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Introduction (1)

Cost of environmental policy

- Direct: abatement cost within a sector
- Indirect: impacts on other sectors

Top-down models:

- Pros: capture indirect cost by endogenous market adjustments
- Cons: limited ability to represent detailed bottom-up technological information

Efforts to enrich top-down models with technology details in a consistent mathematical framework

- Coupling: Boehringer and Rutherford (2009); Rausch and Mowers (2014)
- Direct representation: Boehringer and Rutherford (2008)
  - Smooth curve (traditional approach): Boeters and Bollen (2012)
  - Step curve (hybrid approach): Kiuila and Rutherford (2013)
Introduction (2): Traditional approach

\[ p_{t,r} \geq \left\{ \theta_{n,r} (\mu_{n,r} p_{n,w,t,r})^{1-\sigma_{n,r}} + (1 - \theta_{n,r}) \right\}^{1/1-\sigma_{n,r}} \perp Y_{n,t,r} \geq 0 \]

where \( p_{t,r} \) is the output price of electricity which is treated as a homogenous commodity. \( p_{n,c,t} \) is a CES price index of capital, labor, and other inputs. \( p_{n,w,t,r} \) denotes the price of fixed factor wind resource. \( \theta_{n,r} \) denotes the benchmark share of the fixed factor and \( \sigma_{n} \) is the elasticity of substitution between the resource and non-resource inputs.

\[ \epsilon_{n,r} = \frac{\partial \log Y_{n,r}}{\partial \log p_{r}} = \sigma_{n,r} \frac{1 - \theta_{n,r}}{\theta_{n,r}}. \]

\( \mu_{n,r} \) is a multiplicative mark-up factor that describes the price of the first MWh of wind generated with technology \( n \) relative to a benchmark electricity generating technology, i.e., a carbonized coal.

Source: Rausch and Karplus (2014)
Introduction (3): Hybrid approach

Described in Kiuila and Rutherford (2013)

A case study has been provided for transport sector in Switzerland. 8 technologies are included in their example – only 8 steps in cost curves.
This paper shows that a hybrid approach, which is more flexible and precise than traditional approaches, because it can

- Represent complex shape for abatement technologies and renewable technologies
  - Complex shape is very common for many-step abatement technologies and renewable technologies with heterogeneous resource information
  - We integrate a many-step supply curve for China’s offshore wind into a recursive dynamic down model as an example
- Replicate the empirically-observed “wind rush” phenomenon

Large quantities of wind capacity will be cyclically deployed upon reaching threshold electricity prices with decreasing cost or rising explicit/implicit subsidies
A stylized model (1)

X: Electricity sector (fossil-based), Y: Other sectors

A backstop electricity generation technology, say wind, is represented using the hybrid approach suggested by Kiuila and Rutherford (2013)

- It can produce a homogeneous good of X using K, L, and different grades of resources (i.e. different classes of wind).
- It

| Table 1: Illustrative benchmark social accounting matrix (SAM) for a closed economy. |
|-------------------------------|-------------------|------------|
| X & Y | CONS |
| PX & 1000 | -1000 |
| PY | 10000 | -10000 |
| PL & -450 | -5000 | 5450 |
| PK & -450 | -5000 | 5450 |
| PF & -50 | 50 |
| PE & -50 | 50 |

Note: PX – electricity sector; PY – other goods and services; PL – labor; PK – capital; PF – fossil fuel; PE – emissions allowance.
A stylized model (2)

Supply curve of wind under carbon policy

- Static
- Simulated

Simulated curves is different as the top-down model incorporates the general equilibrium effect including complex interactions between price changes of factors and commodities

- Decreased price of capital

Simulated and static supply curves of the backstop electricity generation technology (wind).

Decreasing capital price (vertical axis) with narrowing emissions cap (horizontal axis: ratio of emissions cap to the benchmark).
A stylized model (3)

Wind Rush” phenomenon

Cyclical rapid increase of wind installation triggered by subtle changes of policy stringency

An “enclosure movement” in China: wind farms pay money to the local government in order to secure land.

Cyclical increase and stagnation of wind installation (BX, right vertical axis) and price of emissions allowance (PE, left vertical axis) with narrowing emissions cap (horizontal axis: ratio of emissions cap to the benchmark emissions).
A numerical example for China’s offshore wind

A pedagogic GTAPinGAMS style model (Rutheford, 2010) using GTAP 8 data
China and other regions, 10 sectors
Modern Era Retrospective-analysis for Research and Applications (MERRA) for wind resources (Zhang et al, 2014)

A carbon tax is levied from 2012 to 2047 to reduce China’s emissions intensity by 17% every five years (comparable to the 12th Five-Year Plan target).

Wind is selected as an example of renewable technology here for the following three reasons:
b) The shape of China’s offshore supply curve is irregular, which allows the hybrid approach to illustrate its advantage in capturing complex shape of the potential site of offshore wind power in China is normally closed to load center, therefore additional grid integration cost can be approximately neglected in the model;
c) There is almost no offshore wind installation in the base year of the model, which makes the calibration easier, and it is convenient to model the offshore wind as a backstop technology.
A numerical example for China’s offshore wind

Offshore wind supply curve
- 92-step curve under 1 yuan (2007 price)/kWh

Curve fitting

\[
\text{Residual} = \sum_{k}(\text{offshoreCurve}_{n,\text{Gen}} - \text{offshoreCurve}_{n-1,\text{Gen}}) \times (\text{offshoreCurve}_{n,P} - \text{optLine}_{\arg\min_m \{\text{optLine}_m - \text{offshoreCurve}_{n,P}\}})
\]

\[
< 0.01 \times (\text{offshoreCurve}_{n,\text{Gen}} - \text{offshoreCurve}_{1,\text{Gen}}) \times (\text{offshoreCurve}_{n,P} - \text{offshoreCurve}_{1,P})
\]
A numerical example for China’s offshore wind

- Very precise approximation
- Consistent capacity and generation
Thank you!

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