Emissions Reduction in the Global Steel Industry and Policy Measures

Group Project Topic

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Context

The steel industry is among the most carbon-intensive sectors, accounting for approximately 7% of global greenhouse gas emissions. Meeting the goals of the Paris Agreement, which aim to limit global warming to well below 2°C, requires substantial decarbonization of steel production. Unilateral climate policies (for example, sub-national carbon taxes or emissions trading systems) can create a risk of carbon leakage, whereby emissions shift to countries with less stringent climate policies. This concern has prompted calls for border carbon adjustments, which aim to level the playing field for domestic producers and reduce incentives for leakage. Policymakers worldwide are therefore exploring different policy instruments to lower emissions in the steel sector.

Starting Point

We provide a simple, single-country partial-equilibrium model of the steel industry as a baseline.

Tasks

- Extend the model to a multi-region framework and simulate the impacts of various policy instruments (carbon taxes, emissions trading systems, and technology standards) on the steel sector's greenhouse gas emissions.
- Assess the effectiveness of these climate policy instruments in reducing emissions. Compute potential carbon-leakage rates and discuss the implications for policy design.
- Evaluate the effectiveness of border carbon adjustments in mitigating leakage, and analyze the trade-offs between protecting domestic producers and achieving global emissions reductions.

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A Simple Steel Industry Model

This model is largely based on Mathiesen and Mæstad (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 tonne crude steel production $a_{t,f}$:

Technology	Iron Ore (tonne)	Coking Coal (tonne)	Steel Scrap (tonne)	Electricity (MWh)	Natural Gas (tonne)
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 unit: tonne for materials, MWh for electricity) $\bar{V}_f$:

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 tonne 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 Mæstad . "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 run the model, we set initial values for the variables. These values allow the model to be solved, but because the model relies on simplifying assumptions it will not reproduce every detail of empirical data. For our analysis, we therefore construct a reference crude steel price and plant-level production quantities that are consistent with the model's cost structure and demand constraint; these serve as the reference point.

In the GAMS file, we create a set of fictitious plants. To make these plants heterogeneous, we assume additive, factor-specific costs $\tau_{i,f} \sim U(0, 0.1)$. Capacities are drawn from $\hat{Y}_i \sim U(10, 15)$. For the reference production of each plant, we assume $\bar{Y}_i = \hat{Y}_i - \delta_i$ with $\delta_i \sim U(0, 5)$. Reference demand $\bar{D}$ is the sum of those production quantities, $\bar{D} = \sum_{i \in I} \bar{Y}_i$, and we solve the following problem:

$$\begin{aligned} &\min_{\{Y_i\}_{i\in I}} \sum_{i\in I} \sum_{f\in F} a_{t(i),f}(\bar{V}_f + \tau_{i,f})Y_i \\ &\text{subject to} \quad \sum_{i\in I} Y_i \geq \bar{D} \quad \text{and} \quad \hat{Y}_i \geq Y_i \quad \text{for all } i \in I. \end{aligned}$$

We obtain the 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, $\bar{R}_i$, equal the negative of the shadow prices associated with the capacity constraints.
- The production quantities that solve the calibration problem are the reference quantities for each plant.
- Reference factor input quantities are

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

- Reference emissions from each factor are

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

Variables

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

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 permits:

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