The Economic Implications of Carbon Financial Frictions

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Motivation

Adam Smith (1776)[1]

Every individual necessarily labours to render the annual revenue of the society as great as he can... He is in this, as in many other ways, led by an invisible hand to promote an end which was no part of his intention... By pursuing his own interest he frequently promotes that of the society more effectually than when he really intends to promote it.

- But what about the public goods and externalities?
- It is well known that the market fails to allocate resources efficiently in the presence of externalities.
- One of the most important externalities is the environmental externalities, such as the CO2 emission.

[1] "Wealth of nations" (1776), Book IV, Chap II

Motivation

- So, governments decided to intervene in the market to correct the market failure.
- This means that they are reallocating resources in the economy.
- But, what are the costs of this reallocation?

Literature

Not a comprehensive list

- Carbon pricing literature:
  - Shapiro and Walker (2018): They show that the emissions reductions in the US are primarily driven by within-product changes in emissions intensity rather than changes in output or in the composition of products produced.
- Misallocation literature:
  - Hsieh and Klenow (2009): They show that misallocation of resources can explain the large differences in the total factor productivity across countries.
  - Whited and Zhao (2021): They estimate real losses arising from the cross-sectional misallocation of financial liabilities.

Contribution

- Most of the prior literature has focused on the success of environmental policies in reducing the emissions and the elasticity of emissions with respect to the carbon tax.
- However, the costs of these policies have been less studied.
- This paper aims to fill this gap by investigating the costs of reallocating resources.

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Model

I have a closed monopolistic competition economy with firm heterogeneity:

- The real output for firms i in sector s is:

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

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- The real output in each sector s is:

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

- Total real output is:

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

Model

- The firm's emission is:

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

Model

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  - It could be simplified as:

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

    where $\mu_s = 0$ and $\theta_s = 1$.

- The sector and economy-wide emission is defined as:

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

Model

- The nominal profit for firms:

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

- To maximize the profit, first firm chooses the capitals and labor to minimize the cost of production and then chooses the price level.
- Then the firm chooses the optimal price level to maximize the profit.

Model

Optimal Allocation

- First step:

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

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

then we can rewrite the optimal capital level as:

$$\begin{aligned}\hat{K}_{si} &= B_{si}(\alpha_s z_{si}^{k\,(\gamma_s-1)} + (1-\alpha_s))^{\frac{\gamma_s}{\gamma_s-1}} \\ &= G_{si}(\alpha_s + (1-\alpha_s)z_{si}^{k\,(1-\gamma_s)})^{\frac{\gamma_s}{\gamma_s-1}}\end{aligned}$$

and then the optimal labor ratio is:

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

Model

Optimal Allocation

- Optimal input levels for given output is:

$$G^*_{si} = \frac{\bar{Y}_{si}}{\hat{A}_{si}} \left(\alpha_s + (1 - \alpha_s) {z^k_{si}}^{(1-\gamma_s)} \right)^{\frac{\gamma_s}{1-\gamma_s}} {z^l_{si}}^{(1-\beta_s)}$$

$$B^*_{si} = \frac{\bar{Y}_{si}}{\hat{A}_{si}} \left(\alpha_s {z^k_{si}}^{(\gamma_s-1)} + (1 - \alpha_s) \right)^{\frac{\gamma_s}{1-\gamma_s}} {z^l_{si}}^{(1-\beta_s)}$$

$$L^*_{si} = \frac{\bar{Y}_{si}}{\hat{A}_{si}} {z^l_{si}}^{\beta_s}$$

- The emission level is:

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

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

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

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Reallocation

- The real output is unobservable, making it difficult to calculate the gains from reallocation.
- To overcome this obstacle, the optimal allocations of Green and Brown capital are plugged into the firm-level CES aggregate to obtain the optimal firm-level.
- An estimate of the actual firm-level real output is calculated by plugging in the observed Green and Brown capital.
- The economy-wide real output is then calculated by aggregating the firm-level values into sectors and sectors into the aggregate economy, allowing for a comparison between the optimal and actual aggregated output to measure aggregate gains.

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:

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

Reallocation

- The optimal input ratios are:

$$z_s^k = (\frac{\alpha_s}{1-\alpha_s})^{\gamma_s}$$
$$z_s^l = \frac{1-\beta_s}{\beta_s}\frac{1}{1-\alpha_s}(\alpha_s z_s^{k(\gamma_s-1)} + (1-\alpha_s))^{\frac{1}{1-\gamma_s}}\lambda_L$$

- The optimal output and emissions for firm under the social planner's problem are:

$$\hat{Y}_{si} = \hat{A}_{si} z_s^{l-\beta} \hat{L}_{si}$$
$$\hat{E}_{si} = \frac{\tilde{A}_{si}}{\hat{A}_{si}}(\frac{\phi_s}{z_s^l})^{\theta_s} z_{si}^{l\ \beta_s} \hat{Y}_{si} = \tilde{A}_{si}(\frac{\phi_s}{z_s^l})^{\theta_s} \hat{L}_{si}$$

Reallocation

Resources allocation

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

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

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

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

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Assumptions

- First, I made some simplifying assumptions:
  - $\mu_s = 0$
  - $\theta_s = 1$

  so the emission is:

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

- Second, there is no friction in the market, so $\tau^p_{si} = \tau_{G_{si}} = \tau_{B_{si}} = \tau_{l_{si}} = 0$, now the profit is:

$$\begin{aligned}
\pi_{si} &= P_{si} Y_{si} - (r^G_{si} G_{si} + r^B_{si} B_{si} + w_{si} l_{si} + \tau_E E_{si}) \\
&= P_{si} Y_{si} - (r^G_{si} G_{si} + (r^B_{si} + \tau_E \tilde{A}_{si}) B_{si} + w_{si} l_{si})
\end{aligned}$$

Calibration

- I use tables from Martinsson et al. (2024) to calibrate the model.
- The model is calibrated to the Swedish economy.
- Labor values:
  - $L = 250 \quad (\sim 234)$
  - $W = 500,000$ SEK
  - $\beta = 0.6 \quad (\sim 0.6083)$
- Capital values:
  - $r_B = r_G = 11\%$
- Elasticities:
  - $\sigma = \infty$

Model equations

Under assumptions

$$z_{si}^{k} = \left(\frac{\alpha_s}{1-\alpha_s} \frac{r_B + \tau_E \tilde{A}}{r_G} \right)^{\frac{1}{\gamma_s}}$$

$$z_{si}^{l} = \frac{1-\beta}{\beta} \frac{1}{\alpha_s} \left(\alpha_s + (1-\alpha_s) {z_{si}^{k}}^{1-\gamma_s} \right)^{\frac{1}{1-\gamma_s}} \frac{W}{r_G}$$

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

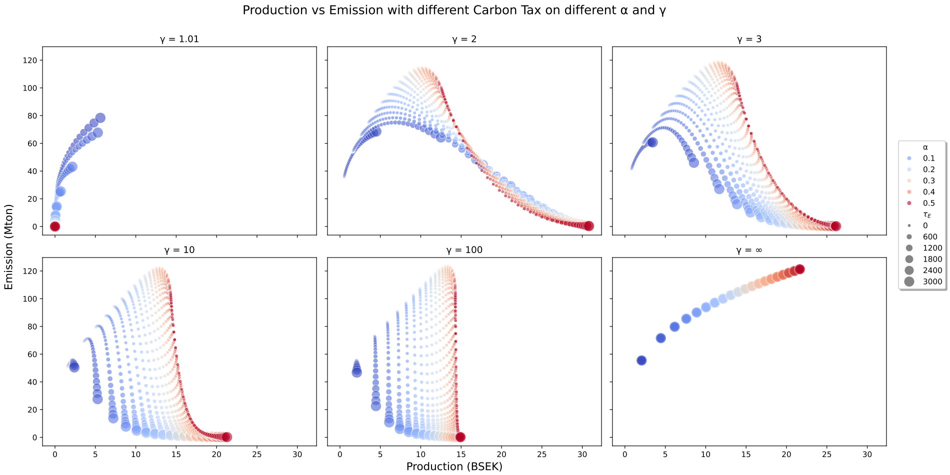
$$PY = \hat{A}_{si} {z_s^{l}}^{1-\beta} L_{si} \qquad , \qquad E_{si} = \tilde{A}_{si} (\frac{\phi_s}{z_{si}^{l}})^{\theta_s} L_{si}$$

Now I need to set the values of α_s, γ_s, $\hat{A}$, and $\tilde{A}$ to match the summary statistics of Emission-to-sales ratio (~ 0.0072), the elasticity of carbon tax on emissions' intensity (~ 2) in Martinsson et al. (2024), and the total output in the economy (~ 10 BSEK).

Simulation

- The model is simulated for 1200 firms.
- All the firms are in the same sector with different productivity levels which are drawn from a lognormal distribution.
- Firm level labor are drawn from a lognormal distribution with mean 250 and standard deviation 900.

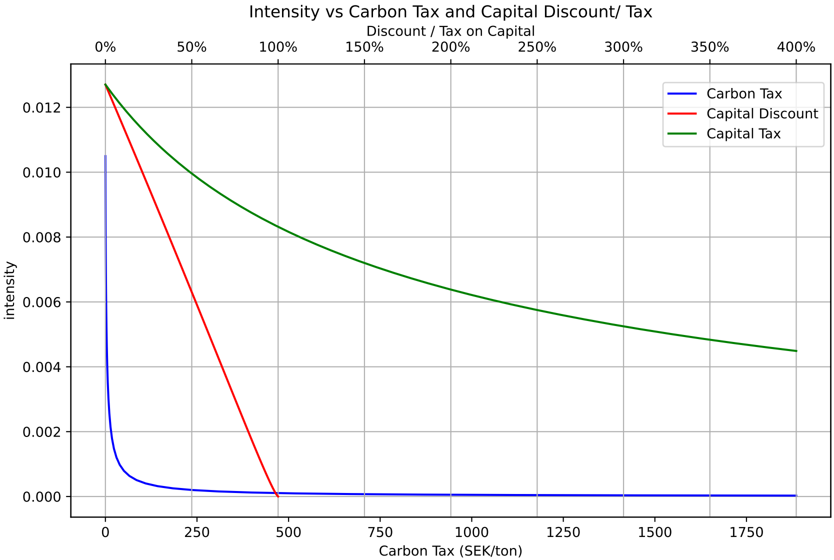
Calibration results



Calibration results

- I need to have an average $\hat{A} = 0.15$ and $\tilde{A} = 0.02$ to match the emission-to-sales ratio, and the total output ($\sim$ 10 BSEK) in economy.
- I need to have $\alpha_s = 0.42$, $\gamma_s = 1.63$ to match the elasticity of carbon tax on emissions' intensity.

Calibration results



Calibration results

τ_E	Green Discount
0	0.00%
10	65.66%
100	92.93%
500	97.98%
1000	98.99%
3000	100.00%

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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

Data

- **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
  - Employing abatement costs as a proxy for green capital
  - Exploring relationships between green bonds and green capital
  - Using bond issuance as a proxy for green capital concentration

Thank you!

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