Within-Country Leakage due to the Exemption of Small Emitters from Emissions Pricing

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Motivation: Small Emitters Exempted

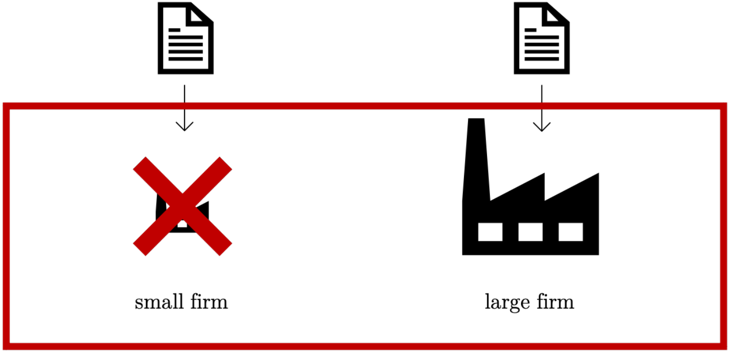
In a world with smaller and larger firms in a sector, ...

small firm

large firm

Motivation: Small Emitters Exempted

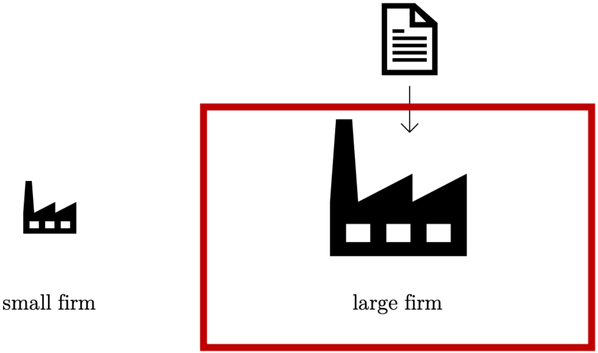
... introducing emissions pricing...



...can push the smaller firms out of the market due to higher fixed costs for monitoring, reporting, and verification of the emissions.

Motivation: Small Emitters Exempted

Hence, some emissions pricing systems only apply to larger emitters.



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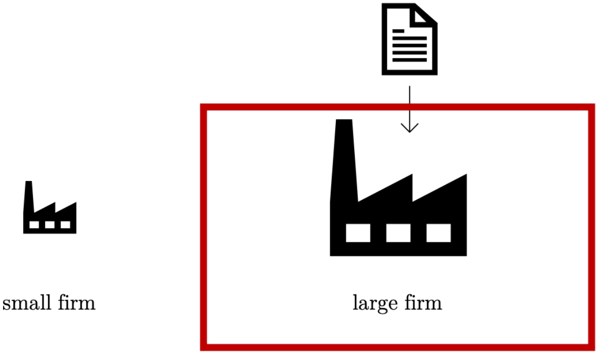

Examples are: Carbon taxes in Singapore, Chile and parts of Canada, and the European Union Emissions Trading System (EU ETS).

Motivation: Carbon Pricing Systems with Regulatory Thresholds

Country	System	Threshold	Within-Sector Coverage
27 EU + IS, LI, NO, GB-NI	ETS	Production capacity, e.g., 20MW thermal power input (combustion), or small emitters 25 000t CO_2e	Unknown
Canada	Mixed (Large Emitter Program)	50 000t CO_2e (most jurisdictions)	Unknown
Chile	Carbon Tax (+ planned ETS)	50MW thermal power generation (combustion) (+ ETS: 25 000t CO_2)	Unknown
Singapore	Carbon Tax	25 000t CO_2e	80%

Table 1: Carbon Pricing Systems in Different Countries

Motivation: EU ETS Cap decreasing - but not the regulatory thresholds

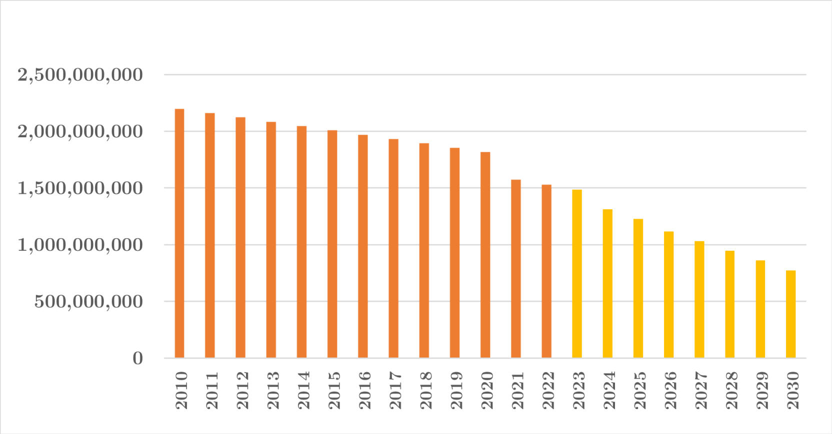

Figure 1: EU ETS number of allowances for stationary installations (w/o maritime and air transport)
(via Glowacki Law Firm, 2021; Umweltbundesamt, 2023)

Table of Contents

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What are the effects on aggregate emissions of the exempted firms?

→ *They increase in the emissions price - leading to within-country leakage.*

Can the exemption be welfare-maximising?

→ *Yes, if the social costs of emissions are low or the fixed costs for monitoring, verification, and reporting are high.*

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Table of Contents

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- **emissions pricing** with fixed and variable costs

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- face the households' **CES utility** (w. one final good Q for simplicity):

$$U = Q = \left[\int_{\omega\in\Omega} q(\omega)^{\frac{\sigma-1}{\sigma}} \mathbf{d}\omega\right]^{\frac{\sigma}{\sigma-1}}$$

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  with $1 < \sigma < \infty$ (σ is substitutability)
- hence, the households' **demand** is: (index firms with ϕ)

$$q(\phi) = QP^{\sigma}p(\phi)^{-\sigma} = RP^{\sigma-1}p(\phi)^{-\sigma}$$

Model Environment - Firms II

- **produce** $q(\phi) = \phi(1 - a(\phi))l(\phi)$
- **emit** $e(\phi) = (1 - a(\phi))^{1/\alpha} l(\phi)$

  with $a(\phi)$ emissions abatement & $l(\phi)$ units of labour (Copeland and Taylor, 2004)

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$$\rightarrow \qquad q(\phi) = \phi e(\phi)^{\alpha} l(\phi)^{1-\alpha}$$

with $\alpha \in (0, 1)$ and $\forall a(\phi) > 0$

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- and **fixed costs** of production: $f = \begin{cases} f_y + f_r & \text{if } \phi \geq \phi_r \\ f_y & \text{if } \phi < \phi_r \end{cases}$

The labour market clears and wages are set as numeraire, $w = 1$.

Firm Behaviour

(1) Firms minimise costs by choosing both input intensities:

$$\frac{e(\phi)}{q(\phi)} = \frac{1}{\phi}\left[\frac{1-\alpha}{\alpha}\frac{h(\phi)}{w}\right]^{\alpha-1}$$
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(2) and maximise their profit such that their price is:

$$p(\phi) = \frac{\sigma}{\sigma-1}\ \frac{1}{\phi}\ \frac{h(\phi)^{\alpha} w^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}$$

details of the optimisation

Regulated firms are cleaner

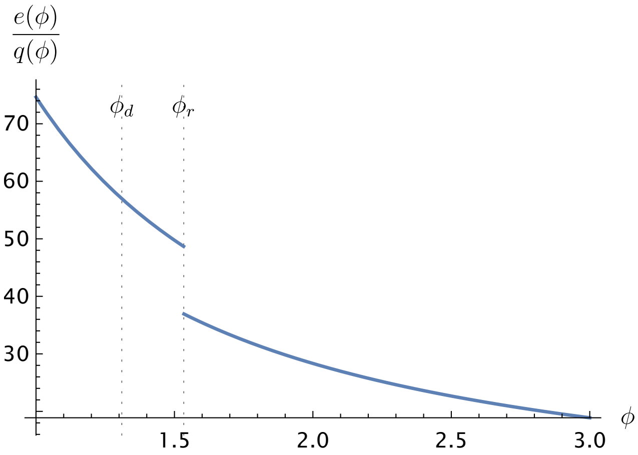

Figure 2: Optimal firm emission intensity along the productivity distribution

Equilibrium: the survival threshold can be found via average profits

(1) Zero Cutoff Profit Condition (ZCP)

Average profits given that the marginal firm at survival threshold just breaks even.

(2) Free Entry Condition (FE)

For firms to enter, the market entry costs must equal the expected profit.

Equilibrium: the survival threshold can be found via average profits

(1) Zero Cutoff Profit Condition (ZCP)

$$\bar{\pi}(\phi_d) = w f_y \left[\frac{\theta}{\theta - \sigma + 1}\eta(p_r) - 1\right] - \underbrace{b w f_r}_{\text{bureaucratic effort of regulation}} \tag{ZCP}$$

$$\text{with } \eta(p_r) = \left(1 - b^{\frac{\theta-\sigma+1}{\theta}}\left[1 - \left(\frac{c_e}{p_r + c_e}\right)^{\alpha(\sigma-1)}\right]\right) \leq 1$$

(2) Free Entry Condition (FE)

$$\bar{\pi}(\phi_d) = \frac{w f_e}{1 - G(\phi_d)} = w f_e \phi_d^{\theta} \tag{FE}$$

Details on the ZCP and FE Conditions

Equilibrium: finding the survival threshold

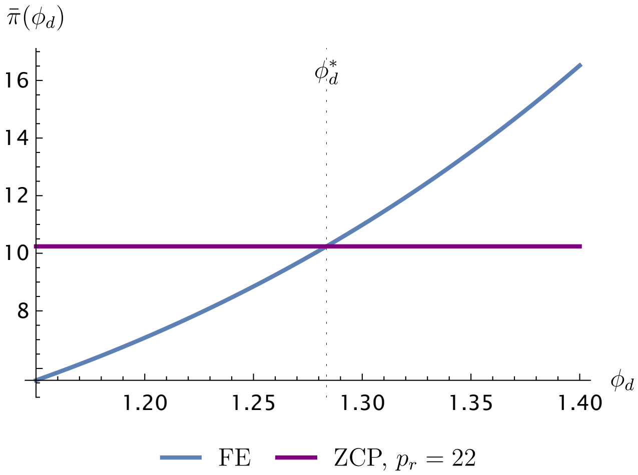

Figure 3: Average profits (in million USD) and the domestic cutoff value

Equilibrium: higher emissions price increases advantage of exempted firms

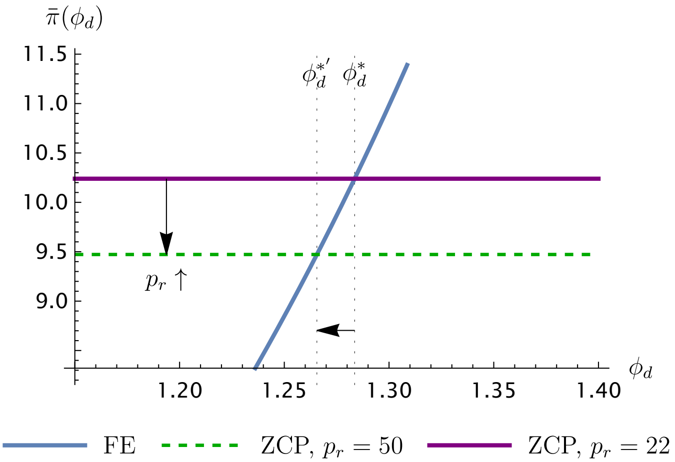

Figure 4: Average profits (in million USD) and the domestic cutoff value

Equilibrium: smaller firms benefit from exemption and survive

from (ZCP) & (FE):

$$\phi_d = \left[\frac{f_y}{f_e}\left(\frac{\theta}{\theta-\sigma+1}\eta(p_r)-1\right)-b\frac{f_r}{f_e}\right]^{\frac{1}{\theta}} \qquad \forall b \in [0,1), \quad \text{with } \frac{\partial \eta(p_r)}{\partial p_r} < 0.$$

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Proposition: *Exempting smaller firms from emissions pricing benefits the lower part of the productivity distribution relatively more such that the firm participation threshold moves down,* ***allowing more unproductive firms to stay in the market****.*

Equilibrium: asymmetry matters

Proposition: *If and only if profits along the firms' productivity distribution are affected asymmetrically, emissions pricing has an effect on firm selection.*

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If all firms are regulated ($b = 1$) or none ($b = 0$):

$$\phi_d = \left[\frac{f}{f_e} \frac{\sigma - 1}{\theta - \sigma + 1} \right]^{\frac{1}{\theta}} \qquad \text{for } b = 0 \vee b = 1,$$

such that the threshold does not depend on the emissions price as in Richter et al. (2021) or Anouliès (2017), Konishi and Tarui (2015).

Aggregation - Revenue Shifting

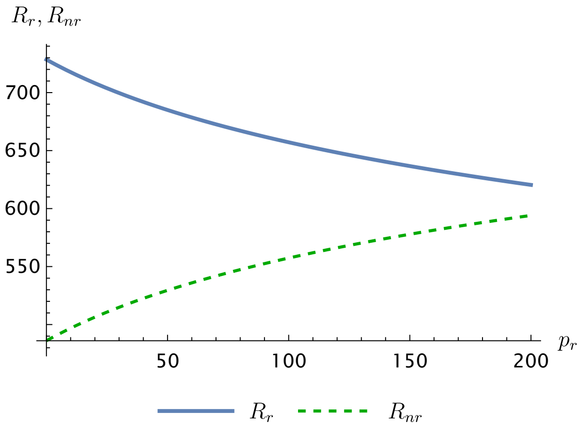

Figure 5: Revenue shifting for an increase in emissions price, here illustrated for $b = 0.2$, in billion USD

Aggregation - Within-Country Leakage

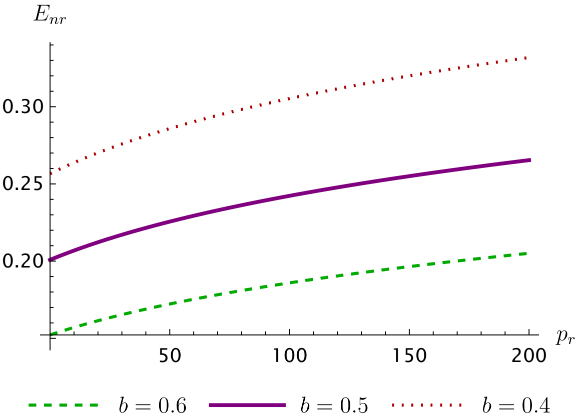

Figure 6: Unregulated firms' emissions and the emissions price for different levels of coverage, in billion tons of CO_2e

Parametrisation Strategy

Manufacturing

based on US manufacturing data

Carbon Tax (w. FA)

based on EU ETS:

- threshold: 25 000tCO2e
- free allocation: s = 0.1

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→ 66.5% of Emissions regulated

Parameter Choices with Sources

Parameter	Description	Value	Source
L	Labour supply	12.79M	U.S. Bureau of Labor Statistics (2023)
w	Wage	\$89 872	U.S. Bureau of Labor Statistics (2023)
b	Share of regulated firms	0.375	own calculation with 66.5% of emissions regulated
α	Energy share in production	0.0678	U.S. Energy Information Administration (2022*a*)
σ	Elasticity of substitution	4.76	Shapiro and Walker (2018)
θ	Firms' productivity homogeneity	5.51	Shapiro and Walker (2018)
c_e	Emissions-related energy costs	\$64	U.S. Energy Information Administration (2022*b*)
p_r	Emissions price	\$22	Trading Economics (2023)
f_y	Operating fixed costs	$\$5.17M/w$	The Boyd Company, Inc. (2021)
f_e	Entry fixed costs	$0.5f_y$	LaPlue (2019)
f_r	Regulation fixed costs	$\$35\,392/w$	Coria and Jaraitė (2019)
f_x	Export fixed costs	$\$5.17M/w$	LaPlue (2019)
τ	Iceberg trade costs	1.3	LaPlue (2019)
$\underline{e}$	Emission threshold	25 000t CO_2e	European Commission (2009)
s	Benchmarking share for free allocation	0.1	European Commission (2021)
SCE	Social Costs of Emissions per ton	\$185	Rennert et al. (2022)

Table 2: Parameter choices, based on 2020 USD values

Table of Contents

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- Free allocation of permits

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- Exporting of goods to foreign market possible

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Alternative Exemption Criterion:

- Emissions threshold for exempting firms

Extension 1: Free Allocation of Permits - higher average profits

Regulated firms don't have to auction all permits; they get $\hat{e}(\phi)$ for free:

$$\pi(\phi|\phi > \phi_r) = \frac{r(\phi)}{\sigma} - w(f_y + f_r) + p_r \underbrace{\hat{e}(\phi)}_{= z\tilde{q}(\phi)}$$

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z: average emission intensity of the s% most productive firms,
$\tilde{q}(\phi)$: output capacity when not regulated.

Extension 1: Free Allocation of Permits - a compensating force

$$\phi_d = \left[\frac{f_y}{f_e} \left(\frac{\theta}{\theta - \sigma + 1} \eta(p_r) - 1 \right) - b \frac{f_r}{f_e} + \underbrace{\rho(p_r) \frac{b^{\frac{\theta - \sigma}{\theta}} s^{\frac{1}{\theta}}}{w f_e}}_{\text{free allocation effect}} \right]^{\frac{1}{\theta}}$$

with $\frac{\partial \eta(p_r)}{\partial p_r} < 0$ and $\frac{\partial \rho(p_r)}{\partial p_r} > 0$.

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$$\text{with } \frac{\partial \eta(p_r)}{\partial p_r} < 0 \text{ and } \frac{\partial \rho(p_r)}{\partial p_r} > 0.$$

$$\text{with } \rho(p_r) = R(\phi_d P)^{\sigma - 1} \frac{\theta^2}{(1+\theta)(\theta - \sigma)} \left(\frac{\sigma}{\sigma - 1} \right)^{-\sigma} p_r \frac{\alpha^{1 - \alpha + \alpha\sigma}}{(p_r + c_e)^{1-\alpha} \; c_e^{\alpha\sigma}} \left(\frac{1 - \alpha}{w} \right)^{(\sigma - 1)(1 - \alpha)}$$

Survival Threshold with Free Allocation

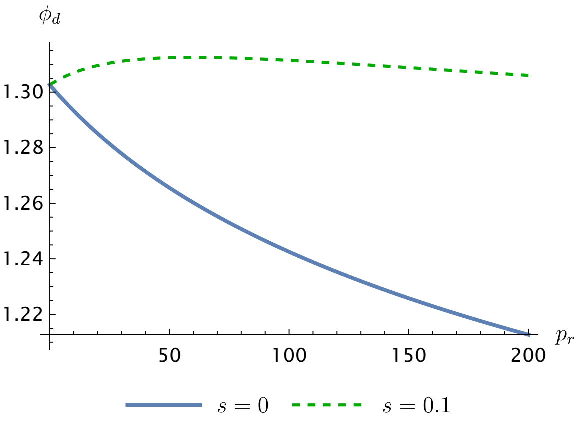

Figure 7: Survival threshold without free allocation ($s = 0$), then adding free allocation based on the emission intensity of the cleanest 10 % of firms ($s = 0.1$)

Extension 2: Opening the Economy

Assuming $\phi_x > \phi_r > \phi_d$, there exist the following two ZCP now:

$$\pi_d(\phi_d) = \frac{r_d(\phi_d)}{\sigma} - wf_y = 0$$

$$\pi_x(\phi_x) = \frac{r_x(\phi_x)}{\sigma} - \underbrace{wf_x}_{\text{(overhead) fixed export costs}} = 0$$

$$\text{with} \quad \underbrace{r_x(\phi)}_{\text{revenue abroad}} = \underbrace{R_j P_j^{\sigma-1}}_{\text{market abroad}} \left(\underbrace{\tau}_{\text{iceberg costs}} \frac{\sigma}{\sigma-1} \frac{1}{\phi} \frac{h(\phi)^{\alpha} w^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}} \right)^{1-\sigma}$$

Extension 2: Opening the Economy - higher average profits

The average profits increase in the chance to export, $\chi(p_r)$:

$$\bar{\pi} = \bar{\pi}_d(\phi_d) + \chi(p_r)\bar{\pi}_x(\phi_x)$$

$$\text{with } \chi(p_r) = \mathcal{P}(\phi \geq \phi_x | \phi \geq \phi_d) = \left(\frac{\phi_d}{\phi_x}\right)^{\theta}$$

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The average profits increase in the chance to export, $\chi(p_r)$:

$$\bar{\pi} = \bar{\pi}_d(\phi_d) + \chi(p_r)\bar{\pi}_x(\phi_x)$$

$$\text{with } \chi(p_r) = \mathcal{P}(\phi \geq \phi_x | \phi \geq \phi_d) = \left(\frac{\phi_d}{\phi_x}\right)^{\theta}$$

With trade, the least efficient firms cannot survive:

$$\phi_d = \left[\frac{f_y}{f_e}\left(\frac{\theta}{\theta - \sigma + 1}\eta(p_r) - 1\right) - b\frac{f_r}{f_e} + \underbrace{\chi(p_r)\frac{\sigma - 1}{1 + \theta - \sigma}\frac{f_x}{f_e}}_{\text{trade effect}}\right]^{\frac{1}{\theta}}$$

with $\frac{\partial \eta(p_r)}{\partial p_r} < 0$ and $\frac{\partial \chi(p_r)}{\partial p_r} < 0$.

Survival Threshold with Free Allocation or Trade

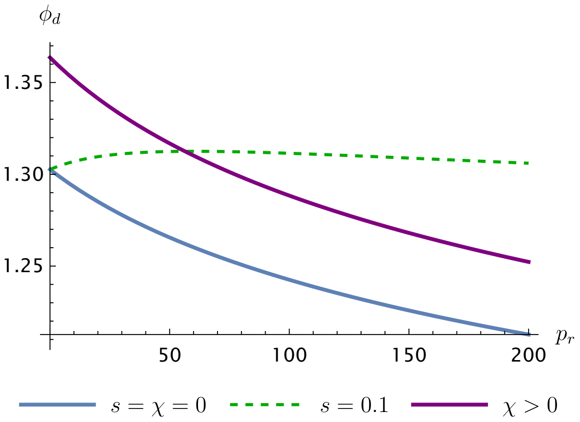
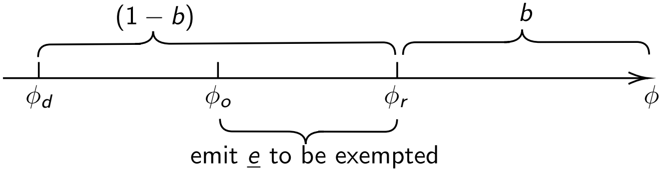
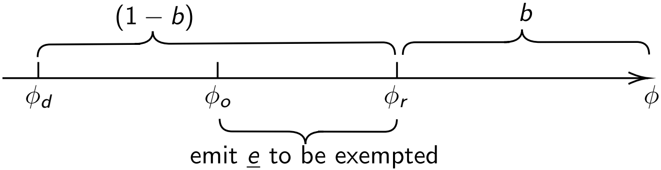


Figure 8: Survival threshold without free allocation/trade ($s = \chi = 0$), then adding free allocation based on the emission intensity of the cleanest 10 % of firms ($s = 0.1$) or trade ($\chi > 0$)

Alternative Exemption Criterion: the Emission Threshold $\underline{e}$

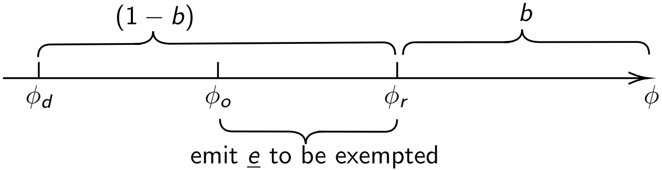




<u>Effects for $p_r \uparrow$:</u>

- as before: more of dirtier firms ($\phi_d \downarrow$)
- new: less regulated firms ($\phi_r \uparrow$)

Alternative Exemption Criterion: the Emission Threshold $\underline{e}$



Effects for $p_r \uparrow$:

- as before: more of dirtier firms ($\phi_d \downarrow$)
- new: less regulated firms ($\phi_r \uparrow$)

$\rightarrow$ within-country leakage even higher

Details

Bunching at the Emission Threshold $\underline{e}$

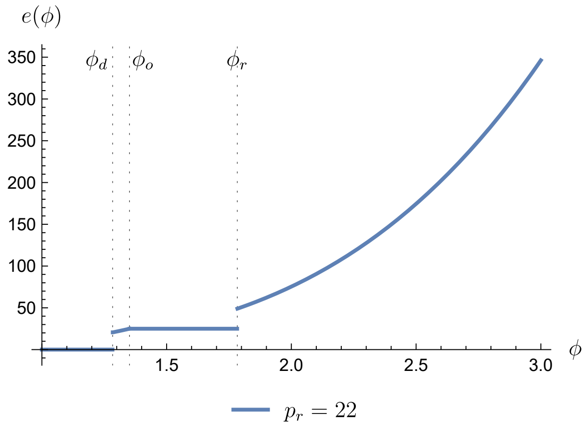


Figure 9: Emissions per firm with an emissions threshold for regulation, in thousand tons of CO_2e

More Bunching at the Emission Threshold $\underline{e}$ for higher p_r

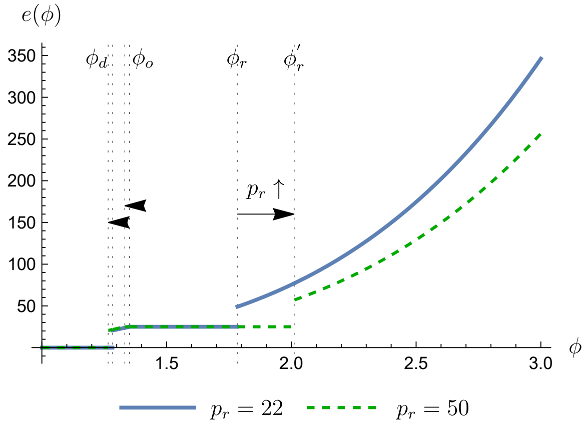


Figure 10: Emissions per firm with an emissions threshold for regulation and a change in emissions prices from 22 to 50, in thousand tons of CO_2e

Table of Contents

Welfare: $W = Q - \frac{SCE}{P}E$

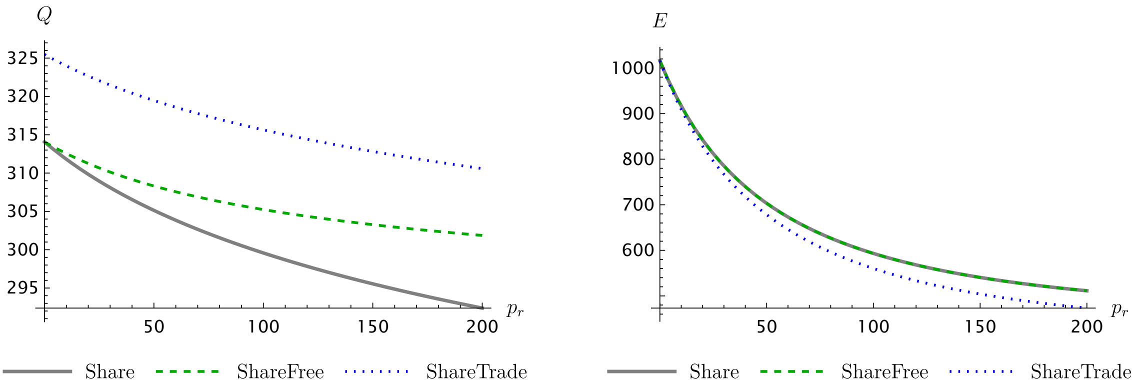


Figure 11: Aggregate Output vs. Emissions, in million utils and in million tons of CO_2e

Welfare: $W = Q - \frac{SCE}{P} E$

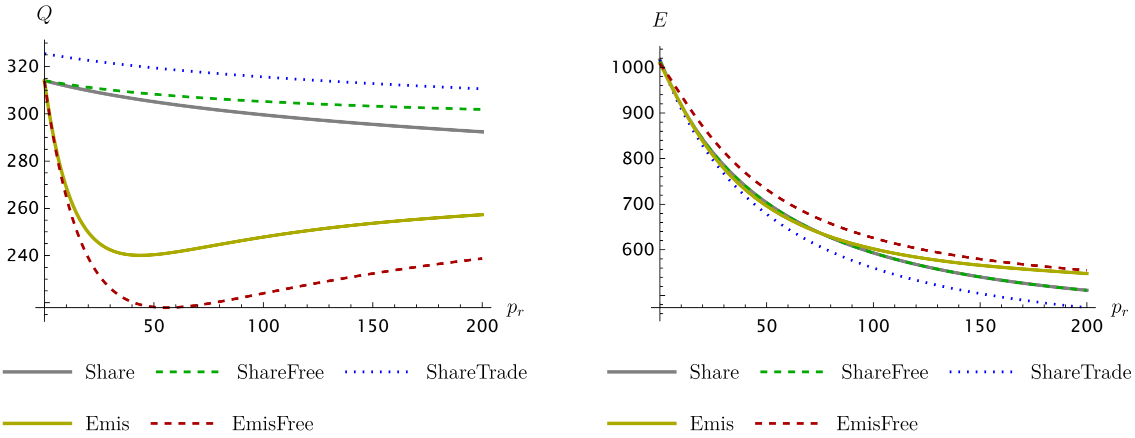


Figure 12: Aggregate Output vs. Emissions, in million utils and in million tons of CO_2e

Welfare convex or concave in p_r, depending on exemption criterion & SCE

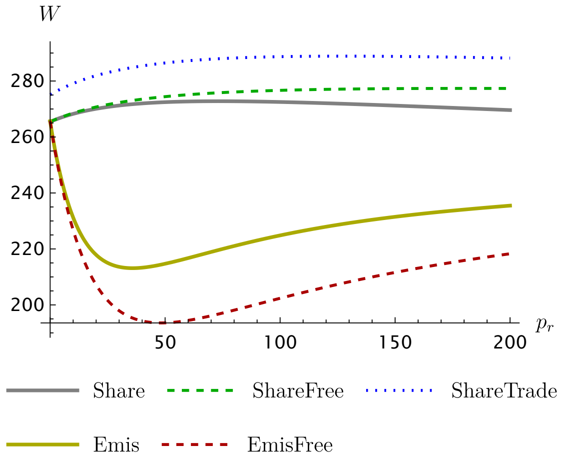


Figure 13: Welfare along different emissions prices, in million utils

Labels Overview

Abbreviation	**Fixed Exemption Criterion**	**Extension**
Share	b share of firms regulated	—
ShareFree	b share of firms regulated	Free permits for regulated
ShareTrade	b share of firms regulated	Exporting goods possible
Emis	$\underline{e}$ emissions threshold	—
EmisFree	$\underline{e}$ emissions threshold	Free permits for regulated

Table 3: Different scenarios considered in the welfare analysis

Survival and Regulation Thresholds

Regulating everyone is best

more: survival more: emission threshold

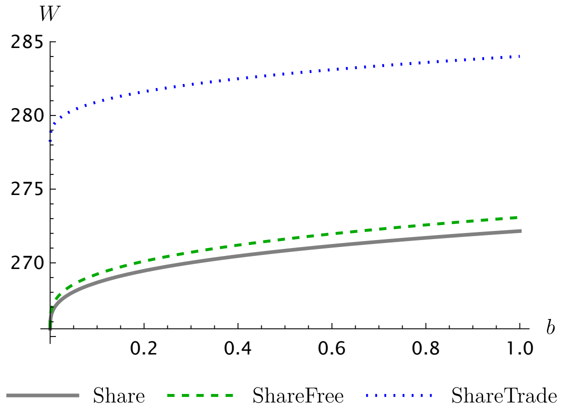


Figure 14: Welfare for different scenarios along different shares of firms being regulated, in million utils

Fixed regulatory costs of $f_r = \$35392/w = 0.39$ are too low

more

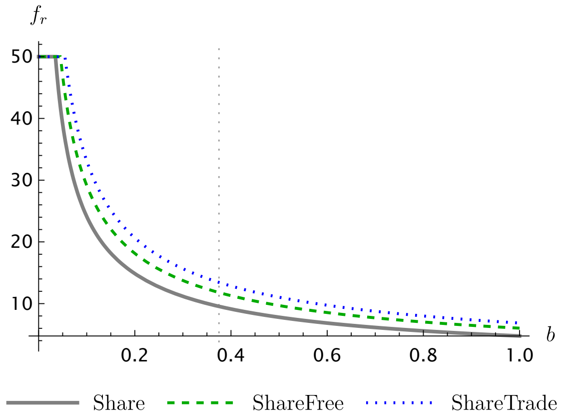


Figure 15: Fixed regulatory costs which make different levels of coverage of firms welfare-maximising, in number of employees (with $b = 0.375$ indicated)

Social Costs of Emissions of $SCE = \$185$ are too high

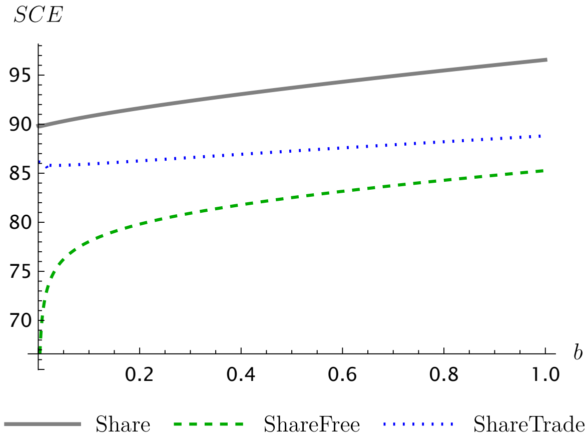


Figure 16: Social Costs of Emissions needed for different levels of coverage b to be welfare-maximising, in USD

Table of Contents

Conclusion

I study the policy of exempting small emitters from emissions pricing.

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It leads to:

- more of the **small, unproductive firms** being able to survive

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- **trade-off** of emission reductions vs. output maximisation for optimal exemption

Conclusion

I study the policy of exempting small emitters from emissions pricing.

<u>It leads to:</u>

- more of the **small, unproductive firms** being able to survive
- **within-country leakage** for a change in emissions price
- **trade-off** of emission reductions vs. output maximisation for optimal exemption

→ **Adjustments** of exemption regulations needed over time.

Thank you!

Thank you for your interest in my work.
I am happy to answer your questions!

(and let's make sure those thresholds are adjusted!)

Points to work on in the future

- examine different industries, in particular w.r.t. **productivity dispersion**
- allow for within-country **leakage between different sectors**: incorporate multiple sectors, as in Shapiro and Walker (2018) or as in Richter et al. (2021)
- get more **data on scope and characteristics** of exempted firms across countries, e.g. size distribution across sectors, countries' policies for exempted firms

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Simplified: Welfare-Maximising Exemption for Emissions Target

Target $\hat{E} = E_{nr} + E_r$

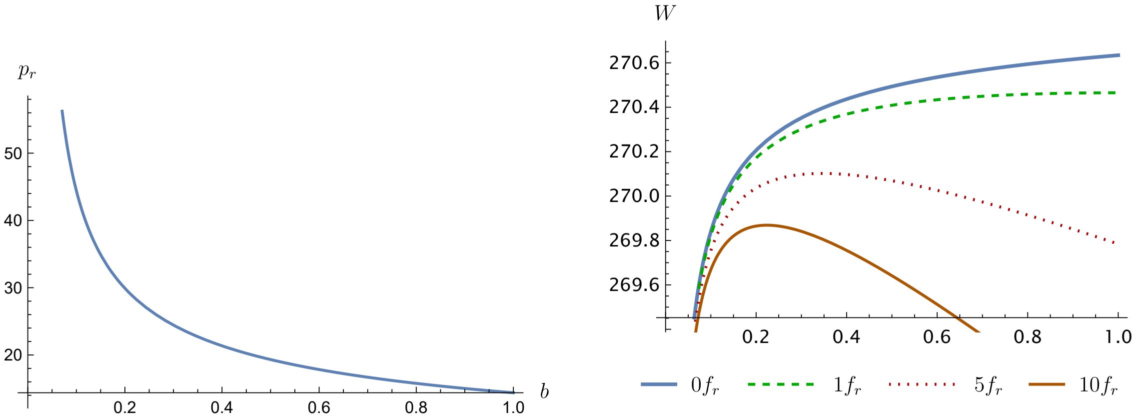


Figure 17: Emissions price, households' utility, and coverage with a binding emissions target

Exempted Firms

For the EU ETS, the exemption is part of a directive such that the application falls under **national implementation.**

- “according to reports submitted in 2015, 8 countries (DE, ES, FR, HR, IS, IT, SI, UK) are making use of this carve-out, especially for installations with combustion activities and ceramics production.” (Glowacki Law Firm, 2021)

  ceramics: many smaller firms
- equivalent measures to be taken by EU member states when exempting

  monitoring, reporting, and verification still needed, both to be approved on EU level
- "Hospitals can be excluded from the EU ETS under Article 27, irrespective of their emissions or thermal capacities.” (Glowacki Law Firm, 2021)

Assumptions

- Monopolistic Competition:
  Prices decreasing in productivity is empirically backed (Shapiro and Walker, 2018), describes love for variety in simple functional way, allows for product heterogeneity
- CES (constant elasticity of substitution) utility function:
  " Research finds that non-CES utility functions, such as the linear demand system, translog utility, and certain generalizations which can allow for endogenous markups can be described as part of the same "gravity" family of models. While this implies that their measures of the gains from trade are closely related, these structures do not always obtain the kind of tractable closed-form relationships we use here (Melitz and Ottaviano 2008, Feenstra and Weinstein 2017, Arkolakis et al. forthcoming)." (Shapiro and Walker, 2018)
- Pareto distribution:
  "Finally, the Pareto technology distribution has plausible theoretical microfoundations (Gabaix, 1999; Luttmer, 2007) and provides a good fit to the empirical firm distribution, at least in the upper tail (Axtell, 2001; Eaton, Kortum, and Kramarz, 2011)." (Shapiro and Walker, 2018)

Details: Behaviour in Autarky I

Households optimise as follows:

$$\min_{q(\omega)} \underbrace{\int_{\omega\in\Omega} p(\omega)q(\omega)\mathbf{d}\omega}_{\text{expenditure}} + \lambda \left(\underbrace{Q - \left[\int_{\omega\in\Omega} q(\omega)^{\frac{\sigma-1}{\sigma}}\mathbf{d}\omega\right]^{\frac{\sigma}{\sigma-1}}}_{\text{for Q units of utility}} \right)$$

$$\rightarrow q(\omega) = QP^{\sigma}p(\omega)^{-\sigma} = RP^{\sigma-1}p(\omega)^{-\sigma}$$

Firms can be indexed with ϕ (instead of ω)
and minimise costs by choosing the following input intensities:

$$\frac{e(\phi)}{q(\phi)} = \frac{1}{\phi}\left[\frac{1-\alpha}{\alpha}\frac{h(\phi)}{w}\right]^{\alpha-1}$$

$$\frac{l(\phi)}{q(\phi)} = \frac{1}{\phi}\left[\frac{1-\alpha}{\alpha}\frac{h(\phi)}{w}\right]^{\alpha}$$

Details: Behaviour in Autarky II

Firms maximise their profit:

$$\pi(\phi) = \underbrace{r(\phi)}_{\text{revenue}} - \underbrace{TC(\phi)}_{\text{total costs}} = [p(\phi) - c(\phi)]\, q(\phi) - wf$$

with $c(\phi) = h(\phi)\frac{e(\phi)}{q(\phi)} + w\frac{l(\phi)}{q(\phi)} = \frac{1}{\phi}\ \frac{h(\phi)^\alpha w^{1-\alpha}}{\alpha^\alpha(1-\alpha)^{1-\alpha}}$

such that their price is:

$$p(\phi) = \frac{\sigma}{\sigma - 1}\ \frac{1}{\phi}\ \frac{h(\phi)^\alpha w^{1-\alpha}}{\alpha^\alpha(1-\alpha)^{1-\alpha}}$$

back

Details: Equilibrium

(1) Zero Cutoff Profit Condition

$$\bar{\pi}(\phi_d) = wf_y \left(\frac{\theta}{\theta - \sigma + 1} \eta(p_r) - 1 \right) - \underbrace{bwf_r}_{\text{bureaucratic effort of regulation}} \tag{1}$$

$$\text{with } \eta(p_r) = \left(1 - b^{\frac{\theta - \sigma + 1}{\theta}} \left[1 - \left(\frac{c_e}{p_r + c_e} \right)^{\alpha(\sigma - 1)} \right] \right) \leq 1$$

(2) Free Entry Condition

$$\bar{\pi}(\phi_d) = \frac{wf_e}{1 - G(\phi_d)} = \underbrace{wf_e}_{\text{entry fee}} \; \phi_d^{\theta} \tag{2}$$

Details: Equilibrium

Zero Cutoff Profit Condition (ZCP)

The threshold for zero profits is ϕ_d, defined via:

$$\pi(\phi_d) = \frac{r(\phi_d)}{\sigma} - wf_y \quad = 0$$

The average profit in the domestic market is:

$$\begin{aligned}\bar{\pi}(\phi_d) &= \int_{\phi_d}^{\phi_r} \pi(\phi)\mu(\phi)\ \mathbf{d}\phi + \int_{\phi_r}^{\infty} \pi(\phi)\mu(\phi)\ \mathbf{d}\phi \qquad \forall b \in [0,1) \\ &= wf_y \left\{ \frac{\theta}{\theta - \sigma + 1} \eta(p_r) - 1 \right\} - \underbrace{b w f_r}_{\text{bureaucratic effort of regulation}} \qquad (3)\end{aligned}$$

$$\text{with } \eta(p_r) = \left(1 - b^{\frac{\theta-\sigma+1}{\theta}} \left[1 - \left(\frac{c_e}{p_r + c_e} \right)^{\alpha(\sigma-1)} \right] \right) \leq 1$$

and $\frac{\partial \bar{\pi}}{\partial \eta(p_r)} > 0$, $\frac{\partial \eta(p_r)}{\partial b} < 0$, $\frac{\partial \eta(p_r)}{\partial p_r} < 0$

Details: Equilibrium

Free Entry Condition (FE)

$$\underbrace{wf_e}_{\text{entry fee}} = \underbrace{\int_{\phi_d}^{\infty} \pi(\phi) g(\phi) \mathbf{d}\phi}_{\text{expected profit}} \tag{4}$$

$$= (1 - G(\phi_d)) \underbrace{\int_{\phi_d}^{\infty} \pi(\phi) \mu(\phi) \mathbf{d}\phi}_{\bar{\pi}(\phi_d)}$$

$$\rightarrow \bar{\pi}(\phi_d) = \frac{wf_e}{1 - G(\phi_d)} = wf_e \phi_d^{\theta} \tag{5}$$

back

Details: Aggregation I

Mass of firms, price level and aggregate resource constraint ($\forall b \in [0,1)$):

$$M = \frac{L}{f_y \eta(p_r)} \frac{1+\theta-\sigma}{\theta(\sigma - \sigma\alpha + \alpha)}$$

$$P = \left(\frac{L}{f_y} \frac{1}{\sigma - \sigma\alpha + \alpha}\right)^{\frac{1}{1-\sigma}} \frac{\sigma}{\sigma - 1} \frac{c_e^{\alpha} w^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}} \phi_d^{-1}$$

$$R = wL + p_r E_r + c_e(E_r + E_{nr})$$

Regulated Firms' Emissions:

A **change in the emissions cap** (for an ETS) directly translates only into a **change in the emissions price**!

$$E_r = \hat{E} = \frac{\left[\frac{c_e}{p_r + c_e}\right]^{\alpha(\sigma-1)+1} b^{\frac{\theta-\sigma+1}{\theta}}}{\eta(p_r)} \frac{wL}{c_e} \frac{\alpha(\sigma-1)}{\sigma - \alpha(\sigma-1)}$$

Details: Aggregation II

Unregulated Firms' Emissions ($\forall b \in [0,1)$)

$$E_{nr} = \frac{\left(1 - b^{\frac{\theta-\sigma+1}{\theta}}\right)}{\left(1 - b^{\frac{\theta-\sigma+1}{\theta}}\right) + \left[\frac{c_e}{p_r + c_e}\right]^{\alpha(\sigma-1)} b^{\frac{\theta-\sigma+1}{\theta}}} \frac{\alpha(\sigma-1)}{\sigma - \alpha(\sigma-1)} \frac{wL}{c_e}$$

back

Details: Fix $\underline{e}$

$$\phi_o: \quad \underline{e} = e(\phi_o) = \frac{q(\phi_o)}{\phi_o}\left[\frac{1-\alpha}{\alpha}\frac{c_e}{w}\right]^{\alpha-1}$$

$$\phi_r: \quad \lim_{\phi\downarrow\phi_r} \pi(\phi) = \lim_{\phi\uparrow\phi_r} \pi(\phi)$$

$$\pi(\phi|\phi \geq \phi_r) = \frac{1}{\sigma}RP^{\sigma-1}\left(\frac{\sigma-1}{\sigma}\,\phi\,\frac{\alpha^\alpha(1-\alpha)^{1-\alpha}}{(c_e+p_r)^\alpha w^{1-\alpha}}\right)^{\sigma-1} - w(f_y+f_r)$$

__Firm Selection:__

$$\underbrace{wf_e\phi_d^\theta}_{\text{FE}} = \underbrace{\int_{\phi_d}^{\phi_o}\pi(\phi)\mu(\phi)\,\mathbf{d}\phi + \int_{\phi_o}^{\phi_r}\pi(\phi)\mu(\phi)\,\mathbf{d}\phi + \int_{\phi_r}^{\infty}\pi(\phi)\mu(\phi)\,\mathbf{d}\phi}_{\text{ZCP}}$$

back

Aggregate Emissions under Extensions back

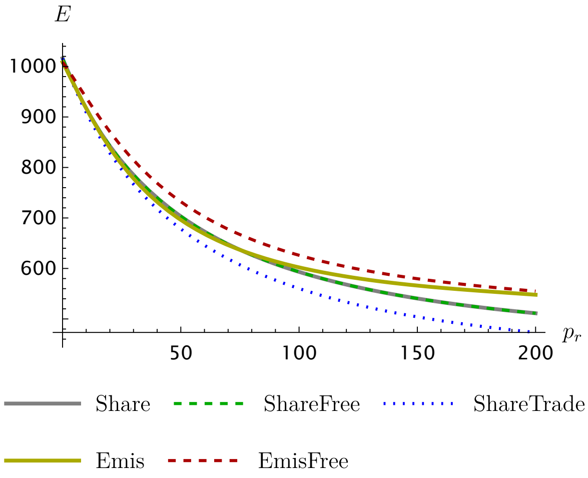


Figure 18: Aggregate Emissions along different emissions prices, in million tons of CO_2e

Aggregate Production under Extensions

back

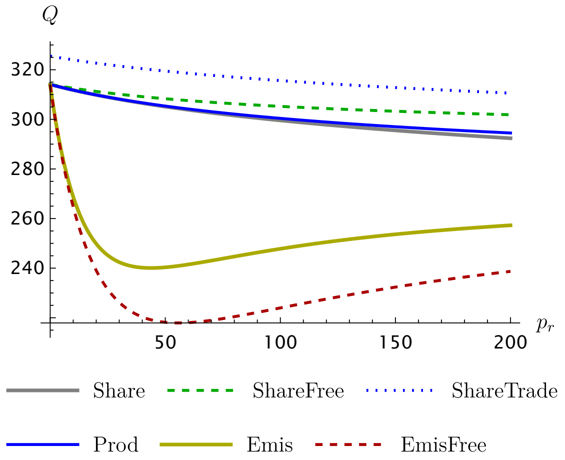
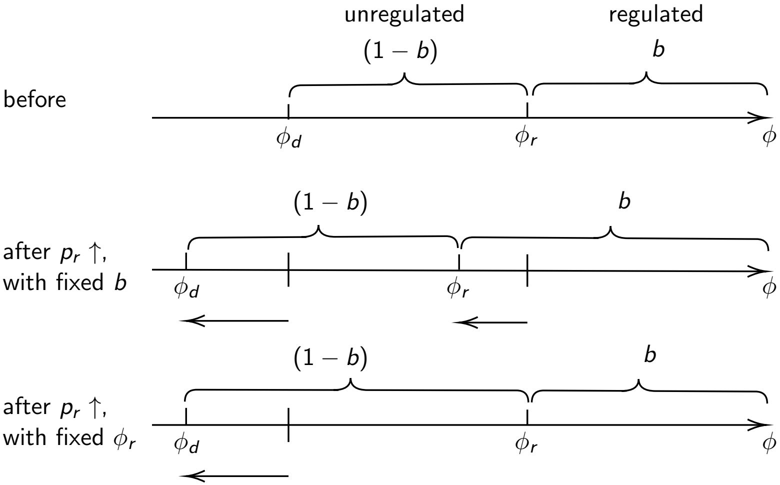


Figure 19: Aggregate Output along different emissions prices, in million utils

Alternative: Fix ϕ_r



Regulation and Survival back

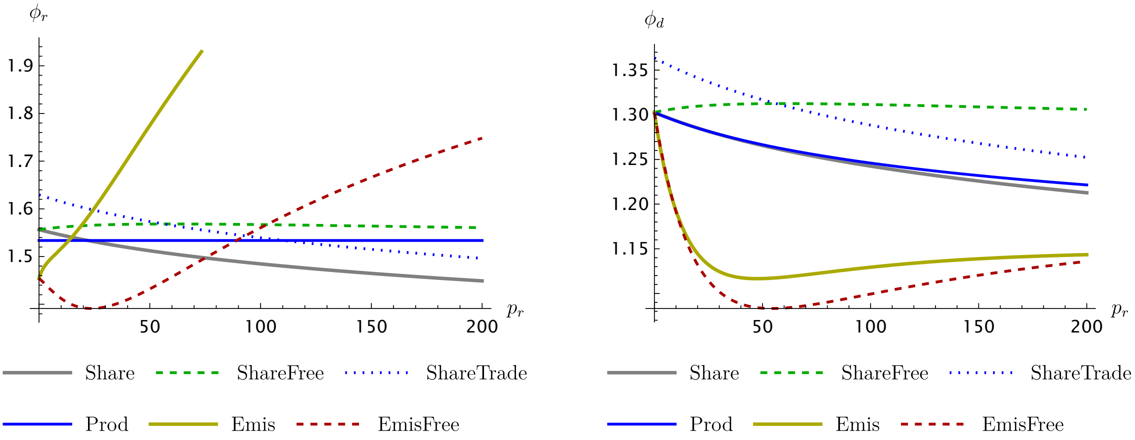


Figure 20: Regulatory and survival thresholds for different scenarios along the emissions price

The smaller the exemption, the bigger the benefit of being exempted back

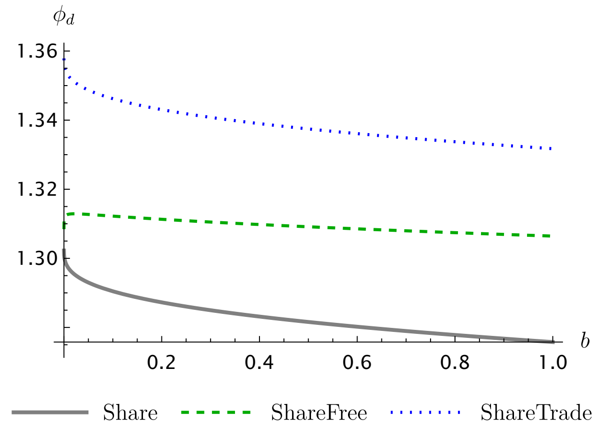


Figure 21: Survival threshold for different shares of regulated firms

The smaller the exemption, the more inefficiencies back

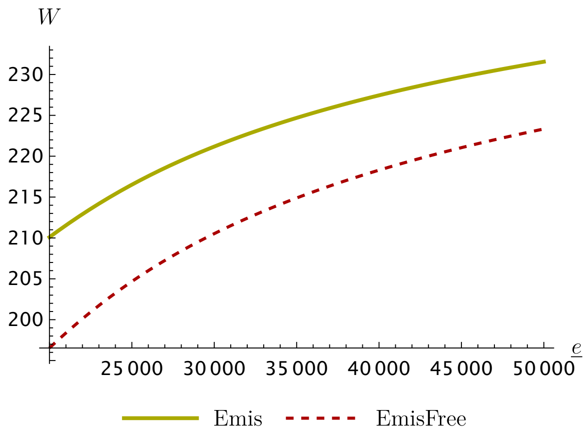


Figure 22: Welfare along different emissions thresholds for regulation, in million utils

The smaller the exemption, the more inefficiencies back

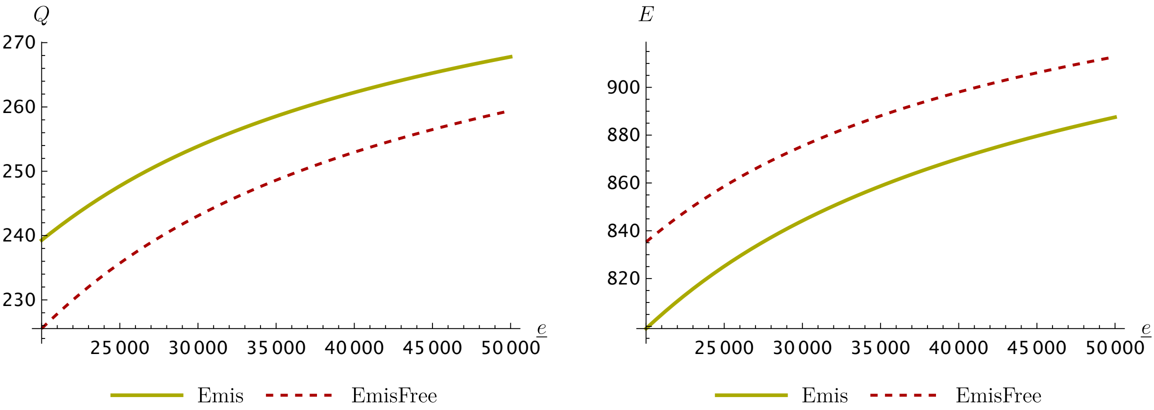


Figure 23: Output and Emissions along different emissions thresholds for regulation, in million utils and CO_2e

Fixed regulatory costs with different implications across scenarios back

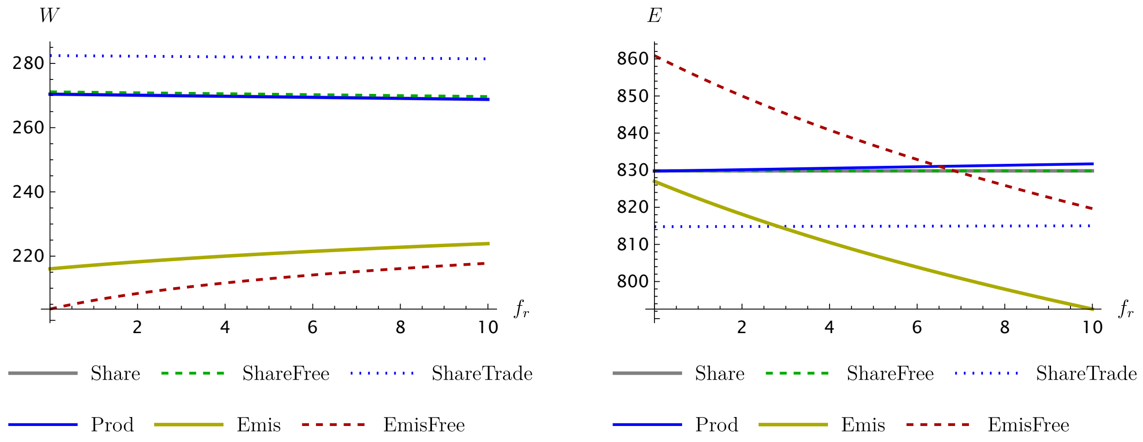


Figure 24: Welfare and Emissions along different levels of regulatory fixed costs, in million utils and CO_2e