POTENTIAL GAINS FROM TRADING BAD OUTPUTS: The case of U.S. electric power plants

by

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INTRODUCTION

Coal-fired electric power plants produce, in addition to good output (kwh), multiple bad outputs (CO₂, NOₓ, and SO₂).

We investigate the impact on good output production by allowing for trade of individual bads (and combinations of them), while regulating the industry bad outputs. We set the latter to the total observed amounts.
POLLUTING TECHNOLOGIES

\( x \in \mathbb{R}_+^m \) input vector

\( y \in \mathbb{R}_+^m \) desirable output vector, divisibility

\( u \in \mathbb{R}_+^n \) bad undesirable output vector

\[ P(x) = \{ (y, u) : x \text{ can produce } (y, u) \} \]

the output set, technology

\( \text{The black box} \)

(one may go into the black box by modeling the technology as a network)
An Output Set

1. Nulljointness \((y, u) \in P(x), u = 0 \Rightarrow y = 0\)

2. Weak disposability of \((y, u)\)

\((y, u) \in P(x), 0 \leq \theta \leq 1 \Rightarrow (\theta y, \theta u) \in P(x)\)

3. Strong (free) disposability of \(y\)

\((y, u) \in P(x), y' \leq y \Rightarrow (y', u) \in P(x)\)

Additional Standard Axioms.
The Activity Analysis/Data Envelopment (DEA) Formulation

$\mathcal{P}(x^t) = \{ (y^t, x^t) : \sum_{m=1}^{K} z^t_{km} y^t_m = y^t_k, \quad k = 1, \ldots, M \}$

$\sum_{k=1}^{K} z^t_{kj} u^t_j = u^t_j, \quad j = 1, \ldots, J$

$\sum_{k=1}^{K} z^t_{kn} x^t_n = x^t_n, \quad n = 1, \ldots, N$

$z^t_k \geq 0, \quad j$
1. $\sum_{i=1}^{J} u_{ij} > 0$, $\sum_{k=1}^{K} u_{kj} > 0$ null jointness

2. $y^t_{m}$ and $u^t_{i}$: weak disposability

3. $y^t_{m}$: strong disposability of good outputs

4. $x^t_{n}$: strong disposability of inputs

5. $z^t_{t} \geq 0$, constant returns to scale
Objective Function

\[ M = 1 \]

\[ \max_y y^t \quad s.t. \quad (y^t, u^t) \leq P^t(x^t) \]

maximize feasible output,
given input and bad output
COMMAND AND CONTROL

\[
\max y' \\
\uparrow \\
\text{plant #1}
\]

\[
\begin{align*}
x' & \rightarrow P(x') \\
& \rightarrow u'
\end{align*}
\]

\[x', u' \text{ observed inputs and bad outputs}\]

\[
y_{cc} = \sum_{k=1}^{k} \max_{y_k}
\]
TRADING BADS

\[ y_j^{TP} = \max \ y^1 + y^2 \]
Data Sources

Sample: coal-fired power plants in 1995-2005
- At least 95 percent of BTUs from coal
- 80 power plants in sample
- Good output: net electricity generation (in kWh) from EIA-767 survey (from EIA-767 survey)
- Bad outputs: CO$_2$, NO$_x$, and SO$_2$ emissions (from EPA Continuous Emissions Monitoring System, CEMS).

Inputs
- Capital: value of plant and equipment (derived using data from FERC Form 1 and EIA-412 surveys)
- Labor: number of employees (from FERC Form 1 and EIA-412 surveys)
- Fuel: consumption of coal, oil, and natural gas (in BTUs) from EIA-767 survey
RESULTS

Figure 1. Annual Ratios of $Y_{j'}/Y_0$

$j' = 1, 2, 3$
RESULTS

Figure 2. Annual Geometric Means of \( \frac{Y_{j}^{pp}}{Y_{j}^{cc}}, j=1, \ldots, 3 \).
MODELING GOOD AND BAD OUTPUTS IN A NETWORK

$X \rightarrow p^1 \rightarrow p^2 \rightarrow y^f \rightarrow y^f \rightarrow u^f$

$P^1$ subtechnology 1

$P^2 \rightarrow 2$

$X = x^1 + x^2$

$(y^f,u^f)$ final output

$u^i$ intermediate output