Resource Reallocation with Carbon Emission Policies

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Motivation

- Climate crisis intensifies: rising temperatures, extreme weather.

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- Government interventions steer markets towards sustainability.
- Key policies: carbon pricing, renewable subsidies to curb emissions.
- Economic impacts:
  - Limitation in fossil fuel usage.
  - Adoption of renewable technologies.

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  - Limitation in fossil fuel usage.
  - Adoption of renewable technologies.
  - **Reallocation of resources to greener firms/industries.**

Research Question

- **What is the Economic Outcomes of environmental policies due to <u>resources reallocation</u>?**
  - Industry output
  - Firm-level productivity
  - Sector size
  - Emission intensity
  - Total Emission

Literature and Contribution

- Effectiveness of Carbon policies:
  - Martinsson et al. (2024); Shapiro and Walker (2018); Ahmadi, Yamazaki, and Kabore (2022); Andersson (2019)
    Contribution: **Quantify substitution between green and brown capital**

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    Contribution: **Quantify substitution between green and brown capital**
- Misallocation:
  - Whited and Zhao (2021); Hsieh and Klenow (2009); Ai, Li, and Yang (2020); Asker, Collard-Wexler, and De Loecker (2014)
    Contribution: **Misallocation (Reallocation) in the context of environmental policies**

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    Contribution: **Misallocation (Reallocation) in the context of environmental policies**
- Climate Policy Design:
  - Acemoglu, Gancia, and Zilibotti (2012); Acemoglu et al. (2016); Oehmke and Opp (2023)
    Contribution: **Assess alternative instruments in Emission Intensity / resource reallocation trade off**

Road map

1. Develop Economic model with Emission
2. Characterize the allocation of resources
3. Estimate the model by Swedish data
4. Compare the optimal Policy with resource reallocation
5. Discuss the cost of the environmental policies

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Road map

1. Develop Economic model with Emission ✓
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Standard Framework

Hsieh and Klenow (2009)

- Heterogeneous monopolistic competitive firms
- Partial equilibrium
- Cobb-Douglas Production function
- CES aggregator for output
- Normal aggregation of emissions

Extension

Production functions

- Industry s, firm i:

$$Y_{si} = \hat{A}_{si} \hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s}$$

- $\hat{A}_{si}$: total factor of productivity

Firm's profit

Extension

Production functions

- Industry s, firm i:

$$Y_{si} = \hat{A}_{si} \hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s} \quad , \qquad \hat{K} = (\alpha_s G_{si}^{\frac{\gamma_s - 1}{\gamma_s}} + (1-\alpha_s) B_{si}^{\frac{\gamma_s - 1}{\gamma_s}})^{\frac{\gamma_s}{\gamma_s - 1}}$$

$$E_{si} = \tilde{A}_{si} B_{si}$$

Emission General Model

- $\hat{A}_{si}$: total factor of productivity
- α_s: importance of Green capital in the production
- γ_s: elasticity of substitution between Green and Brown capital
- $\tilde{A}_{si}$: emission inefficiency
- Firms maximize over G, B, and L

Firm's profit

Estimation

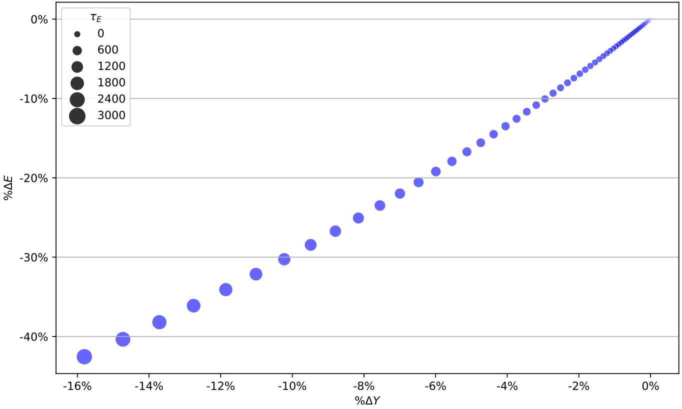
Parameter	Source/Moment
Panel A: Estimation	
α_s	β_G/β_B
β_s	β_G/β_L
σ_s	WL/PY
γ_s	$\beta_{GB}/\beta_B\beta_G$
$Mean(\log(\hat{A}_{si}))$	$Mean(L_{si})$
$Sd(\log(\hat{A}))$	$Sd(L_{si})$
$Mean(\log(\tilde{A}_{si}))$	$Mean(E/PY)$
$Sd(\log(\tilde{A}))$	$Sd(E/PY)$
$Corr(\log(\hat{A}), \log(\tilde{A}))$	$Corr(PY, E/PY)$
Panel B: Additional Moments	
$\left(\frac{\alpha_s}{1-\alpha_s}\frac{(1+\tau_s^B)r_{si}+\tau_s^E\tilde{A}}{(1+\tau_s^G)r_{si}}\right)^{\gamma_s}$	$z_k = G/B$
$\frac{1-\beta}{\beta}\frac{1}{\alpha}\left(\alpha_s + (1-\alpha_s)z_{si}^{k^{-\frac{\gamma_s-1}{\gamma_s}}}\right)^{\frac{1}{\gamma_s-1}}\frac{(1+\tau_s^G)r_{si}}{(1+\tau_s^W)w_{si}}$	$z_l = L/K$
$\gamma\frac{\tilde{A}}{r^B+\tau_E\tilde{A}}z_k$	$\partial z_k/\partial\tau_E$
$\frac{1-\alpha}{\alpha z_{si}^{k^{\frac{\gamma_s-1}{\gamma_s}}}+(1-\alpha)}\frac{\tilde{A}}{r^B+\tau_E\tilde{A}}z_l$	$\partial z_l/\partial\tau_E$
$\frac{\tilde{A}}{r^B+\tau_E\tilde{A}}\left[-\frac{\gamma\alpha}{\circ} - (\frac{w}{\frac{r}{z_l}+w})\frac{1-\alpha}{\triangle}\right]$	$\partial\ln\epsilon/\partial\tau_E$
$\frac{\partial\ln\epsilon/\partial\tau_E}{\frac{1}{\tau_E}+\partial\ln\epsilon/\partial\tau_E}$	$\Delta(\frac{E}{PY})/\Delta(\frac{C}{PY})$
Panel C: Calibration	
r	5%
w	500 TSEK

Calibration

- I just reasonably calibrate the model to match the summary statistics of Martinsson et al. (2024)

Parameter	Value	Source/Moment
Panel A: Estimated Value		
γ	2.48	$\Delta(\frac{E}{PY})/\Delta(\frac{C}{PY})$
$\tilde{A}$	0.002	E/PY
Panel B: Inputs		
σ	5	-
r	5%	-
w	500 TSEK	-
Panel C: Calibrated Value		
β_s	0.6	Martinsson et al. (2024)
α_s	0.25	G/B, Wiedemann (2023)

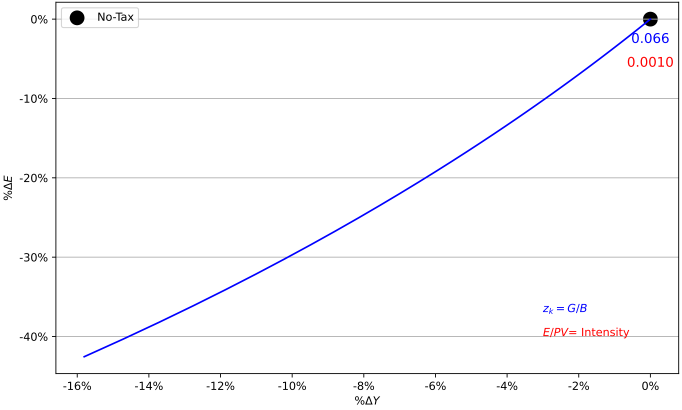
Sensitivity of α

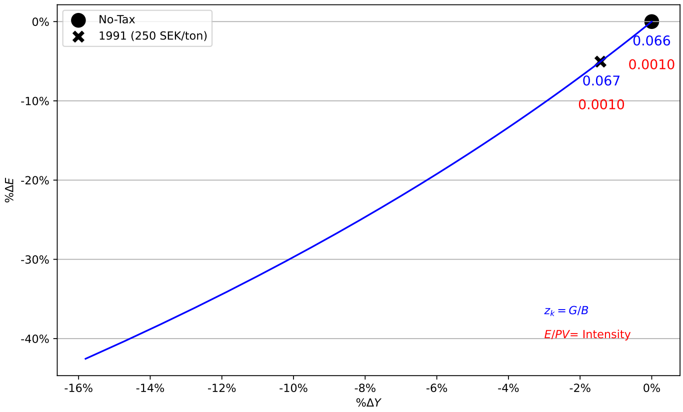


τ_E
0
600
1200
1800
2400
3000
0%
-10%
-20%
-30%
-40%
%ΔE
-16%
-14%
-12%
-10%
-8%
-6%
-4%
-2%
0%
%ΔY

Emission and Production

Results

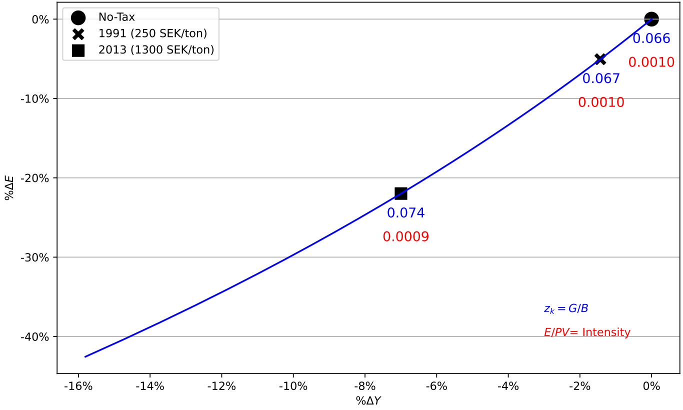




No-Tax
1991 (250 SEK/ton)
0%
-10%
-20%
-30%
-40%
%ΔE
-16%
-14%
-12%
-10%
-8%
-6%
-4%
-2%
0%
%ΔY
0.066
0.0010
0.067
0.0010
$z_k = G/B$
E/PV= Intensity

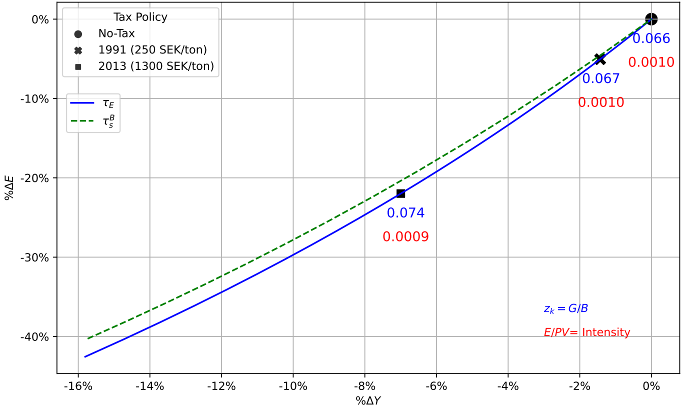
Emission and Production

Results



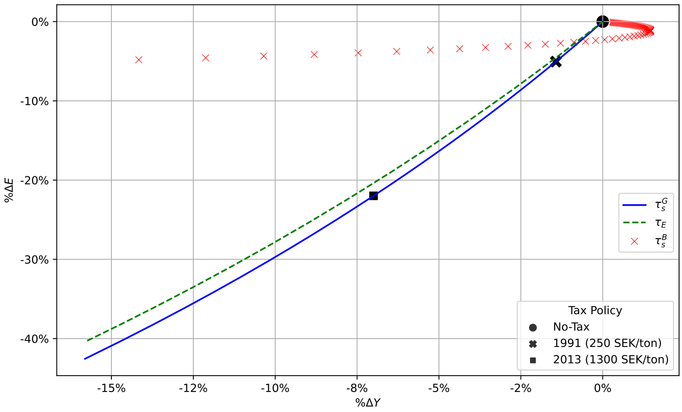
Emission and Production

Results



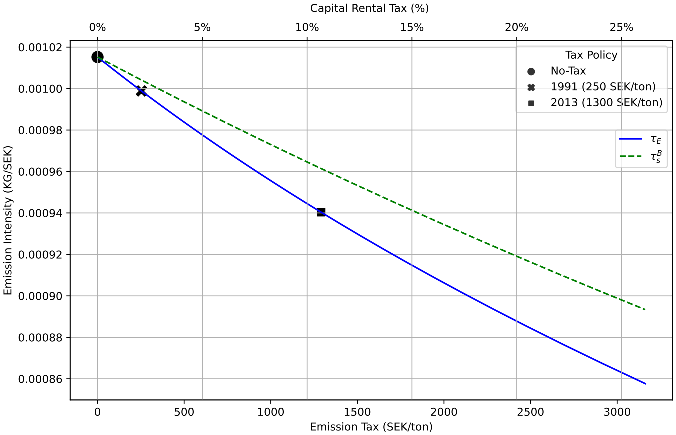
Emission and Production

Results



Carbon Intensity and Tax

Counterfactual



τ_E	τ_G	τ_B
100	9 %	2 %
250	18 %	2 %
500	27 %	4 %
1300	42 %	12 %
3000	55 %	26 %

Future Steps

1. Develop Economic model with Emission
    - Firms could R&D
    - Add Household and Government
    - Firms could enter and exit the market
2. Characterize the allocation of resources
3. Provide a definition of Green and Brown capital
4. Estimate the model by Swedish data
5. Compare the optimal Policy with resource reallocation
6. Discuss the cost of the environmental policies

Thank you!

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Emission General Model

- The firm's emission is:

$$E_{si} = \tilde{A}_{si}\tilde{K}_{si}^{\theta_s} L_{si}^{1-\theta_s} \quad , \qquad \tilde{K} = (\mu_s G_{si}^{\frac{\eta_s - 1}{\eta_s}} + (1-\mu_s) B_{si}^{\frac{\eta_s - 1}{\eta_s}})^{\frac{\eta_s}{\eta_s - 1}}$$

- The nominal profit for firms:

$$\pi_{si} = (1+\tau_{si}^{p}) P_{si} Y_{si} - ([(1+\tau_{G_s}) r_{si} G_{si} + (1+\tau_{B_s}) r_{si} B_{si} + (1+\tau_{l_s}) w_{si} l_{si}] + \tau_E E_{si})$$

Back

Firm's profit

- The nominal profit for firms:

$$\pi_{si} = (1 + \tau_s^p) P_{si} Y_{si}$$

- where
  - τ_s^p is the tax / Demand preference for the firm

Back

Firm's profit

- The nominal profit for firms:

$$\pi_{si} = (1 + \tau_s^p) P_{si} Y_{si} - \Big((1 + \tau_s^G) r_s G_{si} \Big)$$

- where
  - τ_s^p is the tax / Demand preference for the firm
  - τ_s^G is the Green capital subsidy / ESG preference of Financier

Back

Firm's profit

- The nominal profit for firms:

$$\pi_{si} = (1 + \tau_s^p) P_{si} Y_{si} - \Big((1 + \tau_s^G) r_s G_{si} + (1 + \tau_s^B) r_s B_{si} \Big)$$

- where
  - τ_s^p is the tax / Demand preference for the firm
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  - τ_s^B is the Brown capital tax / ESG preference of Financier

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  - τ_s^p is the tax / Demand preference for the firm
  - τ_s^G is the Green capital subsidy / ESG preference of Financier
  - τ_s^B is the Brown capital tax / ESG preference of Financier
  - τ_s^W is the Labor market preference to work in the green/brown sector (Krueger, Metzger, and Wu, 2023)
- The firm chooses the optimal capital and labor to minimize the cost of production and then chooses the price level to maximize the profit

Back

Firm Decision

$$\max_{G_{si}, B_{si}, L_{si}} \quad -Cost \quad \text{s.t.} \quad \hat{A}_{si} \hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

General Model Solution

Firm Decision

$$\max_{G_{si}, B_{si}, L_{si}} \quad -Cost \quad \text{s.t.} \qquad \hat{A}_{si} \hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

$$\frac{G_{si}}{B_{si}} = z_{si}^{k}$$

General Model Solution

Firm Decision

$$\max_{G_{si}, B_{si}, L_{si}} \quad -Cost \quad \text{s.t.} \quad \hat{A}_{si} \hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

$$\frac{G_{si}}{B_{si}} = z_{si}^{k} = \left(\frac{\alpha_s}{1-\alpha_s} \frac{(1+\tau_s^B) r_s + \tau_s^E \tilde{A}}{(1+\tau_s^G) r_s} \right)^{\gamma_s}$$

General Model Solution

Firm Decision

$$\max_{G_{si},B_{si},L_{si}} \quad -Cost \quad \text{s.t.} \quad \hat{A}_{si}\hat{K}_{si}^{\beta_s}L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

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$$\frac{L_{si}}{\hat{K}_{si}} = z_{si}^{l}$$

General Model Solution

Firm Decision

$$\max_{G_{si}, B_{si}, L_{si}} \quad -Cost \quad \text{s.t.} \quad \hat{A}_{si} \hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

$$\frac{G_{si}}{B_{si}} = z_{si}^{k} = \left(\frac{\alpha_s}{1-\alpha_s} \frac{(1+\tau_s^B) r_s + \tau_s^E \tilde{A}}{(1+\tau_s^G) r_s} \right)^{\gamma_s}$$

$$\frac{L_{si}}{\hat{K}_{si}} = z_{si}^{l} = \frac{1-\beta}{\beta} \frac{1}{\alpha_s} \left(\alpha_s + (1-\alpha_s) z_{si}^{k^{-\frac{\gamma_s - 1}{\gamma_s}}} \right)^{\frac{1}{1-\gamma_s}} \frac{(1+\tau_s^G) r_s}{(1+\tau_s^W) w_{si}}$$

General Model Solution

Firm Decision

$$\max_{G_{si}, B_{si}, L_{si}} \quad -Cost \quad \text{s.t.} \qquad \hat{A}_{si} \hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

$$\frac{G_{si}}{B_{si}} = z_{si}^k = \left(\frac{\alpha_s}{1-\alpha_s} \frac{(1+\tau_s^B) r_s + \tau_s^E \tilde{A}}{(1+\tau_s^G) r_s} \right)^{\gamma_s}$$

$$\frac{L_{si}}{\hat{K}_{si}} = z_{si}^l = \frac{1-\beta}{\beta} \frac{1}{\alpha_s} \left(\alpha_s + (1-\alpha_s) z_{si}^{k^{-\frac{\gamma_s - 1}{\gamma_s}}} \right)^{\frac{1}{1-\gamma_s}} \frac{(1+\tau_s^G) r_s}{(1+\tau_s^W) w_{si}}$$

$$E_{si} = \frac{\tilde{A}_{si}}{\hat{A}_{si}} \left(\alpha_s z_{si}^{k^{\gamma_s - 1}} + (1-\alpha_s) \right)^{\frac{\gamma_s}{1-\gamma_s}} z_{si}^{l^{1-\beta}} \bar{Y}_{si}$$

General Model Solution

Firm Decision

$$\max_{G_{si}, B_{si}, L_{si}} \quad -Cost \quad \text{s.t.} \qquad \hat{A}_{si}\hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

$$\frac{G_{si}}{B_{si}} = z_{si}^{k} = \left(\frac{\alpha_s}{1-\alpha_s} \frac{(1+\tau_s^B) r_s + \tau_s^E \tilde{A}}{(1+\tau_s^G) r_s} \right)^{\gamma_s}$$

$$\frac{L_{si}}{\hat{K}_{si}} = z_{si}^{l} = \frac{1-\beta}{\beta} \frac{1}{\alpha_s} \left(\alpha_s + (1-\alpha_s) {z_{si}^{k}}^{-\frac{\gamma_s - 1}{\gamma_s}} \right)^{\frac{1}{1-\gamma_s}} \frac{(1+\tau_s^G) r_s}{(1+\tau_s^W) w_{si}}$$

$$E_{si} = \frac{\tilde{A}_{si}}{\hat{A}_{si}} \left(\alpha_s {z_{si}^{k}}^{\gamma_s - 1} + (1-\alpha_s) \right)^{\frac{\gamma_s}{1-\gamma_s}} {z_{si}^{l}}^{1-\beta} \bar{Y}_{si} = \psi_{si} \bar{Y}_{si}$$

General Model Solution

Firm Decision

$$\max_{G_{si}, B_{si}, L_{si}} \quad -Cost \quad \text{s.t.} \quad \hat{A}_{si} \hat{K}_{si}^{\beta_s} L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

$$\frac{G_{si}}{B_{si}} = z_{si}^{k} = \left(\frac{\alpha_s}{1-\alpha_s} \frac{(1+\tau_s^B) r_s + \tau_s^E \tilde{A}}{(1+\tau_s^G) r_s} \right)^{\gamma_s}$$

$$\frac{L_{si}}{\hat{K}_{si}} = z_{si}^{l} = \frac{1-\beta}{\beta} \frac{1}{\alpha_s} \left(\alpha_s + (1-\alpha_s) z_{si}^{k^{-\frac{\gamma_s - 1}{\gamma_s}}} \right)^{\frac{1}{1-\gamma_s}} \frac{(1+\tau_s^G) r_s}{(1+\tau_s^W) w_{si}}$$

$$E_{si} = \frac{\tilde{A}_{si}}{\hat{A}_{si}} \left(\alpha_s z_{si}^{k^{\gamma_s - 1}} + (1-\alpha_s) \right)^{\frac{\gamma_s}{1-\gamma_s}} z_{si}^{l^{\,1-\beta}} \bar{Y}_{si} = \psi_{si} \bar{Y}_{si}$$

- Firm will then charge markup over the marginal cost

General Model Solution

$$\max \quad -Cost \quad \text{s.t.} \qquad \hat{A}_{si}\hat{K}_{si}^{\beta_s}L_{si}^{1-\beta_s} = \bar{Y}_{si}$$

$$z_{si}^{k} \equiv \frac{G_{si}}{B_{si}} = \left[\frac{\alpha_s}{1-\alpha_s}\frac{\frac{\partial}{\partial B}Cost_{si}}{\frac{\partial}{\partial G}Cost_{si}}\right]^{\gamma_s}$$

$$z_{si}^{l} \equiv \frac{L_{si}}{\hat{K}_{si}} = \frac{1-\beta_s}{\beta_s}\frac{1}{1-\alpha_s}(\alpha_s z_{si}^{k\,(\gamma_s-1)} + (1-\alpha_s))^{\frac{1}{1-\gamma_s}}\frac{\frac{\partial}{\partial B}Cost_{si}}{\frac{\partial}{\partial L}Cost_{si}}$$

$$= \frac{1-\beta_s}{\beta_s}\frac{1}{\alpha_s}(\alpha_s + (1-\alpha_s)z_{si}^{k\,(1-\gamma_s)})^{\frac{1}{1-\gamma_s}}\frac{\frac{\partial}{\partial G}Cost_{si}}{\frac{\partial}{\partial L}Cost_{si}}$$

$$E_{si} = \frac{\tilde{A}_{si}}{\hat{A}_{si}}\left(\frac{\phi_{si}}{z_{si}^{l}}\right)^{\theta_s} {z_{si}^{l}}^{\beta_s}\bar{Y}_{si} = \psi_{si}\bar{Y}_{si}, \quad \text{where} \quad \phi_{si} = \frac{(\mu_s + (1-\mu_s)z_{si}^{k\,(1-\eta_s)})^{\frac{\eta_s}{\eta_s-1}}}{(\alpha_s + (1-\alpha_s)z_{si}^{k\,(1-\gamma_s)})^{\frac{\gamma_s}{\gamma_s-1}}}$$

Back

Model

Optimal firm level price

- Now Firm need to choose the price level to maximize the profit:

$$\max_{P_{si}} \quad \pi_{si} = P_{si} F_{si} - C_{si} F_{si}$$

- Firm-level real output is a function of the sector price, firm price, and sector real output (i.e. $F_{si} = (\frac{P_s}{P_{si}})^{\sigma_s} F_s$)
- Therefore, because the optimal ratio does not depend on the price, the ratio can be maximized out of the problem of the optimal determination of the price, leaving the firm's real output as just a function of price

$$P_{si} = \frac{1}{1+\tau^{p}_{si}} \frac{\sigma_s}{\sigma_s - 1} C_{si}$$

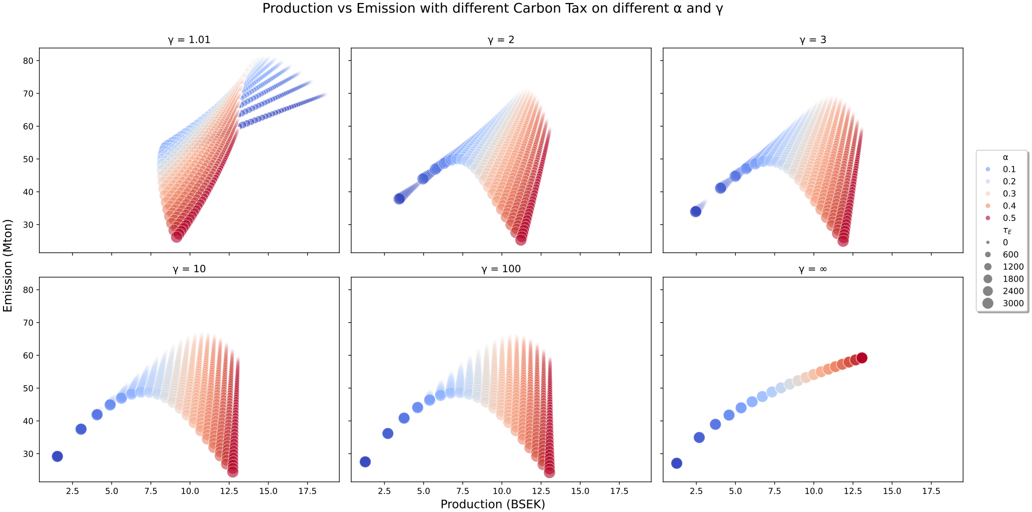
Estimation / Calibration

- My goal is to estimate the parameters sector by sector for Sweden
- I just reasonably calibrate the model to match the summary statistics of Martinsson et al. (2024)

Parameter	**Value**	**Source/Moment**
Panel A: Inputs		
σ	∞	Fully competitive
r	5%	-
w	500 TSEK	-
L	250 (sd = 900)	Martinsson et al. (2024)
Panel B: Calibrated Value		
β_s	0.6	Martinsson et al. (2024)
α_s	0.25	G/B, Wiedemann (2023)
Panel C: Estimated Value		
γ	2.48	$\Delta(\frac{E}{PY})/\Delta(\frac{C}{PY})$
$\tilde{A}$	0.002	E/PY

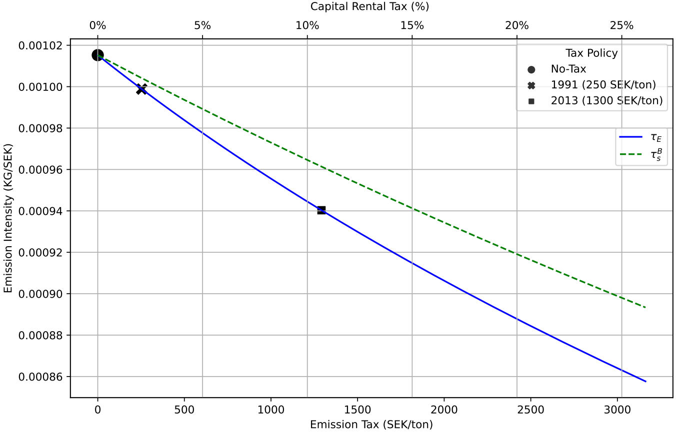
Sensitivity of α Back

Sensitivity analysis



Carbon Intensity and Tax

Counterfactual



τ_E	τ_G	τ_B
100	9 %	2 %
250	18 %	2 %
500	27 %	4 %
1300	42 %	12 %
3000	55 %	26 %

Emission and Production

- Now, we need to find the optimal allocation of resources in the economy under two scenarios:

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Reallocation
Resources allocation

- Now, we need to find the optimal allocation of resources in the economy under two scenarios:

$$\hat{L}_{si} = \frac{\hat{A}_{si}^{\sigma-1}}{\sum_j \hat{A}_{sj}^{\sigma-1}} L_s$$

$$\hat{G}_{si} = \frac{\hat{A}_{si}^{\sigma-1}}{\sum_j \hat{A}_{sj}^{\sigma-1}} \frac{z_s^k}{1+z_s^k} K_s$$

$$\hat{B}_{si} = \frac{\hat{A}_{si}^{\sigma-1}}{\sum_j \hat{A}_{sj}^{\sigma-1}} \frac{1}{1+z_s^k} K_s$$

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$$\hat{L}_{si} = \frac{\hat{A}_{si}^{\sigma-1}}{\sum_j \hat{A}_{sj}^{\sigma-1}} L_s$$

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$$\hat{B}_{si} = \frac{\hat{A}_{si}^{\sigma-1}}{\sum_j \hat{A}_{sj}^{\sigma-1}} \frac{1}{1+z_s^k} K_s$$

$$\tilde{L}_{si} = \frac{\hat{A}_{si}^{\sigma-1} / \tilde{A}_{si}^{\sigma}}{\sum_j \hat{A}_{sj}^{\sigma-1} / \tilde{A}_{sj}^{\sigma}} L_s$$

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- Now, we need to find the optimal allocation of resources in the economy under two scenarios:

$$\hat{L}_{si} = \frac{\hat{A}_{si}^{\sigma-1}}{\sum_j \hat{A}_{sj}^{\sigma-1}} L_s \qquad \tilde{L}_{si} = \frac{\hat{A}_{si}^{\sigma-1} / \tilde{A}_{si}^{\sigma}}{\sum_j \hat{A}_{sj}^{\sigma-1} / \tilde{A}_{sj}^{\sigma}} L_s$$

$$\hat{G}_{si} = \frac{\hat{A}_{si}^{\sigma-1}}{\sum_j \hat{A}_{sj}^{\sigma-1}} \frac{z_s^k}{1+z_s^k} K_s \qquad \hat{G}_{si} = \frac{\hat{A}_{si}^{\sigma-1} / \tilde{A}_{si}^{\sigma}}{\sum_j \hat{A}_{sj}^{\sigma-1} / \tilde{A}_{sj}^{\sigma}} \frac{z_s^k}{1+z_s^k} K_s$$

$$\hat{B}_{si} = \frac{\hat{A}_{si}^{\sigma-1}}{\sum_j \hat{A}_{sj}^{\sigma-1}} \frac{1}{1+z_s^k} K_s \qquad \hat{B}_{si} = \frac{\hat{A}_{si}^{\sigma-1} / \tilde{A}_{si}^{\sigma}}{\sum_j \hat{A}_{sj}^{\sigma-1} / \tilde{A}_{sj}^{\sigma}} \frac{1}{1+z_s^k} K_s$$

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