Environmental Regulations and Productivity Growth: The Case of Fossil-fueled Electric Power Generation

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- During the 1970's, acid rain has become a major environmental issue, and hence tight regulation was imposed on of sulfur emission of the fossil fuel power plants.
- Estimate the parameters of the cost function of the electric power generation.
- Measure the effect of environmental regulation on the change in the cost of the electric power generation.
- Measure the effect on the change in productivity

Cost function:

$$C = C\left(p_L, p_K, p_{F_l}, p_{F_h}, R, Q, T\right)$$

Functional form assumption:

$$\begin{aligned} C \quad = \quad & exp\left[\beta_0 + \sum_i \beta_i lnp_i + \beta_Q lnQ + \beta_R R + \beta_T T\right. \\ & + \frac{1}{2}\sum_i \sum_j \gamma_{ij} lnp_i lnp_j + \sum_i \gamma_{iQ} lnp_i lnQ + \sum_i \gamma_{iR} lnp_i R \\ & + \sum_i \gamma_{iT} lnp_i T + \frac{1}{2}\gamma_{QQ}\left(lnQ\right)^2 + \gamma_{QR} lnQR + \gamma_{QT} lnQT \\ & \left. + \frac{1}{2}\gamma_{RR} R^2 + \gamma_{RT} RT + \frac{1}{2}\gamma_{TT} T^2\right] \end{aligned}$$

L, p_L: labor input, wage
K, p_K: capital, rental rate of capital
F_l, p_{F_l}: low sulfur fuel, price of low sulfur fuel
F_h, p_{F_h}: high sulfur fuel, price of high sulfur fuel
Q: Output (electricity generated)
R: Environmental regulation
T: Time.

From Shephard's Lemma

$$\frac{\partial lnC}{\partial lnp_L} = \frac{p_L L}{C}, \qquad \frac{\partial lnC}{\partial lnp_K} = \frac{p_K K}{C}$$
$$\frac{\partial lnC}{\partial lnp_{F_l}} = \frac{p_{F_l} F_l}{C}, \qquad \frac{\partial lnC}{\partial lnp_{F_h}} = \frac{p_{F_h} F_h}{C}$$

RHS of each equation is the labor share, capital share, low sulfur fuel share, high sulfur fuel share of cost.

The equations that is estimated is:
Cost function:

$$\begin{aligned} lnC &= \beta_0 + \sum_i \beta_i lnp_i + \beta_Q lnQ + \beta_R R + \beta_T T \\ &+ \frac{1}{2}\sum_i \sum_j \gamma_{ij} lnp_i lnp_j + \sum_i \gamma_{iQ} lnp_i lnQ + \sum_i \gamma_{iR} lnp_i R \\ &+ \sum_i \gamma_{iT} lnp_i T + \frac{1}{2}\gamma_{QQ} (lnQ)^2 + \gamma_{QR} lnQR + \gamma_{QT} lnQT \\ &+ \frac{1}{2}\gamma_{RR} R^2 + \gamma_{RT} RT + \frac{1}{2}\gamma_{TT} T^2 + \epsilon_1 \end{aligned} \quad (1)$$

$i \in \{L, K, F_l, F_h\}$
3 Share functions: $i \in \{L, K, F_l\}$

$$\begin{aligned} \frac{p_i i}{C} &= \beta_i + \frac{1}{2}\sum_j [\gamma_{ij} + \gamma_{ji}] lnp_j \\ &+ \gamma_{iQ} lnQ + \gamma_{iR} R + \gamma_{iT} T + \epsilon_{1+i} \end{aligned} \quad (2)$$

Notice that the four share functions $i \in \{L, K, F_l, F_h\}$

$$\frac{p_i i}{C} = \beta_i + \frac{1}{2} \sum_j [\gamma_{ij} + \gamma_{ji}] \, lnp_j$$
$$+\gamma_{iQ} lnQ + \gamma_{iR} R + \gamma_{iT} T + \epsilon_{1+i} \tag{3}$$

are collinear, because

$$\sum_i \frac{p_i i}{C} = 1$$

Hence, for estimation, we only take the first three share equations.

Restrictions imposed on the model:

- Symmetry: $\gamma_{ij} = \gamma_{ji}$
- Homogeneity of degree 1

$$\begin{aligned}
\sum_i \beta_i &= 1 \\
\sum_j \gamma_{ij} &= 0 \ \forall i \\
\sum_i \gamma_{iQ} &= 0 \\
\sum_i \gamma_{iR} &= 0 \\
\sum_i \gamma_{iT} &= 0
\end{aligned}$$

- Testing the hypothesis that environmental regulation did not effect the cost of electricity generation.
  Hypothesis:
$$v_R \equiv \frac{\partial lnC}{\partial R} = 0$$
  That is,
$$\beta_R = \gamma_{LR} = \gamma_{KR} = \gamma_{F_l R} = \gamma_{F_h R} = \gamma_{QR} = \gamma_{RR} = \gamma_{RT} = 0$$
- Testing the hypothesis that the environmental regulation was input neutral
$$\gamma_{LR} = \gamma_{KR} = \gamma_{F_l R} = \gamma_{F_h R} = 0$$

- $\gamma_{F_l R} > 0$, $\gamma_{R_h R} < 0$: strict environmental regulation induced the firms to switch from high sulfur fuel to low sulfur fuel, which are more costly, thereby increasing the cost of electricity generation.

- Scale Effects: hypothesis of constant returns to scale.

$$v_Q \equiv \frac{\partial lnC}{\partial Q} = 1$$

That is,

$$\beta_Q = 1$$

$$\gamma_{LQ} = \gamma_{KQ} = \gamma_{F_lQ} = \gamma_{F_hQ} = \gamma_{QQ} = \gamma_{QR} = \gamma_{QT} = 0$$

- Technological Change: technical change makes no contribution to the rate of productivity growth.

$$V_T \equiv \frac{\partial lnC}{\partial T} = 0$$

which is,

$$\beta_T = \gamma_{LT} = \gamma_{KT} = \gamma_{F_lT} = \gamma_{F_hT} = \gamma_{QT} = \gamma_{RT} = \gamma_{TT} = 0$$

Data

Generation cost, input expenditures, output, input prices, environmental regulations, for 1973-79, for 56 privately owned electric utilities, with fossil fuel generation.

- low sulfur fuel $<$ 1.5 points SO2 per million BTU $<$ high sulfur fuel.

- Regulatory intensity.

$$R_i = \left(\frac{E_t^* - S_t}{E_t^*} \right) \left(\sum_{i=t-1}^{t} \frac{1}{2} \frac{E_i^* - E_i}{E_i^* - S_i} \right)$$

E^*: unconstrained emission rate. (pounds SO2 per million Btu) Calculated from the avearge emission rate of high sulfur fuel.
E: actual emission rate.
S: mandated emission rate.
First term: Legal emission constraint. Proportional reduction in emissions required by the SIP.
Second term: actual enforcement scalar.

- S_t, E_t^*, E_t: downward trend.
- Legal emission constraint: increases until 1976, then slightly falls.
- Enforcement scalar: steadly increase until 1979.
- Measure of regulatory intensity: steady increase until 1979. After 1976, mostly due to an increase in enforcement.

- No regulatory effect, ($v_R = 0$), No input bias, Constant Returns ($v_Q = 1$), No technological change ($v_T = 0$) are all rejected at 1 % significance level.
- v_R steadily increases over time. Regulation became more costly over time.
- $\gamma_{F_lR} > 0$, $\gamma_{R_lR} > 0$, both significant. Regulation induces firms to substitute from high sulfur fuel to low sulfur fuel.
- $v_Q < 1$, Average firms operated at the diseconomy of scale level. Small firms were operating at the economy of scale level.
- 1973-1977: reduced residual productivity growth. Positive residual productivity growth during 1978, 1979.

Year	v_R	v_Q	$-v_T$
1973	.119	.943	.037
1974	.206	.951	.034
1975	.233	.945	.023
1976	.265	.941	.011
1977	.327	.938	.001
1978	.296	.927	-.011
1979	.371	.918	-.026

Sources of Productivity Growth.

$$\bar{v}_G = -\bar{v}_R\,[R(T) - R(T-1)] + (1-\bar{v}_Q)\,[lnQ(T) - lnQ(T-1)] + \bar{v}_T$$

$$\begin{aligned}
\bar{v}_R &\equiv \frac{1}{2}\,[v_R(T) + v_R(T-1)] \\
\bar{v}_Q &\equiv \frac{1}{2}\,[v_Q(T) + v_Q(T-1)] \\
\bar{v}_T &\equiv \frac{1}{2}\,[v_T(T) + v_T(T-1)]
\end{aligned}$$

TABLE 5

SOURCES OF PRODUCTIVITY GROWTH: AVERAGE ANNUAL RATES OF GROWTH
(Means over All Firms)

Period	Number of Firms	Productivity Growth $\bar{v}_G$	Regulation $-\bar{v}_R \cdot [R(T) - R(T-1)]$	Scale $(1 - \bar{v}_Q) \cdot [\ln Q(T) - \ln Q(T-1)]$	Technical Change $\bar{v}_T$
Firms facing binding emission constraints:					
1973–74	24	−.0327	.0050	−.0002	−.0375
1974–75	36	−.0295	−.0038	.0024	−.0282
1975–76	39	−.0271	−.0196	.0088	−.0164
1976–77	39	−.0072	−.0063	.0041	−.0051
1977–78	38	.0017	−.0054	.0011	.0060
1978–79	41	.0139	−.0055	.0010	.0183
Average	...	−.0135	−.0059	.0029	−.0105
Firms not facing binding emission constraints:					
1973–74	32	−.0348	0	−.0011	−.0337
1974–75	20	−.0297	0	−.0008	−.0289
1975–76	17	−.0134	0	.0057	−.0191
1976–77	17	−.0090	0	−.0008	−.0083
1977–78	18	.0076	0	.0039	.0036
1978–79	15	.0273	0	.0083	.0190
Average	...	−.0087	0	.0025	−.0112

firms whose emissions were constrained by regulations increased from 24 to 41 over the sample period. Fifteen of the sample firms were not effectively constrained by sulfur dioxide regulations in 1979; 11 of these were never constrained during the complete sample period.

The overall trend in productivity growth is similar for both groups of firms. Negative rates of productivity growth of more than 3 percent per year at the beginning of the sample period increase steadily and become positive after 1977. However, the average annual rate of productivity growth over the 1973–79 period for the constrained firms is −1.35 percent, which is almost half a percentage point lower than the −0.87 percent average rate for the unconstrained firms.

- Firms facing regulatory constraints have lower overall productivity growth (-0.0135) than those without constraints (-0.0087).
- The effect of regulation is especially strong for the years 1975-76. 1976 was the first year when the air quality standards were supposed to be met.
- Small scale effects.
- Residual technical change mostly negative and similar for the binding and nonbinding firms.