Carbon Emissions, Energy Misallocations and Policy Reform: The Situation in the US and in China

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Overview

Global Warming and Climate Change

- The greenhouse effect has been a growing concern in the last decade. The urgent demand is now to control global warming to 1.5° or 2°.
- As in impactful research done by Figueres et al. (2017), carbon peaking in 2020 and carbon neutrality in 2050 can be two critical points to achieve the goal of controlling deteriorating global warming.
- Concerning reducing carbon emissions, most governments encourage firms to make green investments and to accelerate the energy transition. However, the effects of these policies are full of uncertainty.

Literature Review - Energy Efficiency

- The most popular indicator to measure energy efficiency is the gross domestic product (GDP) per unit of energy used or consumption, as Georgescu-Roegen (1979) mentioned.
- GDP/Energy ignores the substitution relationship between different elements. Hu and Wang (2006) implemented a total factor perspective to address this issue.
- From the total-factor perspective, there are two methods to measure energy efficiency: data envelopment analysis (DEA) and stochastic frontier analysis (SFA).

Literature Review - Energy Efficiency

To improve energy efficiency and to reduce carbon emissions is an essential topic. There are currently three leading solutions to this topic:

- Changing the method of power generation: nuclear power.
- Accelerating innovative technology to reduce carbon emissions: Inflation Reduction Act (IRA).
- Increasing the cost of energy used by enterprises through the taxation of carbon emissions, thereby reducing energy consumption.

- Restuccia and Rogerson (2008) propose that industrial productivity can be significantly improved by reallocating inputs to more capable firms.
- Hsieh and Klenow (2009) introduce a quantitative approach to explore the level of input distortions that captures the problem of resource misallocation. They find that the total factor productivity (TFP) gap between the U.S., India, and China can shrink up to 40% by removing input distortions.
- Restuccia and Rogerson (2017) show that production distortions can hit physically productive firms firmly, resulting in quantitatively essential consequences for the total factor productivity of the macroeconomic.

Research Motivation

- In this paper, we emphasize the importance of "**energy allocation efficiency**."
- Friction and resource misallocation:
  Due to regulations, subsidies, or taxes, less productive firms may have more resources, while more productive firms have fewer resources.
- How to measure resource misallocation:
  Hsieh and Klenow (2009, QJE), a well-cited paper, developed a framework to measure it.

Model

Following the literature, our analysis only emphasizes the role of the supply side:

- There are i individual firms in each subsector. Y_{si} is the output for firm i in the subsector s.
- Subsector-level firms aggregate individual firms' products to generate subsector goods Y_s. (NAICS = 31, 32, 33)
- A representative final good firm: aggregate goods from each subsector to produce the final good Y.

Model - Final Good

The CobbDouglas production function for the final good firm is

$$Y = \prod_{s=1}^{S} Y_s^{\theta_s}, \text{ where} \sum_{s=1}^{S} \theta_s = 1. \tag{1}$$

where Y is the final good output, Y_s is the output of a subsector, and θ_s is the output share for each subsector. Profit maximization entails that

$$P_s Y_s = \theta_s P Y, \tag{2}$$

where P is the price of final goods, and P_s is the price of goods in the subsector.

Model - Subsector

The output in subsector s is aggregated by

$$Y_s = \left(\sum_{i=1}^{M_s} Y_{si}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{3}$$

where σ is the constant elasticity of substitution between Y_{si}. In each manufacturing subsector s, the subsector-level representative firm faces monopolistic competition. Each individual firm si charges P_{si} for each unit of output. The first-order condition implies

$$Y_{si} = \left(\frac{P_{si}}{P_s} \right)^{-\sigma} Y_s \, . \tag{4}$$

The above equation is the demand function for Y_{si}. The price elasticity of demand is equal to σ.

For firm *si*, the production function in Cobb-Douglas form is given by:

$$Y_{si} = A_{si} K_{si}^{\alpha_s} V_{si}^{\beta_s} E_{si}^{1-\alpha_s-\beta_s}, \ \alpha_s, \beta_s, \alpha_s + \beta_s \in (0,1), \quad (5)$$

where A_{si} is total factor productivity (TFP), K_{si} is capital, V_{si} is variable input excluding energy (hereinafter variable input), and E_{si} is energy. α_s and β_s are the output elasticity of capital and variable input, respectively. We assume firm *si* faces output distortion $\tau_{Y_{si}}$, capital distortion $\tau_{K_{si}}$ and energy distortion $\tau_{E_{si}}$. Each firm must decide on input to maximize its profit, which is

$$\pi_{si} = (1 - \tau_{Y_{si}}) P_{si} Y_{si} - P_s^V V_{si} - (1 + \tau_{K_{si}}) R_s K_{si} - (1 + \tau_{E_{si}}) P_E E_{si} \,. \quad (6)$$

Model - Individual Firm (cont.)

First-order conditions are

$$\mathrm{MRPV}_{si} \triangleq \beta_s \frac{\sigma - 1}{\sigma} \frac{P_{si} Y_{si}}{V_{si}} = P_s^V \frac{1}{1 - \tau_{Y_{si}}}, \tag{7}$$

$$\mathrm{MRPK}_{si} \triangleq \alpha_s \frac{\sigma - 1}{\sigma} \frac{P_{si} Y_{si}}{K_{si}} = R_s \frac{1 + \tau_{K_{si}}}{1 - \tau_{Y_{si}}}, \tag{8}$$

$$\mathrm{MRPE}_{si} \triangleq (1 - \alpha_s - \beta_s) \frac{\sigma - 1}{\sigma} \frac{P_{si} Y_{si}}{E_{si}} = P_E \frac{1 + \tau_{E_{si}}}{1 - \tau_{Y_{si}}}. \tag{9}$$

These three equations show the critical concept of resource misallocation. We assume that the supply of variable input, $\bar{V}_s$, and capital $\bar{K}_s$, is fixed in each subsector.

Limitation of Indirect Approach: Heterogeneity, Adjustment Costs, and Measurement Error.

Model - Marginal Cost

Combining first-order conditions, we obtain the following capital-variable input ratio and the energy-variable input ratio described as

$$\frac{K_{si}}{V_{si}} = \frac{\alpha_s}{\beta_s}\frac{P_s^V}{R_s}\frac{1}{(1+\tau_{K_{si}})}, \tag{10}$$

$$\frac{E_{si}}{V_{si}} = \frac{1-\alpha_s-\beta_s}{\beta_s}\frac{P_s^V}{P_E}\frac{1}{(1+\tau_{E_{si}})}. \tag{11}$$

The above equations indicate the input ratio for firm si. The marginal cost of output for an individual firm is

$$MC_{si} = \left(\frac{R_s}{\alpha_s}\right)^{\alpha_s}\left(\frac{P_s^V}{\beta_s}\right)^{\beta_s}\left(\frac{P_E}{\gamma_s}\right)^{\gamma_s}\frac{(1+\tau_{K_{si}})^{\alpha_s}(1+\tau_{E_{si}})^{\gamma_s}}{A_{si}}. \tag{12}$$

where $\gamma_s \equiv 1-\alpha_s-\beta_s$.

Model - Energy and Carbon Emission

By the optimal energy-variable input ratio of firm si, the energy usage is

$$E_{si} = Y \cdot \frac{(1-\alpha_s-\beta_s)MC_{si}}{(1+\tau_{E_{si}})P_E} \frac{\theta_s}{P_s} \left(\frac{P_{si}}{P_s}\right)^{-\sigma}. \tag{13}$$

The total energy usage E aggregates the E_{si} of all manufacturing firms,

$$E = \sum_{s=1}^{S} E_s = \sum_{s=1}^{S} \left(\sum_{i=1}^{Ms} E_{s_i} \right), \tag{14}$$

where E_s is the energy usage in subsector s. The total carbon emissions is

$$C = \sum_{s=1}^{S} \left(\sum_{i=1}^{Ms} \xi_{si} E_{si} \right). \tag{15}$$

$\xi_{si} \equiv C_{si}/E_{si}$ is carbon intensity measuring each firm si generated pollution by using each unit of energy in the production process and C_{si} is the carbon emission for each firm.

Model - Brown Output and Green Output

The value of brown output, denoted by Y_B, is

$$Y_B = Y - P_E E. \tag{16}$$

The green output, denoted by Y_G, is the brown output adjusted by the externality caused by the carbon emissions because of the energy usage in the production process of manufacturing goods. That is,

$$Y_G = Y_B - \lambda C. \tag{17}$$

Here, $\lambda > 0$ measures the negative externality caused by each unit of carbon emitted to the environment.

Model - Allocation Efficiency

Based on Foster, Haltiwanger, and Syverson (2008) and Hsieh and Klenow (2009), the physical productivity (TFPQ) and revenue productivity (TFPR) of a firm are defined as

$$\mathrm{TFPQ}_{si} \triangleq A_{si} = \frac{Y_{si}}{K_{si}^{\alpha_s} V_{si}^{\beta_s} E_{si}^{1-\alpha_s-\beta_s}}, \tag{18}$$

$$\mathrm{TFPR}_{si} \triangleq P_{si} A_{si} = \frac{P_{si} Y_{si}}{K_{si}^{\alpha_s} V_{si}^{\beta_s} E_{si}^{1-\alpha_s-\beta_s}}. \tag{19}$$

Then, we obtain

$$\mathrm{TFP}_s = \left[\sum_{i=1}^{M_s} \left(A_{si} \cdot \frac{\overline{\mathrm{TFPR}}_s}{\mathrm{TFPR}_{si}} \right)^{\sigma-1} \right]^{\frac{1}{\sigma-1}}. \tag{20}$$

Data

Our data are mainly from Compustat and EiKON with Datastream.

- Compustat has complete corporate financial information, including revenue, cost of goods sold (COGS), capital stock, wage bills, etc.
- Datastream covers the financial data and includes information such as energy usage and the carbon emissions of companies.

Table: Summary Statics (Year=2019, NAICS=31, 32, 33)

United States	**Mean**	**Median**	**No. obs**
Sales (million dollar)	12,869	4510	279
Fixed capital (million dollar)	9,726	2148	279
Variable input (million dollar)	7,528	2513	279
Energy expense (million dollar)	401	41	279
Carbon emission (ton)	1,781,107	210,000	279

Accounting Framework

The accounting framework is as follows:

$$1-\tau_{Y_{si}}=\frac{\sigma}{\sigma-1}\frac{P_s^V V_{si}}{\beta_s\cdot P_{si}Y_{si}}, \tag{21}$$

$$1+\tau_{K_{si}}=\frac{\alpha_s}{\beta_s}\frac{P_s^V V_{si}}{R_s K_{si}}, \tag{22}$$

$$1+\tau_{E_{si}}=\frac{1-\alpha_s-\beta_s}{\beta_s}\frac{P_s^V V_{si}}{P_E E_{si}}, \tag{23}$$

$$A_{si}=\kappa_s\frac{(P_{si}Y_{si})^{\frac{\sigma}{\sigma-1}}}{K_{si}^{\alpha_s}V_{si}^{\beta_s}E_{si}^{1-\alpha_s-\beta_s}}. \tag{24}$$

Here, κ_s is a constant ratio.

The Distribution of TFPR

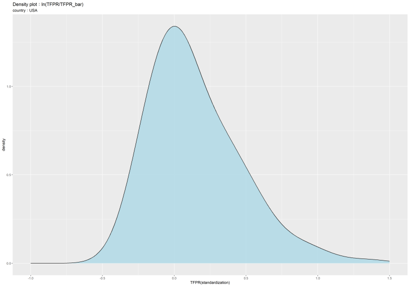

Figure: USA

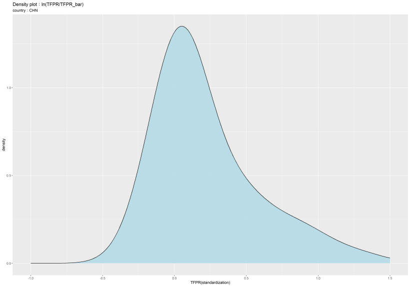

Figure: CHN

Benchmark Results (in percentage)

US	Y_B/Y	Y_G/Y	$Y/Y_{\mathrm{efficiency}}$
31	99.06	98.95	85.84
32	97.65	97.38	41.47
33	99.68	99.62	75.93
Aggregate	97.88	97.50	61.03

China	Y_B/Y	Y_G/Y	$Y/Y_{\mathrm{efficiency}}$
31	97.93	97.88	87.33
32	93.43	92.01	46.86
33	99.01	98.91	87.74
Aggregate	97.53	97.22	83.09

Policy Effect

We consider policy effects under three scenarios:

- Ad valorem taxes: a 10% increase in energy prices.
- Specific taxes: an increment in the energy tax.
- Quasi-efficient case: a comprehensive correction of the energy distortion.

US	Y	E	Y_B	λC	Y_G
I ($\gamma = 1.1, t = 0$)	-0.37	- 9.43	-0.08	- 9.43	-0.04
II ($\gamma = 1, t = 0.05$)	-0.08	- 9.71	0.23	- 9.31	0.27
II ($\gamma = 1, t = 0.10$)	-0.14	-16.66	0.39	-15.93	0.45
II ($\gamma = 1, t = 0.15$)	-0.20	-22.20	0.51	-21.24	0.59
III (correction of energy distortion)	7.24	- 0.29	7.48	10.52	7.47

The Distribution of Energy Productivity (case 1)

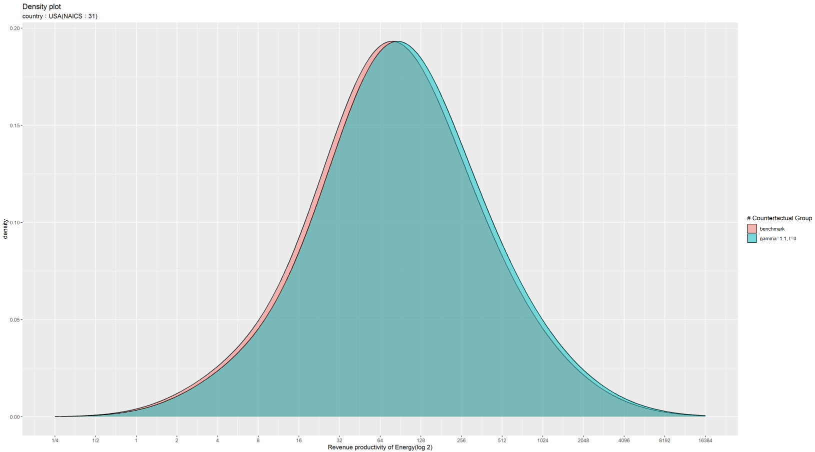

Figure: USA

The Distribution of Energy Productivity (case 2)

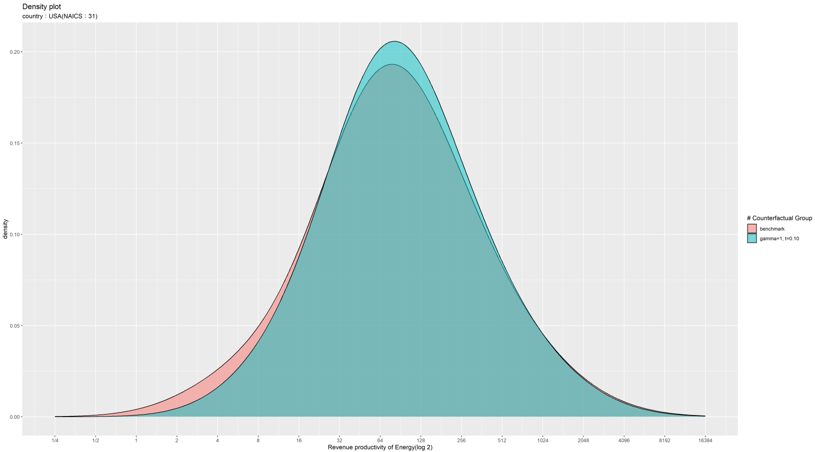

Figure: USA

Conclusion and Research Challenge

- We recompute firm output as green output and show that energy distortions lead to resource misallocations in manufacturing industries, while reallocation may promote green output when raising energy costs.
- Increasing energy prices by correcting distortions at a fixed rate of 0.1 may significantly reduce energy usage and carbon emissions, with minor impacts on manufacturing outputs and improved green outputs.

The End