Corporate Social Responsibility, Environmental Emissions and Time-Consistent Taxation

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Motivation

- There is an increase in the adoption of voluntary corporate practices by firms that pay attention to consumer welfare, environmental issues, and green production.
- KPMG Survey of Sustainability Reporting 2020:
  - 80% of companies worldwide report on sustainability.
  - 40% of companies acknowledge the financial risks of climate change.
  - Most firms have targets in place to reduce their carbon emissions.
- ESG criteria are a set of standards designed to enhance transparency and accountability within a firm's operations, guiding them towards improved governance, environmental-friendly practices, and social responsibility (United Nations, 2004; 2023).

Motivation: Voluntary corporate decisions adopted by part of the automotive industry

- In 2019, Volvo confirmed the end of its diesel engines in favor of electrification and hybrid solutions to lower emissions.
- In 2020, BMW committed to procuring 100% of its electricity from renewable sources for its operations by 2050.
- Mercedes-Benz is also committed to making its entire passenger car fleet carbon-neutral by the close of 2039.
- In 2019, Volkswagen accelerated plans to electrify its fleet, committing to launch 70 fully electric models by 2028.
- Tesla has become the most valuable automaker by market cap.

See for instance:
www.carthrottle.com/post/volvo-has-finally-confirmed-the-end-of-its-diesel-engines

www.wemeanbusinesscoalition.org/blog/

bmw-joins-growing-list-of-automakers-committed-to-boldclimate-action/

Questions addressed

1. How optimal emission taxation must address CSR motivations?
2. What CSR motivations are better for reducing environmental emissions?

Problem

- We formally model a Cournot duopoly market in which a corporate socially responsible (CSR) firm interacts with a profit-maximizing firm and where the market is regulated with an emission tax.
- We consider three different kinds of CSR firm behaviors:
  - i consumer-friendly.
  - ii environmentally-friendly.
  - iii consumer-environmentally friendly.
- To the best of our knowledge, this work is the first to formally solve a Cournot duopoly analyzing different types of CSR behavior under a time-consistent emission tax.

Related Literature

- Pigouvian taxation: attempt to internalize marginal environmental damage through taxation.
  - Perfect competition: Pigou, 1920. The Economics of Welfare & Baumol, 1972. On taxation and the control of externalities.
  - Monopoly: Barnett, 1980. The Pigouvian tax rule under monopoly.
  - Oligopoly: Simpson, 1995. Optimal pollution taxation in a Cournot duopoly.
- Time-consistent game: Petrakis & Xepapadeas, 2003. Location decisions of a polluting firm and the time consistency of environmental policy.

Related Literature: CSR-firms as consumer-friendly firms

Authors	Title	Year	CSR-firm's objective function
Kim, SL, Lee, SH, & Matsumura, T	Corporate social responsibility and privatization policy in a mixed oligopoly	2019	$U_i = \pi_i + \alpha CS$, where $\alpha_i \in (0, 1)$ represents the CSR level, which is exogenously given. That is, CSR implies the private firm is interested in consumers' surplus in addition to its profit.
García, A, Leal, M & Lee, SH	Time-inconsistent environmental policies with a consumer-friendly firm: Tradable permits versus emission tax	2018	$V_0 = \pi_0 + \theta CS$, where $\theta \in [0, 1]$ measures the degree of concern on consumer surplus that the consumer-friendly firm has, which is exogenously given.
Xu, L & Lee, SH	Corporate Social Responsibility and Environmental Taxation with Endogenous Entry	2018	$G = \pi_0 + \alpha CS$, where $\alpha \in [0, 1]$. They assume that CSR initiative includes both profitability and consumer surplus, as a proxy of its concern for consumers, and thus the objective of the CSR-firm is a combination of consumer surplus and its profit.
Fanti, L & Buccella, D	Corporate social responsibility, profits and welfare with managerial firms	2017	$W_i = \pi_i + kCS$, where $k \in [0, 1]$ denotes the weight that CSR firms assign to consumer surplus.

Related Literature: CSR-firms as consumer-friendly firms

Authors	Title	Year	CSR-firm's objective function
Lambertini, L & Tampieri, A	Incentives, performance and desirability of socially responsible firms in a Cournot oligopoly	2015	$O_c sr = \pi_{csr} - gq_{csr} + zQ^2/2$, where O_{csr} represents the objective function of a firm adopting a CSR statute, gq_{csr} represents environmental damage and $z \in [0, 1]$ denotes the weight that the firm assigns to consumer surplus.
Matsumura, T & Ogawa, A	Corporate Social Responsibility or Payoff Asymmetry? A Study of an Endogenous Timing Game	2014	$V_i = \theta_i SW + (1 - \theta_i)\pi_i$, where $\theta_i \in [0, 1)$, SW is the total social surplus (sum of the firms' profits and consumer surplus), and π_i is firm i's profit.
Goering, G	The Profit-Maximizing Case for Corporate Social Responsibility in a Bilateral Monopoly	2014	$\lambda_r = \pi_r + \gamma CS$, where π_r represents profits plus a given fraction ($\gamma > 0$) of the consumer surplus (CS) of its customers'.
Brand, B & Grothe, M	Social responsibility in a bilateral monopoly	2014	$\nu_i = \pi_i + \theta_i CS$, where θ_i indicates the weight put on consumer surplus.

Related Literature: CSR-firms as environment-friendly firms

Authors	Title	Year	CSR-firm's objective function
Barcena-Ruiz, JC & Sagasta, A	International trade and environmental corporate social responsibility	2022	$V_i = \pi_i - \alpha ED_i$, where ED_i is the cost of factoring environmental considerations into all business activities, with $\alpha \in [0, 1/2]$ is the weight attached to environmental damage.
Xu, L; Chen, Y & Lee, SH	Emission tax and strategic environmental corporate social responsibility in a Cournot–Bertrand comparison	2022	$V_i = \pi_i + \beta ED$, where $\beta_i \in [0, 1]$ is the degree of ECSR (environmental corporate social responsibility).
Fukuda K & Ouchidab Y	Corporate social responsibility (CSR) and the environment: Does CSR increase emissions?	2022	$V = \pi + \theta(CS - D(E))$, where $\theta \in [0, 1]$ is the degree of CSR. $\theta(CS - D(E))$ is called social concern.

The model

- Consider an industry with two polluters: one CSR firm and a profit-maximizing private firm, which competes à la Cournot.
- Total output: $Q = q_0 + q_1$.
- Inverse demand function $f(Q)$.
- Both firms discharge pollution into the environment, d_i, generating $D(d_0, d_1)$ in total environmental damage.
- Total productions costs: $c_i = c(q_i, w_i)$, where w_i represents resources devoted to pollution treatment.
- Two ways of reducing d_i: reduce output q_i, or more resources w_i to the abatement of pollution.
- We also consider a tax on emissions, t, which is chosen by the regulator.

The model

Firms profit function:

$$\pi_i(q_i, w_i) = f(Q)q_i - c(q_i, w_i) - d_i(q_i, w_i)t \qquad (1)$$

In addition, the CSR firm cares not only for its profits but also for a fraction of the consumer surplus, CS, as a proxy of the firm's concern for consumers and/or for environmental damage produced by the duopoly, D, as a proxy of the firm's concern for the environment:

$$\nu_0 = \pi_0 + \theta CS - \gamma D(d_0, d_1) \qquad (2)$$

The interest of the regulator is the social welfare:

$$SW = CS + f(Q)(q_0 + q_1) - c_0 - c_1 - D(d(q_0, w_0), d(q_1, w_1)) \qquad (3)$$

with $CS = \int_0^Q f(z)dz - f(Q)Q$

Some definitions

- **Profit Maximizing Firm (pm)**: The firm has only a profit maximizing objective $\Rightarrow \theta = 0$ and $\gamma = 0$.
- **Consumer friendly Firm (cf)**: Its objective is a combination of consumer surplus, and its profit $\Rightarrow \theta > 0$ and $\gamma = 0$.
- **Environmentally friendly Firm (ef)**: Maximize its material profit minus environmental emissions produced by the duopoly $\Rightarrow \theta = 0$ and $\gamma > 0$.
- **Consumer-Environment friendly Firm (cef)**: Its objective is a combination of consumer surplus, and its profit minus environmental emissions produced by the duopoly $\Rightarrow \theta > 0$ and $\gamma > 0$.

Assumptions

- The inverse demand function $f(Q)$ is twice continuously differentiable, with $\frac{\partial f(Q)}{\partial Q} < 0$ whenever $f(Q) > 0$ and $lim_{Q \to \infty} f(Q) = 0$, with $q_0, q_1 \geq 0$.
- Cost functions $c = c(q_i, w_i)$ $\forall i = 0, 1$ are increasing and twice continuously differentiable.
- The emission level functions $d = d(q_i, w_i)$ and the emissions damage function $D(d(q_0, w_0), d(q_1, w_1))$ $\forall i = 0, 1$ are increasing in production, $\frac{\partial d}{\partial q_i} > 0$ and $\frac{\partial D}{\partial q_i} > 0$ and decreasing in abatement effort, $\frac{\partial d}{\partial w_i} < 0$ and $\frac{\partial D}{\partial w_i} < 0$, and twice continuously differentiable, with $\frac{\partial^2 D}{\partial q_i^2} > 0$ and $\frac{\partial^2 D}{\partial w_i^2} > 0$.

The model

The optimization problem faced by the private firm:

$$\max_{q_1, w_1} \pi_1(q_1, w_1) = f(Q)q_1 - c_1(q_1, w_1) - d_1(q_1, w_1)t \tag{4}$$

The optimization problem faced by the CSR firm:

$$\max_{q_0, w_0} \nu_0(q_0, w_0) = f(Q)q_0 - c_0(q_0, w_0) - d_0(q_0, w_0)t + \theta\left(\int_0^Q f(z)dz - f(Q)(Q)\right) - \gamma D(d_0(q_0, w_0), d_1(q_1, w_1)) \tag{5}$$

The optimization problem faced by the regulator:

$$\max_{t} SW = \int_0^Q f(z)dz - c_0(q_0, w_0) - c_1(q_1, w_1) - D(d_0(q_0, w_0), d_1(q_1, w_1)) \tag{6}$$

The model: Two strategies to solve the problem

1. Simultaneous game (Barnett, 1980).
2. Three-stage sequential game (Petrakis & Xepapadeas, 2003).

The model: Two strategies to solve the problem

1. **Simultaneous game (Barnett, 1980)**.
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The simultaneous game

Definition

A strategy for the regulator is a tax amount $t \geq 0$ and a strategy for the firms is $\rho_i(q_i, w_i)$, where $\rho_i(\cdot)$ is a mapping of the decisions (q_i, w_i). An equilibrium of this simultaneous game is a triplet $(t^*, \rho(q_0^*, w_0^*), \rho(q_1^*, w_1^*))$ such that:

(i) $\pi_1(t^*, \rho(q_0^*, w_0^*), \rho(q_1^*, w_1^*)) \geq \pi_1(t^*, \rho(q_0^*, w_0^*), \rho(q_1, w_1^*))$

(ii) $\pi_1(t^*, \rho(q_0^*, w_0^*), \rho(q_1^*, w_1^*)) \geq \pi_1(t^*, \rho(q_0^*, w_0^*), \rho(q_1^*, w_1))$

(iii) $\nu_0(t^*, \rho(q_0^*, w_0^*), \rho(q_1^*, w_1^*)) \geq \nu_0(t^*, \rho(q_0, w_0^*), \rho(q_1^*, w_1^*))$

(iv) $\nu_0(t^*, \rho(q_0^*, w_0^*), \rho(q_1^*, w_1^*)) \geq \nu_0(t^*, \rho(q_0^*, w_0), \rho(q_1^*, w_1^*))$

(v) $SW(t^*, \rho(q_0^*, w_0^*), \rho(q_1^*, w_1^*)) \geq SW(t, \rho(q_0^*, w_0^*), \rho(q_1^*, w_1^*))$

Some results

The welfare maximizing tax is given by:

$$t^*_{sim} = \frac{(1-\gamma)\,\frac{\partial D}{\partial d_0}\frac{\partial d_0^*}{\partial t} + \frac{\partial D}{\partial d_1}\frac{\partial d_1^*}{\partial t}}{\frac{\partial d_0^*}{\partial t} + \frac{\partial d_1^*}{\partial t}} + \frac{(q_0 - \theta Q)\,\frac{dq_0^*}{dt}\frac{\partial f(Q)}{\partial q_0} + q_1\frac{dq_1^*}{dt}\frac{\partial f(Q)}{\partial q_1}}{\frac{\partial d_0^*}{\partial t} + \frac{\partial d_1^*}{\partial t}} \qquad (7)$$

Some results

Corollary

An increase in parameter θ, which represents the fraction of total consumer surplus that is of concern to the CSR firm, increases the equilibrium Pigouvian tax: $\frac{dt^*_{sim}}{d\theta} = -\frac{Q^* \frac{dq^*_0}{dt} \frac{\partial f(Q^*)}{\partial q_0}}{\frac{\partial d^*_0}{\partial t} + \frac{\partial d^*_1}{\partial t}} > 0$*, while an increase in parameter γ, which measures the CSR firm's degree of concern on environmental emissions, decreases the equilibrium Pigouvian tax:*

$\frac{dt^*_{sim}}{d\gamma} = -\frac{\frac{\partial D^*}{\partial d_0} \frac{\partial d^*_0}{\partial t}}{\left(\frac{\partial d^*_0}{\partial t} + \frac{\partial d^*_1}{\partial t}\right)} < 0.$

Some results

Proposition

In the duopoly setting in which a CSR firm interacts with a profit-maximizing firm, tax comparison for different CSR motivations is as follows:

(i) $t^*_{ef} \leq t^*_{pm} \leq t^*_{cf}$

(ii) $t^*_{ef} \leq t^*_{pm} < t^*_{cef} \leq t^*_{cf}$ whenever $\theta Q \frac{\partial f(Q)}{\partial q_0} \frac{dq^*_0}{dt} + \gamma \frac{\partial D}{\partial d_0} \frac{\partial d^*_0}{\partial t} > 0$

(iii) $t^*_{ef} \leq t^*_{cef} \leq t^*_{pm} \leq t^*_{cf}$ whenever $\theta Q \frac{\partial f(Q)}{\partial q_0} \frac{dq^*_0}{dt} + \gamma \frac{\partial D}{\partial d_0} \frac{\partial d^*_0}{\partial t} \leq 0$

Graphically

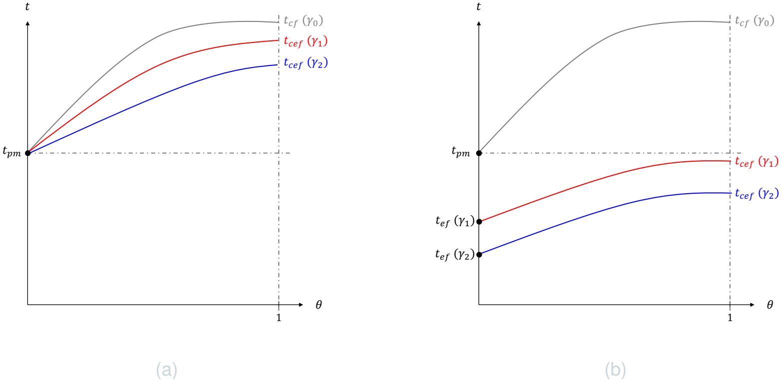


Figure: Optimal Pigouvian Taxes for different CSR motivations ($\gamma_0 = 0 < \gamma_1 < \gamma_2$)

- Panel (a) shows condition (ii) form Proposition.
- Panel (b) shows condition (iii) from Proposition.

The model: Two strategies to solve the problem

1. Simultaneous game (Barnett, 1980).
2. **Three-stage sequential game (Petrakis & Xepapadeas, 2003)**.

The three-stage sequential game

- Time consistent game. Why?
  - Decisions that involve investment – **Abatement** $\Rightarrow$ sunk cost.
  - It is not credible that the regulator will announce its tax policy before knowing the committed abatement investment by the firms.
- Therefore, we model the problem in a three-stage game and we restrict our attention to pure strategies.
  - First stage: the firms decide simultaneously their abatement effort w_i.
  - Second stage: the regulator imposes the tax t.
  - Third stage: the firms decide simultaneously their production level q_i.

The three-stage sequential game

Definition

A strategy for the regulator is a tax amount $t \geq 0$ and a strategy for the firms is $\rho_i(q_i, w_i)$, where $\rho_i(\cdot)$ is a mapping of the decisions (q_i, w_i).

The firms are the first movers with their abatement decision, where an equilibrium is given by:

(i) $\pi_1(\rho_1(q_1^*, w_1^*)) \geq \pi_1(\rho_1(q_1^*, w_1))$
(ii) $\nu_0(\rho_0(q_0^*, w_0*)) \geq v_0(\rho_0(q_0^*, w_0))$

The regulator is a second-mover player, and the equilibrium is such that:

(i) $SW(t^*, \rho_i(q_i^*, w_i)) \geq SW(t, \rho_i(q_i^*, w_i))$

The firms are the third mover with the production decision, where an equilibrium is:

(i) $\pi_1(\rho_1(q_1^*, w_1)) \geq \pi_1(\rho_1(q_1, w_1))$
(ii) $\nu_0(\rho_0(q_0^*, w_0)) \geq \nu_0(\rho_0(q_0, w_0))$

Some results

The SPNE welfare-maximizing tax for the three-stage sequential game is:

$$t^*_{3stage} = \frac{\frac{\partial q_1}{\partial w_1}\left(\frac{\partial c_0}{\partial w_0} + d_0\frac{\partial t}{\partial w_0} + \theta Q\frac{\partial f(Q)}{\partial w_0} + \gamma\frac{\partial D}{\partial w_0} - q_0\frac{\partial f(Q)}{\partial w_0}\right)}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1} - \frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}} - \frac{\frac{\partial q_0}{\partial w_0}\left(\frac{\partial c_1}{\partial w_1} + d_1\frac{\partial t}{\partial w_1} - q_1\frac{\partial f(Q)}{\partial w_1}\right)}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1} - \frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}} \tag{8}$$

Corollary

Whenever $\frac{\frac{\partial q_1}{\partial w_1}}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1}-\frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}} > 0$*, an increase in the fraction of consumer surplus that is concern to the CSR firm,* θ*, will increase the equilibrium Pigouvian tax, that is* $\frac{\partial t^*_{3stage}}{\partial \theta} = \frac{Q\frac{\partial q_1}{\partial w_1}\frac{\partial f(Q)}{\partial w_0}}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1}-\frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}} > 0$ *only when* $\frac{\partial f(Q)}{\partial w_0} > 0$*. On the other hand, an increase in parameter* γ*, the degree of concern on environmental emissions, decreases the equilibrium Pigouvian tax, which means* $\frac{\partial t^*_{3stage}}{\partial \gamma} = \frac{\frac{\partial q_1}{\partial w_1}\frac{\partial D}{\partial w_0}}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1}-\frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}} < 0$*.*

Proposition

Whenever $\frac{\partial q_1}{\partial w_1} > 0$, $\frac{\partial f(Q)}{\partial w_0} > 0$ and $\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1} - \frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0} > 0$, in the three-stage ex-post game in which a CSR firm interacts with a profit-maximizing firm, taxes comparison for different CSR motivations is as follows:

(i) $t^*_{ef} \leq t^*_{pm} \leq t^*_{cf}$

(ii) $t^*_{ef} \leq t^*_{pm} \leq t^*_{cef} \leq t^*_{cf}$ whenever $\theta Q \frac{\partial f(Q)}{\partial w_0} + \gamma \frac{\partial D}{\partial w_0} > 0$

(iii) $t^*_{ef} \leq t^*_{cef} \leq t^*_{pm} \leq t^*_{cf}$ whenever $\theta Q \frac{\partial f(Q)}{\partial w_0} + \gamma \frac{\partial D}{\partial w_0} < 0$

Graphically

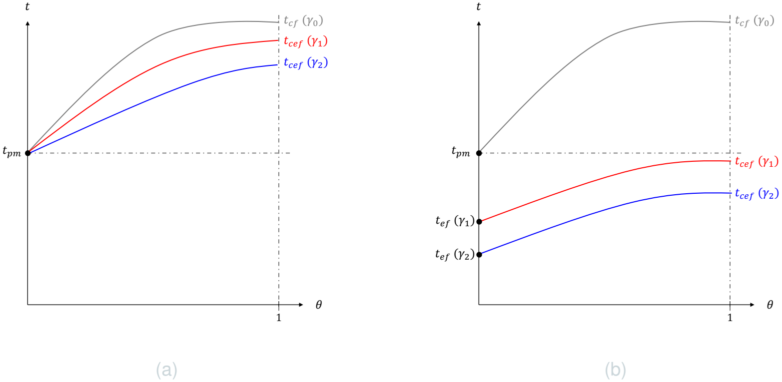


Figure: Optimal Pigouvian Taxes for different CSR motivations
$(\gamma_0 = 0 < \gamma_1 < \gamma_2)$

- Panel (a) shows condition (ii) form Proposition.
- Panel (b) shows condition (iii) from Proposition.

Policy implications

1. Strategic behavior.
2. Price elasticity of demand.

Strategic behavior

Definition (Bulow et al., 1985)

After totally differentiating the first-order conditions, we have that:

- **Substitutes** implies that $\frac{\partial \pi_1}{\partial q_0} < 0 \left(\frac{\partial \nu_0}{\partial q_1} < 0 \right)$, that is, firm's 1 (firm's 0) profitability is less when firm 0 (firm 1) increases its output, q_1 (q_0), (or acts more aggressively). *Strategic substitutes* in turn are defined as $\frac{\partial^2 \pi_1}{\partial q_1 \partial q_0} < 0$ ($\frac{\partial^2 \ \nu_0}{\partial q_0 \partial q_1} < 0$), meaning that the marginal profit of firm 1 is less when firm 0 acts more aggressively.
- **Complements** implies that $\frac{\partial \pi_1}{\partial q_0} > 0$ ($\frac{\partial \nu_0}{\partial q_1} > 0$), that is, firm's 1 (firm's 0) profitability is more when firm 0 (firm 1) increases its output, q_1 (q_0), (or acts more aggressively). *Strategic complements* in turn are defined as $\frac{\partial^2 \pi_1}{\partial q_1 \partial q_0} > 0$ ($\frac{\partial^2 \ \nu_0}{\partial q_0 \partial q_1} > 0$), meaning that the marginal profit of firm 1 is more when firm 0 acts more aggressively.

Strategic behavior

- Solving we know that:

$$q_1 = \frac{\frac{\partial c_1}{\partial q_1} + t\frac{\partial d_1}{\partial q_1} - f(Q)}{\frac{\partial f(Q)}{\partial q_1}} \text{ and } q_0 = \frac{\frac{\partial c_0}{\partial q_0} + t\frac{\partial d_0}{\partial q_0} + \gamma\frac{\partial D}{\partial d_0} - f(Q)}{(1-\theta)\frac{\partial f(Q)}{\partial q_0}} + \frac{\theta}{1-\theta}q_1.$$

- Comparing the reaction functions of firm 0 when $\theta = 0$ and $\gamma = 0$ versus $\theta > 0$ and $\gamma > 0$, it is clear that the firm's output in the first case is higher than in the second case:

$$\frac{\frac{\partial c_0}{\partial q_0} + t\frac{\partial d_0}{\partial q_0} - f(Q)}{\frac{\partial f(Q)}{\partial q_0}} \geq \frac{\frac{\partial c_0}{\partial q_0} + t\frac{\partial d_0}{\partial q_0} + \gamma\frac{\partial D}{\partial d_0} - f(Q)}{(1-\theta)\frac{\partial f(Q)}{\partial q_0}} + \frac{\theta}{1-\theta}q_1.$$

- The response of firm 1 to the behavior of firm 0 is to increase its production: $\frac{\partial q_1}{\partial q_0} = -\frac{\frac{\partial f(Q)}{\partial q_0} + q_1\frac{\partial^2 f(Q)}{\partial q_0 \partial q_1}}{\frac{\partial f(Q)}{\partial q_1}} < 0.$

Price elasticity of demand

Using: $\eta_i = -\frac{f(Q^*)}{q_i^*}\frac{\partial q_i^*}{\partial f(Q^*)}$,

$\frac{\partial f(Q)}{\partial w_i} = \frac{\partial f(Q)}{\partial q_i}\frac{\partial q_i}{\partial w_i}$ and $\frac{\partial D}{\partial w_i} = \frac{\partial D}{\partial d_i}\frac{\partial d_i}{\partial w_i}$, $\forall i = 0, 1$, we can re-write t^* as:

$$t^*_{sim} = \frac{(1-\gamma)\frac{\partial D}{\partial d_0}\frac{\partial d_0^*}{\partial t} + \frac{\partial D}{\partial d_1}\frac{\partial d_1^*}{\partial t}}{\frac{\partial d_0^*}{\partial t} + \frac{\partial d_1^*}{\partial t}} - \frac{\frac{f(Q^*)}{\eta_0}\frac{dq_0^*}{dt} + \frac{f(Q^*)}{\eta_1}\frac{dq_1^*}{dt} + \theta Q\frac{dq_0^*}{dt}\frac{\partial f(Q)}{\partial q_0}}{\frac{\partial d_0^*}{\partial t} + \frac{\partial d_1^*}{\partial t}} \tag{9}$$

$$t^*_{3stage} = \frac{\frac{\partial q_1}{\partial w_1}\left(\frac{\partial c_0}{\partial w_0} + d_0\frac{\partial t}{\partial w_0} + (1-\theta)\frac{f(Q)}{\eta_0}\frac{\partial q_0}{\partial w_0} + \gamma\frac{\partial D}{\partial d_0}\frac{\partial d_0}{\partial w_0}\right)}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1} - \frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}} - \frac{\frac{\partial q_0}{\partial w_0}\left(\frac{\partial c_1}{\partial w_1} + d_1\frac{\partial t}{\partial w_1} + \frac{f(Q)}{\eta_1}\frac{\partial q_1}{\partial w_1}\right)}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1} - \frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}} \tag{10}$$

Perfect elastic demand

	Simultaneous game t^*_{sim}	Three stage game t^*_{3stage}
$\theta = 0$, $\gamma = 0$	$\frac{\partial D}{\partial d_0}$	$\frac{\frac{\partial q_1}{\partial w_1}\left(\frac{\partial c_0}{\partial w_0}+d_0\frac{\partial t}{\partial w_0}\right)-\frac{\partial q_0}{\partial w_0}\left(\frac{\partial c_1}{\partial w_1}+d_1\frac{\partial t}{\partial w_1}\right)}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1}-\frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}}$
$\theta > 0$, $\gamma = 0$	$\frac{\partial D}{\partial d_0}-\frac{\theta Q\frac{dq_0^*}{dt}\frac{\partial f(Q)}{\partial q_0}}{\frac{\partial d_0^*}{\partial t}+\frac{\partial d_1^*}{\partial t}}$	$\frac{\frac{\partial q_1}{\partial w_1}\left(\frac{\partial c_0}{\partial w_0}+d_0\frac{\partial t}{\partial w_0}\right)-\frac{\partial q_0}{\partial w_0}\left(\frac{\partial c_1}{\partial w_1}+d_1\frac{\partial t}{\partial w_1}\right)}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1}-\frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}}$
$\theta = 0$, $\gamma > 0$	$\frac{\partial D}{\partial d_0}-\frac{\gamma\frac{\partial D}{\partial d_0}\frac{\partial d_0^*}{\partial t}}{\frac{\partial d_0^*}{\partial t}+\frac{\partial d_1^*}{\partial t}}$	$\frac{\frac{\partial q_1}{\partial w_1}\left(\frac{\partial c_0}{\partial w_0}+d_0\frac{\partial t}{\partial w_0}+\gamma\frac{\partial D}{\partial d_0}\frac{\partial d_0}{\partial w_0}\right)-\frac{\partial q_0}{\partial w_0}\left(\frac{\partial c_1}{\partial w_1}+d_1\frac{\partial t}{\partial w_1}\right)}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1}-\frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}}$
$\theta > 0$, $\gamma > 0$	$\frac{\partial D}{\partial d_0}-\frac{\gamma\frac{\partial D}{\partial d_0}\frac{\partial d_0^*}{\partial t}+\theta Q\frac{dq_0^*}{dt}\frac{\partial f(Q)}{\partial q_0}}{\frac{\partial d_0^*}{\partial t}+\frac{\partial d_1^*}{\partial t}}$	$\frac{\frac{\partial q_1}{\partial w_1}\left(\frac{\partial c_0}{\partial w_0}+d_0\frac{\partial t}{\partial w_0}+\gamma\frac{\partial D}{\partial d_0}\frac{\partial d_0}{\partial w_0}\right)-\frac{\partial q_0}{\partial w_0}\left(\frac{\partial c_1}{\partial w_1}+d_1\frac{\partial t}{\partial w_1}\right)}{\frac{\partial q_0}{\partial w_0}\frac{\partial d_1}{\partial w_1}-\frac{\partial q_1}{\partial w_1}\frac{\partial d_0}{\partial w_0}}$

Perfect inelastic demand

- When $\eta_0 \rightarrow 0$ and $\eta_1 \rightarrow 0$, the marginal damage will be always greater than the optimal emission tax.
- **Simultaneous game**, $t^*_{sim} \rightarrow -\infty$, independently of the CSR motivations of the firms, which in practice means no taxes ($t^*_{sim} = 0$) or even a subsidy.
- **Three-stage game** $t^*_{3stage} \rightarrow 0$.

Numerical exercise

Using standard function specifications (Petrakis & Xepapadeas, 2003 or Fukuda & Ouchida, 2020):

- $Q = q_0 + q_1$, $f(Q) = a - Q$, $a > 0$.
- $c(q_i, w_i) = cq_i + w^2/2$.
- $d_i(q_i, w_i) = q_i - w_i$.
- $D(q_i, w_i) = d_i(q_i, w_i)^2/2 = (q_i - w_i)^2/2$

Aggregated equilibrium levels for specific CSR motivations for the simultaneous game

	PM $(\theta=0,\gamma=0)$	CF $(\theta=1,\gamma=0)$	EF $(\theta=0,\gamma=1)$	CEF $(\theta=1,\gamma=1)$
t^*	$\frac{7(a-c)}{43}$	$\frac{a-c}{4}$	$\frac{6(a-c)}{59}$	$\frac{2(a-c)}{11}$
Q^*	$\frac{24(a-c)}{43}$	$\frac{3(a-c)}{4}$	$\frac{32(a-c)}{59}$	$\frac{8(a-c)}{11}$
W^*	$\frac{14(a-c)}{43}$	$\frac{a-c}{2}$	$\frac{22(a-c)}{59}$	$\frac{6(a-c)}{11}$
D^*	$\frac{50(a-c)^2}{1849}$	$\frac{(a-c)^2}{32}$	$\frac{50(a-c)^2}{3481}$	$\frac{2(a-c)^2}{121}$
SW^*	$\frac{15(a-c)^2}{43}$	$\frac{3(a-c)^2}{8}$	$\frac{20(a-c)^2}{59}$	$\frac{4(a-c)^2}{11}$

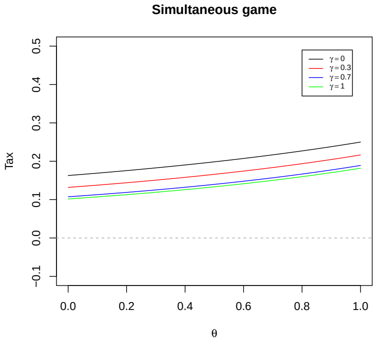
These are the results of a profit-maximizing firm with PM=profit maximizing, CF=Consumer friendly, EF=environmentally friendly, CEF=consumer-environmentally friendly.

Aggregated equilibrium levels for specific CSR motivations for the three-stage game

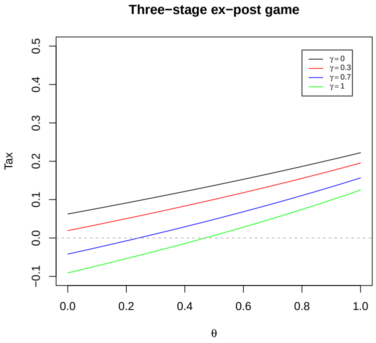
	PM $(\theta = 0, \gamma = 0)$	CF $(\theta = 1, \gamma = 0)$	EF $(\theta = 0, \gamma = 1)$	CEF $(\theta = 1, \gamma = 1)$
t^*	$\frac{a-c}{16}$	$\frac{2(a-c)}{9}$	$-\frac{(a-c)}{11}$	$\frac{a-c}{8}$
Q^*	$\frac{5(a-c)}{8}$	$\frac{7(a-c)}{9}$	$\frac{13(a-c)}{22}$	$\frac{3(a-c)}{4}$
W^*	$\frac{a-c}{4}$	$\frac{5(a-c)}{9}$	$\frac{2(a-c)}{11}$	$\frac{a-c}{2}$
D^*	$\frac{9(a-c)^2}{128}$	$\frac{2(a-c)^2}{81}$	$\frac{81(a-c)^2}{968}$	$\frac{(a-c)^2}{32}$
SW^*	$\frac{11(a-c)^2}{32}$	$\frac{260(a-c)^2}{729}$	$\frac{1313(a-c)^2}{4356}$	$\frac{67(a-c)^2}{200}$

These are the results of a profit-maximizing firm with PM=profit maximizing, CF=Consumer friendly, EF=environmentally friendly, CEF=consumer-environmentally friendly.

Optimal Emission Taxes for different CSR motivations

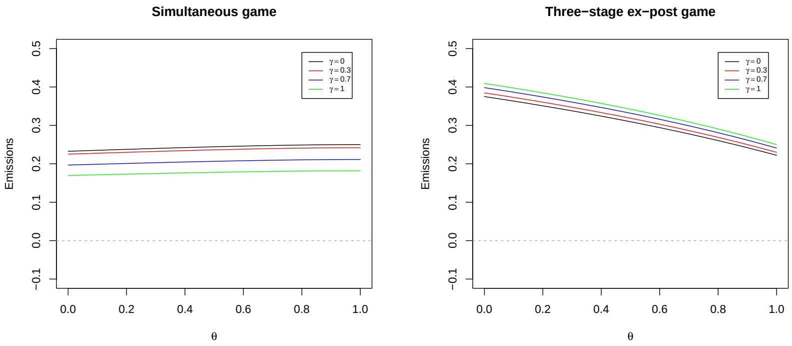


(a)



(b)

Total emissions under different CSR motivations



Concluding remarks

- We found different optimal, welfare enhancing, taxation rules when considering different CSR motivations.
- Using two different settings to model the Cournot duopoly, we found the same behavior in terms of taxation. However, in terms of emissions and environmental damage, the results are mixed.
- Based on the results of the three-stage game, we found that the best motivations for improving the state of the environment are consumer-friendly behavior and not environmentally-friendly firm.
- Our findings are relevant for environmental regulation, as they imply that behavioral biases, caused in this case by non-profit motives, must be considered when designing optimal emission taxes. A potential way to implement this policy could be through reporting and certification of CSR practices. This provides an avenue for future research on the subject.

Next steps

- Can CSR increase international trade?
- Special Issue on Environmental Economics and Economic Dynamics.