The Economic Costs and Resource Reallocation in Carbon Emission Policies

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April, 2024

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6. Estimation and Data

Motivation

- Climate is changing, and it is going fast
- Environmental policies are designed to reduce the emissions and Save the planet

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- Therefore, Governments intervene in the market to reduce the emissions
- This intervention could lead to
  - Fall in inputs
  - Introduce new inputs
  - Reallocation of resources

Research Question

- This reallocation could transfer resources from high to low productivity firms.
  - **This could lead to a fall in the output of the economy**
  - But, what if this reallocation is optimal?

Research Question

- This reallocation could transfer resources from high to low productivity firms.
  - **This could lead to a fall in the output of the economy**
  - But, what if this reallocation is optimal?
- So, the question is: **What is the Cost/Benefit for environmental policies due to this reallocation?**

Literature and Contribution

- Effectiveness of Carbon policies
  - Evidences are mixed (There are lots of papers on this topic)
  - Martinsson et al. (2024) find the elasticity of carbon tax on emissions' intensity

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- Misallocation and Reallocation
  - Resources are not allocated optimally allocated in the economy (Whited and Zhao, 2021; Hsieh and Klenow, 2009)

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Standard Framework

Hsieh and Klenow (2009)

- Closed economy with heterogenous monopolistic competitive firms
- Production function is Cobb-Douglas
- CES aggregator for the sector and economy-wide output

$$Y_s = \left(\sum_{i=1}^{I} Y_{si}^{\frac{\sigma_S - 1}{\sigma_S}} \right)^{\frac{\sigma_S}{\sigma_S - 1}}$$

$$Y = \Pi_1^S Y_s^{\lambda_s}, \quad \text{where} \quad \sum^{S} \lambda_s = 1$$

- Emission will be summed up to get the sector and economy-wide emission

$$E_s = \sum_{i=1}^{I} E_{si}, \quad E = \sum_{s=1}^{S} E_s$$

Model

Production functions

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

- $\hat{A}_{si}$ is the total factor productivity

Model

Production functions

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

- $\hat{A}_{si}$ is the total factor productivity
- α_s is the importance of Green capital in the production
- γ_s is the elasticity of substitution between Green and Brown capital

Model

Production functions

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

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

where

Emission General Model

- $\hat{A}_{si}$ is the total factor productivity
- α_s is the importance of Green capital in the production
- γ_s is the elasticity of substitution between Green and Brown capital
- $\tilde{A}_{si}$ is the emission intensity

Firm's profit

- The nominal profit for firms:

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

- where
  - τ^{p}_{si} is the tax / Demand preference for the firm

Firm's profit

- The nominal profit for firms:

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

- where
  - τ^{p}_{si} is the tax / Demand preference for the firm
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Firm's profit

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  - τ_{s}^{G} is the Green capital subsidy / ESG preference of Financier
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  - τ_{s}^{W} is the Labor market preference to work in the green/brown sector

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  - τ_{s}^{W} is the Labor market preference to work in the green/brown sector
- The firm chooses the optimal capital and labor to minimize the cost of production and then chooses the price level to maximize the profit

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

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

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

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

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Firm Decision

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

General Model Solution

Firm Decision

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- Firm will then charge markup over the marginal cost

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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)
- I will set the $\hat{A} = 0.01$ to match the total output in the economy ($\sim$ 10 BSEK).

Parameters

Parameter	**Value**	**Source/Moment**
	Panel A: Inputs	
σ	∞	Fully competitive
r	5%	-
w	500 TSEK	-
L	250 (sd $=$ 900)	Martinsson et al. (2024)

Parameters

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Panel A: Inputs		
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Panel B: Calibrated Value		
β_s	0.6	Martinsson et al. (2024)
α_s	0.25	G/B, Wiedemann (2023)

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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	10.34	Elasticity of carbon tax
$\tilde{A}$	0.018	E/PY

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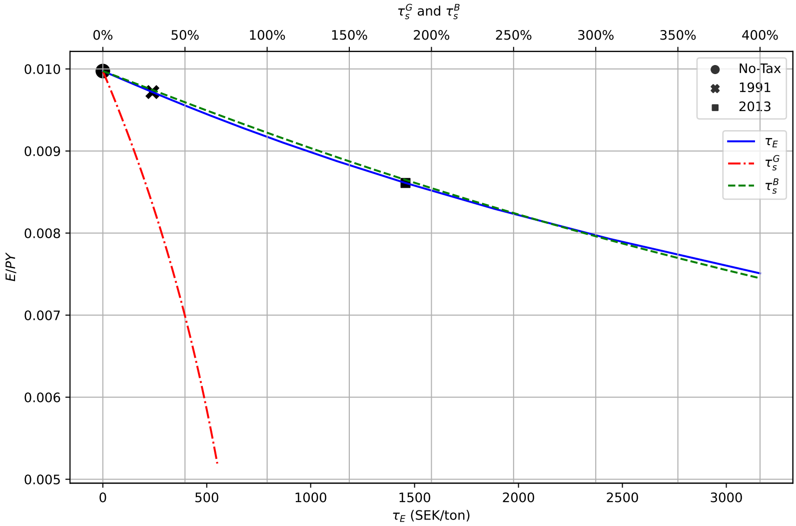
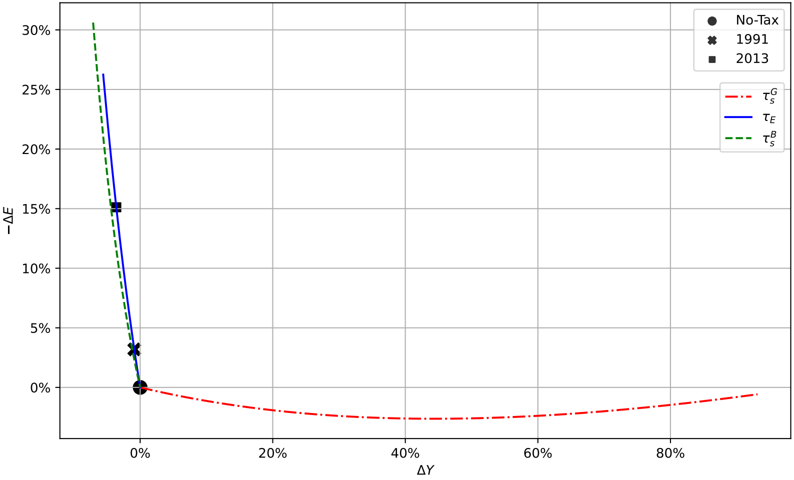
Results



τ_s^G and τ_s^B
0%
50%
100%
150%
200%
250%
300%
350%
400%
No-Tax
1991
2013
τ_E
τ_s^G
τ_s^B
0.010
0.009
0.008
0.007
0.006
0.005
E/PY
0
500
1000
1500
2000
2500
3000
τ_E (SEK/ton)

Results



No-Tax
1991
2013
τ_s^G
τ_E
τ_s^B
30%
25%
20%
15%
10%
5%
0%
$-\Delta E$
0%
20%
40%
60%
80%
ΔY

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Reallocation

- Social planner's problem:

$$\begin{aligned} \max \quad & \left(\sum_i \hat{Y}_{si}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \\ s.t. \quad & \sum_i \hat{L}_{si} = L_s \\ & \sum_i \hat{E}_{si} = E_s \\ & \sum_i \hat{G}_{si} + \hat{B}_{si} = K_s \end{aligned}$$

- Lagrangian:

$$\mathcal{L}_s = \left(\sum_i \hat{Y}_{si}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} + \lambda_L (L_s - \sum_i \hat{L}_{si}) + \lambda_E (E_s - \sum_i \hat{E}_{si}) + (K_s - \sum_i \hat{G}_{si} + \hat{B}_{si})$$

- 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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Estimation

- Estimates the model:
  - Estimate production functions' parameters using an extension of the method in Kmenta (1967)
  - Use nonlinear regression of value-added on debt and equity's residuals to estimate A_{is}
  - Calibrate σ to match $\hat{GK}_{si} + \hat{BK}_{si}$ with the $GK_{si} + BK_{si}$ in the data
- With the parameters in hand, I can use the framework to compute the hypothetically efficient levels of debt and equity for each firm
- Compare value-added computed with these efficient levels to value-added computed with actual levels, thus obtaining the reallocation gains

Data

- **Dataset Source and Inspiration**
  - Based on the methodology detailed by Martinsson et al. (2024)
  - Combines plant- and company-level data spanning 1990 to 2015
- **Data Inclusions**
  - **CO2 Emissions**: Data from the Swedish Environmental Protection Agency (SEPA), includes EU ETS emissions
  - **Registry Data**: Sourced from Upplysningscentralen (UC) for 1990-1997 and Bisnode Serrano for 1998 to 2015
- **Dataset Focus**
  - Captures company-level information: resources used, outcomes, and environmental impact
  - Details include capital and labor (inputs), sales and value addition (outputs), CO2 emissions
  - Additional data on industry sector, location, and ownership
- **Challenges and Solutions**
  - Difficulty in distinguishing between green and brown capital
  - Exploring relationships between green bonds and green capital
  - Using bond issuance as a proxy for green capital concentration

Thank you!

References I

Acemoglu, Daron, Gino Gancia, and Fabrizio Zilibotti. 2012. "Competing engines of growth: Innovation and standardization." *Journal of Economic Theory*, 147(2): 570–601.

Acemoglu, Daron, Ufuk Akcigit, Douglas Hanley, and William Kerr. 2016. "Transition to clean technology." *Journal of political economy*, 124(1): 52–104.

Hsieh, Chang-Tai, and Peter J Klenow. 2009. "Misallocation and manufacturing TFP in China and India." *The Quarterly journal of economics*, 124(4): 1403–1448.

Kmenta, Jan. 1967. "On estimation of the CES production function." *International Economic Review*, 8(2): 180–189.

Martinsson, Gustav, László Sajtos, Per Strömberg, and Christian Thomann. 2024. "The Effect of Carbon Pricing on Firm Emissions: Evidence from the Swedish CO2 Tax." *The Review of Financial Studies*, hhad097.

Whited, Toni M, and Jake Zhao. 2021. "The misallocation of finance." *The Journal of Finance*, 76(5): 2359–2407.

Wiedemann, Moritz. 2023. "Green stewards: Responsible institutional investors foster green capex." *Available at SSRN 4618793*.

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:

$$\pi_{si} = (1+\tau_{si}^{p})P_{si}Y_{si} - \left(\left[(1+\tau_{G_{si}})r_{si}^{G}G_{si} + (1+\tau_{B_{si}})r_{si}^{B}B_{si} + (1+\tau_{l_{si}})w_{si}l_{si}\right] + \tau_E E_{si}\right)$$

Back

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

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

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

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

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

Back

- 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

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

Sensetivity analysis