(z) dz - D(E), \quad a, b > 0, \tag{1}$$

where $x(z)$ denotes the consumption of good $z \in [0,1]$ and $D(E)$ is the damage from total pollution $E$ with $D' > 0$. The consumer maximizes his/her utility subject to the budget constraint $\int_0^1 p(z)x(z)dz = I$, where $p(z)$ denotes the price of good $z$ and $I$ is the consumer's income.[6] The first-order condition for utility maximization yields the inverse demand functions

$$p(z) = \frac{1}{\lambda} \left[ a - bx(z) \right], \tag{2}$$

where

$$\lambda = \frac{a \int_0^1 p(z)dz - bI}{\int_0^1 p(z)^2 dz}$$

denotes the marginal utility of income.

In each industry, all firms in the economy share an identical technology represented by a linear production function $y_i(z) = l_i(z)/\alpha(z)$, where $y_i(z)$ and $l_i(z)$ denote the output and employment of firm $i$ in sector $z$, $i = 1, \ldots, n(z)$, and $\alpha(z)$ is the unit labor requirement in sector $z \in [0,1]$. Each firm in industry z emits pollution $e_i(z) = \epsilon_i(z) y_i(z)$, where $\epsilon_i(z)$ is firm $i$'s emission coefficient, which is inversely dependent on the firm's pollution abatement level, $r_i(z)$, that is, $\epsilon_i(z) = \bar{\epsilon}/r_i(z)$, $\bar{\epsilon} > 0$. The abatement activity incurs costs, and following Kennedy (1994), the per-unit abatement cost is given by $\beta(z) r_i(z)$, where the higher the value of $\beta(z)$ is, the less advanced abatement technology the industry has.[7]

Pollution emissions are controlled by a national government that implements a pollution tax policy. We denote the pollution tax rate per unit of emission by $t$. Then, the profit of firm i in industry $z$ is given by $\pi_i(z) = p(z)y_i(z) - wl_i(z) - te_i(z) - \beta(z) r_i(z) y_i(z)$, where $w$ denotes the wage. Given the specifications concerning demand, employment, and pollution emissions, profits can be rewritten as[8]

$$\pi_i(z) = \left[ a - b \sum_{j=1}^{n(z)} y_j(z) - w\alpha(z) - t \frac{\bar{\epsilon}}{r_i(z)} - \beta(z) r_i(z) \right] y_i(z). \tag{3}$$

[6] The consumer takes the environmental damage as given when he/she determines demand for goods.

[7] The abatement activities are assumed to use a specific factor (e.g., knowledge or skilled labor specific to each industry). Thus, we can interpret $\beta(z)$ as reflecting the price of the specific factor in industry $z$.

[8] As discussed in Neary (2003), this model has one degree of freedom in solving for nominal variables, which means that we can choose an arbitrary numéraire without affecting the model's properties. Thus, we choose the marginal utility of income as the numéraire; $\lambda = 1$.

Since we are considering a continuum of industries, firms are large and thus have high market power in their own markets but small in the economy as a whole, meaning that they take the wage as given. Each firm determines its output $y_i(z)$ as a Cournot oligopolist and chooses its abatement level $r_i(z)$. The first-order conditions are

$$\frac{\partial \pi_i(z)}{\partial y_i(z)} = a - b\sum_{j=1}^{n(z)} y_j(z) - w\alpha(z) - t\frac{\bar{\epsilon}}{r_i(z)} - \beta(z)r_i(z) - by_i(z) \leq 0, \tag{4}$$

$$\frac{\partial \pi_i(z)}{\partial r_i(z)} = \left[t\frac{\bar{\epsilon}}{r_i(z)^2} - \beta(z)\right] y_i(z) \leq 0. \tag{5}$$

Since we assume firms with identical technology in each sector, we focus on the symmetric equilibrium in which all firms choose the same levels of output and abatement within the sector and thus denote $y_i(z) = y(z)$ and $r_i(z) = r(z)$ for all $z \in [0, 1]$. By also assuming that the parameters satisfy the conditions for interior solutions, we can rewrite the first-order conditions (4) and (5) as[9]

$$a - b\left[n(z) + 1\right] y(z) - w\alpha(z) - t\frac{\bar{\epsilon}}{r(z)} - \beta(z)r(z) = 0, \tag{6}$$

$$t\frac{\bar{\epsilon}}{r(z)^2} - \beta(z) = 0. \tag{7}$$

From (7), the abatement level of each firm in industry $z$ can be derived as

$$r(z) = \sqrt{\frac{t\bar{\epsilon}}{\beta(z)}}. \tag{8}$$

Clearly, an increase in the pollution tax rate, $t$, enhances pollution abatement per firm. Moreover, an industry with more efficient abatement technology (i.e., a smaller $\beta(z)$) has more abatement per firm.

By substituting (8) into (6) and solving for $y(z)$, the Cournot–Nash equilibrium output of each firm in industry $z$ can be derived as follows:

$$y(z) = \frac{a - w\alpha(z) - 2\sqrt{t\bar{\epsilon}\beta(z)}}{b\left[n(z) + 1\right]}. \tag{9}$$

The equilibrium output depends not only on $t$ but also on $w$; both have a negative effect on $y(z)$. In addition, an industry with more efficient production or abatement technology (i.e., a smaller $\alpha(z)$ and $\beta(z)$) has more output per firm.

From (3), (8), and (9), the equilibrium profit of each firm is

$$\pi(z) = \frac{\left[a - w\alpha(z) - 2\sqrt{t\bar{\epsilon}\beta(z)}\right]^2}{b\left[n(z) + 1\right]^2} = by(z)^2. \tag{10}$$

[9] It is clear that for any $t, \bar{\epsilon}, \beta(z) > 0$, there exists $r(z) > 0$ that satisfies (7). In light of (8), the condition for $y(z) > 0$ that satisfies (6) is $a - w\alpha(z) - 2\sqrt{t\bar{\epsilon}\beta(z)} > 0$. This condition can be fulfilled if, for example, $a$ is sufficiently large.

Thus, the properties of the equilibrium profit follow those of the equilibrium output.

From (8) and (9), the emission level per firm in industry $z$ is

$$e(z) = \frac{\bar{\epsilon}}{r(z)} y(z) = \frac{\sqrt{\frac{\bar{\epsilon}\beta(z)}{t}}\left[a - w\alpha(z)\right] - 2\bar{\epsilon}\beta(z)}{b\left[n(z)+1\right]}. \tag{11}$$

Since each firm's emissions are linearly dependent on output, $e(z)$ is negatively dependent on $t$, $w$, and $\alpha(z)$.[10]

Total pollution in this economy is

$$E = \int_0^1 n(z)e(z)dz = \int_0^1 \frac{n(z)}{b\left[n(z)+1\right]}\left\{\sqrt{\frac{\bar{\epsilon}\beta(z)}{t}}\left[a - w\alpha(z)\right] - 2\bar{\epsilon}\beta(z)\right\}dz, \tag{12}$$

which is negatively dependent on $t$ and $w$.

# 3 General equilibrium effects of environmental policy

We have considered the equilibrium in the product markets for a given wage rate w, which should be determined endogenously in general equilibrium. To determine $w$, the labor-market clearing condition should be considered. Let us denote the labor endowment in this economy by $L$. Since the labor demand in industry z is equal to $n(z)\alpha(z)y(z)$, the labor-market clearing condition is given by

$$\int_0^1 n(z)\alpha(z)y(z)dz = L. \tag{13}$$

By substituting (9) into (13) and solving for $w$, it follows that

$$w = \frac{\int_0^1 \nu(z)\alpha(z)\left[a - 2\sqrt{t\bar{\epsilon}\beta(z)}\right]dz - L}{\int_0^1 \nu(z)\alpha(z)^2 dz}, \tag{14}$$

where $\nu(z) \equiv n(z)/\left\{b\left[n(z)+1\right]\right\}$. It is easily verified that $w$ is decreasing in $t$. Intuitively, for a given wage rate, an increase in $t$ reduces firms' outputs in all industries as well as labor demand, which leads to an inward shift in the labor demand curve, thereby reducing the equilibrium wage.

We are now in a position to examine the general equilibrium effect of the pollution tax on the firms' outputs and profits. From (9) and (14),

$$\frac{dy(z)}{dt} = \frac{\partial y(z)}{\partial w}\frac{dw}{dt} + \frac{\partial y(z)}{\partial t} = \frac{\sqrt{\bar{\epsilon}/t}}{b\left[n(z)+1\right]}\left\{\frac{\alpha(z)\int_0^1 \nu(z)\alpha(z)\sqrt{\beta(z)}dz}{\sqrt{\beta(z)}\int_0^1 \nu(z)\alpha(z)^2 dz} - 1\right\}. \tag{15}$$

Thus, the following proposition can be obtained.

[10] The effect of an increase in $\beta(z)$ on $e(z)$ is not the same as that on $y(z)$ because $r(z)$ is also negatively dependent on $\beta(z)$. We can verify that the relationship between $\beta(z)$ and $e(z)$ is inverted-U shaped; $e(z)$ is decreasing (increasing) in $\beta(z)$ for $\beta(z) > (<) \left[a - w\alpha(z)\right]^2/(16t\bar{\epsilon})$.

**Proposition 1.** *An increase in the pollution tax rate increases (decreases) the equilibrium output of each firm in industry $z$ if and only if*

$$\alpha(z)\int_0^1 \nu(z)\alpha(z)\sqrt{\beta(z)}dz > (<)\sqrt{\beta(z)}\int_0^1 \nu(z)\alpha(z)^2 dz \tag{16}$$

*is satisfied.*

To understand this result, suppose that $n(z) = n$. Then, (16) can be simplified to

$$\alpha(z)\int_0^1 \alpha(z)\sqrt{\beta(z)}dz > (<)\sqrt{\beta(z)}\int_0^1 \alpha(z)^2 dz. \tag{17}$$

Suppose further that (i) all industries share a common labor productivity, that is, $\alpha(z) = \bar{\alpha}$ for all $z \in [0, 1]$, or (ii) all industries share a common productivity of pollution abatement, that is, $\beta(z) = \bar{\beta}$ for all $z \in [0, 1]$. In case (i), inequality (17) is reduced to

$$\int_0^1 \sqrt{\beta(z)}dz > (<)\sqrt{\beta(z)},$$

which means that if industry $z$ has more efficient abatement technology (i.e., a smaller $\beta(z)$) than average, an increase in the pollution tax rate enhances production in that industry, and vice versa. Intuitively, if all firms have the same production technology, for a given emission coefficient, all firms respond equally to an increase in $t$ by reducing their emission levels. However, firms with more efficient abatement technologies will increase their abatement effort more in response to an increase in $t$, and these firms can afford to increase outputs without increasing their emissions.

In case (ii), inequality (16) is reduced to

$$\alpha(z)\int_0^1 \alpha(z)dz > (<)\int_0^1 \alpha(z)^2 dz \quad \Leftrightarrow \quad \alpha(z) > (<)\frac{\mu_2^\alpha}{\mu_1^\alpha},$$

where $\mu_1^\alpha \equiv \int_0^1 \alpha(z)dz$ and $\mu_2^\alpha \equiv \int_0^1 \alpha(z)^2 dz$ denote the first and second moments of the technology distribution. The above inequality indicates that if industry $z$ has less efficient production technology (i.e., a larger $\alpha(z)$) than a cutoff level equal to $\mu_2^\alpha/\mu_1^\alpha$, then an increase in $t$ enhances production that industry, and vice versa. Intuitively, an increase in $t$ reduces the equilibrium wage $w$, which means that firms with less efficient production technology can save more costs, and thus, they have an incentive to increase their outputs.

Since $\pi(z) = y(z)^2/b$, the following corollary can be established.

**Corollary 1.** *An increase in the pollution tax rate increases (decreases) the equilibrium profit of each firm in industry $z$ if and only if* (16) *holds.*

From (11) and (14), the general equilibrium effect of the pollution tax on the per-firm emissions in industry $z$ is

$$\frac{de(z)}{dt} = \frac{\partial e(z)}{\partial w}\frac{dw}{dt} + \frac{\partial e(z)}{\partial t} = -\frac{\sqrt{\bar{\epsilon}\beta(z)}\left\{a\left[\int_0^1 \nu(z)\alpha(z)^2 dz - \alpha(z)\int_0^1 \nu(z)\alpha(z)dz\right] + \alpha(z)L\right\}}{2b\left[n(z)+1\right]t^{3/2}\int_0^1 \nu(z)\alpha(z)^2 dz}. \tag{18}$$

The following proposition states a sufficient condition for (18) to be negative.

**Proposition 2.** *An increase in the pollution tax rate reduces the equilibrium emission level of each firm in industry $z$ if $\alpha(z)\int_0^1 \nu(z)\alpha(z)dz \leq \int_0^1 \nu(z)\alpha(z)^2 dz$.*

Proposition 2 indicates that if industry $z$ has a sufficiently efficient production technology compared to other industries such that its unit labor requirement is not greater than $\int_0^1 \nu(z)\alpha(z)^2 dz / \int_0^1 \nu(z)\alpha(z)dz$, then an increase in the pollution tax rate reduces emissions in industry $z$. By contrast, for industries with sufficiently less efficient production technology, more stringent environmental policy might result in more pollution.

Although an increase in the pollution tax rate can lead to more pollution in some industries, total pollution in the economy, $E$, is shown to be unambiguously decreasing in $t$.[11] From (12) and (14), the general equilibrium effect of the pollution tax on the economy's total pollution can be derived as

$$\frac{dE}{dt} = \frac{\partial E}{\partial w}\frac{dw}{dt} + \frac{\partial E}{\partial t} = -\frac{\sqrt{\epsilon}\Delta}{2t^{3/2}\int_0^1 \nu(z)\alpha(z)^2 dz}, \tag{19}$$

where

$$\Delta \equiv a\left[\int_0^1 \nu(z)\sqrt{\beta(z)}dz \int_0^1 \nu(z)\alpha(z)^2 dz - \int_0^1 \nu(z)\alpha(z)dz \int_0^1 \nu(z)\alpha(z)\sqrt{\beta(z)}dz\right] + L\int_0^1 \nu(z)\alpha(z)\sqrt{\beta(z)}dz > 0.$$

**Proposition 3.** *Suppose that all industries operate; $y(z) > 0$ for all $z \in [0,1]$. Then, an increase in the pollution tax rate reduces the equilibrium level of total pollution in the economy.*

*Proof.* See the Appendix. □

# 4 Conclusion

Applying a simple GOLE model, we have shown that although more stringent environmental policy unambiguously reduces total pollution in the economy, some industries may benefit from such policy. Specifically, if an industry has firms that have more efficient abatement technology and/or less efficient production strategies, that industry is more likely to benefit from stricter environmental regulations. Unlike the well-known Porter hypothesis, we do not consider firms' investment in innovative activities but consider the general equilibrium response in the factor market. Thus, our study offers new insight into the relationship between environmental regulation and productivity. Our theoretical results also provide a hypothesis that can be tested empirically; if one obtains industry-level productivity with respect to output and pollution abatement, comparing these variables with the economy-wide average levels of those variables can reveal whether environmental regulation benefits an industry.

[11] Proposition 3 contrasts with the discussion in Fullerton and Heutel (2007, 2010) that in their competitive general equilibrium model, stricter environmental policies may increase total pollution.

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# Appendix: Proof of Proposition 3

From (9) and (14), $y(z) > 0$ for all $z \in [0,1]$ if and only if

$$\frac{\int_0^1 \nu(z)\alpha(z)\left\{a - 2\sqrt{t\bar{\epsilon}\beta(z)}\right\}dz - L}{\int_0^1 \nu(z)\alpha(z)^2 dz} < \frac{a - 2\sqrt{t\bar{\epsilon}\beta(z)}}{\alpha(z)},$$

or, equivalently,

$$\alpha(z)\int_0^1 \nu(z)\alpha(z)\left\{a - 2\sqrt{t\bar{\epsilon}\beta(z)}\right\}dz - \alpha(z)L < \left[a - 2\sqrt{t\bar{\epsilon}\beta(z)}\right]\int_0^1 \nu(z)\alpha(z)^2 dz.$$

Multiplying both sides of the above inequality by $\nu(z)\sqrt{\beta(z)}$ and integrating it over $z \in [0,1]$, we have

$$\begin{aligned}&\int_0^1 \nu(z)\sqrt{\beta(z)}\alpha(z)dz\int_0^1 \nu(z)\alpha(z)\left\{a - 2\sqrt{t\bar{\epsilon}\beta(z)}\right\}dz - L\int_0^1 \nu(z)\sqrt{\beta(z)}\alpha(z)dz\\ &< \int_0^1 \nu(z)\sqrt{\beta(z)}\left[a - 2\sqrt{t\bar{\epsilon}\beta(z)}\right]dz\int_0^1 \nu(z)\alpha(z)^2 dz,\end{aligned}$$

or, equivalently,

$$2\sqrt{t\bar{\epsilon}}\left\{\int_0^1 \nu(z)\alpha(z)^2 dz\int_0^1 \nu(z)\beta(z)dz - \left[\int_0^1 \nu(z)\alpha(z)\sqrt{\beta(z)}dz\right]^2\right\} < \Delta, \tag{20}$$

where $\Delta$ is defined as in the text. Let $f(z) \equiv \sqrt{\nu(z)}\alpha(z)$ and $g(z) \equiv \sqrt{\nu(z)\beta(z)}$. Then, by the Cauchy–Schwarz inequality for integrals,

$$\int_0^1 \nu(z)\alpha(z)^2 dz\int_0^1 \nu(z)\beta(z)dz \geq \left[\int_0^1 \nu(z)\alpha(z)\sqrt{\beta(z)}dz\right]^2$$

holds, which means that the left-hand side of inequality (20) is nonnegative, and thus, $\Delta > 0$. This completes the proof that $dE/dt < 0$.