Emissions Reduction in the Global Steel Industry and Policy Measures

A group project topic

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Context

The production of steel is one of the most carbon-intensive industries, accounting for approximately 7% of global greenhouse gas emissions. Meeting the Paris Agreement goals to limit global warming to below 2°C will require significant decarbonization of the steel industry. However, there is a concern that unilateral climate policies, such as (sub-global) carbon taxes or emissions trading systems, may lead to carbon leakage, whereby emissions simply shift to other countries with less stringent climate policies. This has led to calls for border carbon adjustments, which seek to level the playing field for domestic producers and ensure that carbon leakage does not occur. In this context, policymakers around the world are exploring different climate policy instruments to reduce emissions in the steel industry.

Starting Point

We will provide a simple single-country partial equilibrium model of the steel industry.

Tasks

- Extend the model to a multi-region model. Simulate the impact of various policy instruments on the steel industry's greenhouse gas emissions, such as carbon taxes, emissions trading systems, and technology standards.
- Assess the effectiveness of climate policy instruments for reducing emissions in the steel industry. Calculate the potential carbon leakage rate and discuss the implications of this phenomenon for climate policy design.
- Evaluate the effectiveness of border carbon adjustments in mitigating this risk. Analyze the trade-offs between protecting domestic producers and ensuring global emissions reductions.

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A Simple Steel Industry Model

This simple model is largely based on the model by Mathiesen and Maestad (2004).[1]

Sets

- Steel plants $i \in I = \{1, 2, 3, ..., n\}$
- Factors $f \in F = \{$Iron ore, Coking coal, Steel scrap, Electricity, Natural gas$\}$
- Technologies $t \in T = \{$BOF, EAF, DRI$\}$

Each steel plant will be mapped to a technology with the following notation: the technology of the steel plant i is $t(i)$.

Parameters

- Factor use per ton crude steel production $a_{t,f}$:

Technology	Iron ore (ton)	Coking Coal (ton)	Steel scrap (ton)	Electricity (MWh)	Natural Gas (ton)
BOF	1.401	0.653	0.252	0.033	
EAF			1.026	0.523	
DRI	0.852		0.579	0.707	7.199

- Reference factor market prices (USD per ton or MWh) $\bar{V}_f$:

Iron ore	Coking Coal	Steel scrap	Electricity	Natural Gas
33.0	63.0	136.0	70.0	4.3

- Carbon emissions coefficients (tCO_2e per ton or MWh) κ_f:

Iron ore	Coking Coal	Steel scrap	Electricity	Natural Gas
0.02	2.76	0.01	0.29	2.34

- Price elasticity of supply for each factor ρ_f:

Iron ore	Coking Coal	Steel scrap	Electricity	Natural Gas
1.0	2.0	0.5	0	0

- Price elasticity of demand for steel $\varepsilon = -0.3$
- Plant-specific additional costs of each factor (e.g. transport) $\tau_{i,f}$
- Plant-specific production capacity $\hat{Y}_i$

[1] Mathiesen, Lars, and Ottar Maestad. "Climate Policy and the Steel Industry: Achieving Global Emission Reductions by an Incomplete Climate Agreement." The Energy Journal 25, no. 4 (2004): 91–114. `https://doi.org/10.5547/ISSN0195-6574-EJ-Vol25-No4-5`.

Calibration and reference point

To start the model, we need to set initial values for the variables. Doing so will allow us to solve our model as expected. However, since we are simplifying reality with many assumptions, the model will not completely replicate every detail of empirical data. Therefore, to conduct our economic analysis, we will construct a price for crude steel and production quantities of each plants that are consistent with the cost structure and demand constraint of the model, and use them as the reference point.

In the gams file, some fictive plants are created. To make these plants heterogenous, we assume that they have some additional additive costs $\tau_{i,f} \sim U(0, 0.1)$ when using each factor. They are also different with respect to their capacities $\hat{Y}_i \sim U(10, 15)$. Then we assume for the moment that their production quantities are $\bar{Y}_i = \hat{Y}_i - \delta_i$ where $\delta_i \sim U(0, 5)$. Our reference demand $\bar{D}$ is then the sum of all production quantities: $\bar{D} = \sum_{i \in I} \bar{Y}_i$ and we solve the following problem:

$$\min_{\{Y_i\}_{i\in I}} \sum_{i\in I} \sum_{f\in F} a_{t(i),f}(\bar{V}_f + \tau_{i,f})Y_i$$

$$\text{subject to} \quad \sum_{i\in I} Y_i \geq \bar{D} \quad \text{and} \quad \hat{Y}_i \geq Y_i \quad \text{for all } i \in I.$$

Then we get our reference point as follows:

- The reference price for crude steel $\bar{P}$ is the shadow price of the demand constraint.
- The reference capital rental rates $\bar{R}_i$ are given by the negative of the shadow prices of the capacity constraints.
- Also, the production quantities of each plants that solves this problem are now the reference quantities.
- Then, we get the following reference quantities for factor inputs:

$$\bar{H}_f = \sum_{i\in I} a_{t(i),f} \bar{Y}_i$$

- Lastly, the reference emission level from using each factor is given by:

$$\bar{e}_f = \sum_{i\in I} a_{t(i),f} \kappa_f \bar{Y}_i$$

Variables

- Quantity of crude steel production by plant $\mathbf{Y}_i$
- Price of crude steel $\mathbf{P}$
- Price for each factor $\mathbf{V}_f$
- Capital rental rate for each plant $\mathbf{R}_i$
- Price for carbon emission rights $\mathbf{W}$

Equations

- Zero profit condition of steel plants:

$$\sum_{f \in F} a_{t(i),f}(\mathbf{V}_f + \tau_{i,f}) + \mathbf{R}_i + \sum_{f \in F} \mathbf{W}\kappa_f a_{t(i),f} \geq \mathbf{P} \quad \perp \quad \mathbf{Y}_i \geq 0 \quad \forall i \in I \tag{1}$$

- Market clearance condition for crude steel:

$$\sum_{i \in I} \mathbf{Y}_i \geq \bar{D}\left(1 + \varepsilon\left(\frac{\mathbf{P}}{\bar{P}} - 1\right)\right) \quad \perp \quad \mathbf{P} \geq 0 \tag{2}$$

- Market clearance condition for factors:

$$\bar{H}_f\left(1 + \rho_f\left(\frac{\mathbf{V}_f}{\bar{V}_f} - 1\right)\right) \geq \sum_{i \in I} a_{t(i),f}\mathbf{Y}_i \quad \perp \quad \mathbf{V}_f \geq 0 \quad \forall f \in F \tag{3}$$

- Market clearance condition for capital (plant-specific capacity):

$$\hat{Y}_i \geq \mathbf{Y}_i \quad \perp \quad \mathbf{R}_i \geq 0 \quad \forall i \in I \tag{4}$$

- Market clearance condition for carbon emission rights:

$$\chi\left(\sum_{f \in F} \bar{e}_f\right) \geq \sum_{i \in I}\sum_{f \in F} a_{t(i),f}\kappa_f \mathbf{Y}_i \quad \perp \quad \mathbf{W} \geq 0 \tag{5}$$