Environmental investment and firm performance: A network approach

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Introduction

Reductions to energy use and emissions often require investment in new production methods.

Environmental investments may spur innovations that increase productivity, through design improvements and spillover effects (Clarke et al., 2006).

We introduce firm-level investments, both environmental and production oriented, into a network production model to better account for their role in:

- productivity, efficiency change and technology change
- energy efficiency
- environmental performance

We apply this framework to firm-level data on Swedish manufacturing.

Introduction

Existing environmental network studies include:

- Murty et al. (2012) develop a bi-production technology, connecting conventional production to a pollution-generating technology.
- Färe et al. (2013) break the technology into a production stage and an abatement stage.
- Hampf (2014) incorporates a materials balance condition into a similar two-stage network.

This study connects the production technologies for good and bad outputs through intertemporal investment decisions.

Environmental Investments and Expenditures

- Environmental investments:

  - Pollution treatment, or 'end-or-pipe' techniques (e.g., air filters and scrubbers)

  - Pollution prevention processes (e.g., fuel switching/saving equipment and re-circulation of process gases)

- Environmental expenditures:

  - Operating costs of existing environmental equipment, internal monitoring, personnel training, and remediation costs. (Juraite et al., 2014)

Modeling Framework

We model the production technology, T, for time period t as

$$T^t = \left\{(x^t,\, i^{t-1},\, y^t,\, u^t) : x^t \text{ and } i^{t-1} \text{ can produce } y^t \text{ and } u^t\right\},$$

- $x^t = (x_1^t, \ldots, x_N^t)$ denotes current period resource inputs
- i^{t-1} is total investment from the previous period
- $y^t = (y_1^t, \ldots, y_M^t)$ is current period production output
- $u^t = (u_1^t, \ldots, u_J^t)$ is current period pollution emissions.

We further decompose the technology:

- $i^t = pi^t + ei^t$, production and environmental investments
- $x^t = ex^t + ox^t$, energy inputs and other inputs

Modeling Framework

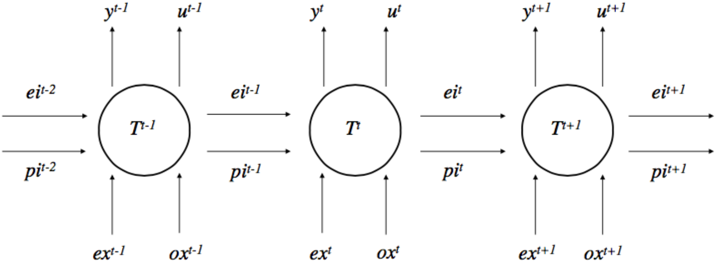

Figure : The Environmental Investment Technology Network

- We estimate the network technology nonparametrically, using Data Envelopment Analysis (DEA) methods (Charnes et al., 1978).

DEA Network Technology Model

$$
\begin{aligned}
T^t =& \{y^t, u^t, x^t, pi^{t-1}, ei^{t-1}\} : \\
y_m^t \leq& \sum_{k=1}^{K} z_k^t y_{km}^t, m = 1, \ldots, M, \\
u_j^t =& \sum_{k=1}^{K} z_k^t u_{kj}^t, j = 1, \ldots, J, \\
x_n^t \geq& \sum_{k=1}^{K} z_k^t x_{kn}^t, n = 1, \ldots, N, \\
pi^{t-1} \geq& \sum_{k=1}^{K} z_k^t pi_k^{t-1}, \\
ei^{t-1} \geq& \sum_{k=1}^{K} z_k^t ei_k^{t-q}, \\
z_k^t \geq& 0,\ k = 1, \ldots, K.
\end{aligned}
$$

Network Technology Indexes

- Our performance indexes are based on quantity indexes, constructed from distance functions (Shephard, 1970), for production output, energy use and pollution emissions.

- Beginning with production output, y, in time period τ, we let

$$D_y^\tau(x^\tau, i^{\tau-1}, y^\tau, u^\tau) = inf\{\theta : (x^\tau, i^{\tau-1}, \frac{y^\tau}{\theta}, u^\tau) \in T^\tau\}$$

- θ measures the feasible proportional increase in current production output, given current inputs, previous investment, and the production technology.

- $0 \leq \theta \leq 1$ and $\theta = 1$ at the frontier.

Production Output Distance Estimation

$$(D_y^t(x^t,\ i^{t-1},\ y^t, u^t))^{-1} = max\,\theta$$

$$\theta y_{k'm}^t \leq \sum_{k=1}^{K} z_k^t y_{km}^t,\ m = 1,\ \ldots,\ M,$$

$$u_{k'j}^t = \sum_{k=1}^{K} z_k^t u_{kj}^t,\ j = 1,\ \ldots,\ J,$$

$$x_{k'n}^t \geq \sum_{k=1}^{K} z_k^t x_{kn}^t,\ n = 1,\ \ldots,\ N,$$

$$ei_{k'}^{t-1} \geq \sum_{k=1}^{K} z_k^t ei_k^{t-1},$$

$$pi_{k'}^{t-1} \geq \sum_{k=1}^{K} z_k^t pi_k^{t-1},$$

$$z_k^t \geq 0,\ k = 1,\ \ldots,\ K.$$

Malmquist Productivity Index

This gives rise to the widely applied Malmquist (1953) productivity index, adapted to our network setting,

$$M_y(\tau, \tau+1) =$$

$$\left[\left(\frac{D_y^{\tau}(x^{\tau+1},\ i^{\tau},\ y^{\tau+1}, u^{\tau+1})}{D_y^{\tau}(x^{\tau},\ i^{\tau-1},\ y^{\tau}, u^{\tau})} \right) \left(\frac{D_y^{\tau+1}(x^{\tau+1},\ i^{\tau},\ y^{\tau+1}, u^{\tau+1})}{D_y^{\tau+1}(x^{\tau},\ i^{\tau-1},\ y^{\tau}, u^{\tau})} \right) \right]^{\frac{1}{2}},$$

where efficiency change is measured as

$$EC_y(\tau, \tau+1) = \frac{D_y^{\tau+1}(x^{\tau+1},\ i^{\tau},\ y^{\tau+1}, u^{\tau+1})}{D_y^{\tau}(x^{\tau},\ i^{\tau-1},\ y^{\tau}, u^{\tau})},$$

and technology change is

$$TC_y(\tau, \tau+1) =$$

$$\left[\left(\frac{D_y^{\tau}(x^{\tau+1},\ i^{\tau},\ y^{\tau+1}, u^{\tau+1})}{D_y^{\tau+1}(x^{\tau+1},\ i^{\tau},\ y^{\tau+1}, u^{\tau+1})} \right) \left(\frac{D_y^{\tau}(x^{\tau},\ i^{\tau-1},\ y^{\tau}, u^{\tau})}{D_y^{\tau+1}(x^{\tau},\ i^{\tau-1},\ y^{\tau}, u^{\tau})} \right) \right]^{\frac{1}{2}}.$$

Energy Efficiency Index (EEI)

To measure energy efficiency, we consider feasible contractions of energy use, given other inputs, investment and outputs using

$$D_{ex}^{\tau}(ex^{\tau}, ox^{\tau}, i^{\tau-1}, y^{\tau}, u^{\tau}) = sup\{\lambda : (\frac{ex^{\tau}}{\lambda}, ox^{\tau}, i^{\tau-1}, y^{\tau}, u^{\tau}) \in T^{\tau}\},$$

- $\lambda \geq 1$ and $\lambda = 1$ at the frontier.

Energy Input Distance Estimation

$$(D_{ex}(ex^t,\, ox^t,\, i^{t-1},\, y^t,))^{-1} = min\,\lambda,\ s.t.$$

$$y^t_{k'm} \leq \sum_{k=1}^{K} z^t_k y^t_{km},\ m = 1,\ ...,\ M,$$

$$u^t_{k'j} = \sum_{k=1}^{K} z^t_k u^t_{kj},\ j = 1,\ ...,\ J,$$

$$x^t_{k'n} \geq \sum_{k=1}^{K} z^t_k x^t_{kn},\ n = 1,\ ...,\ N-1,$$

$$\lambda ex^t_{k'} \geq \sum_{k=1}^{K} z^t_k ex^t_k,$$

$$ei^{t-1}_{k'} \geq \sum_{k=1}^{K} z^t_k ei^{t-1}_k,$$

$$pi^{t-1}_{k'} \geq \sum_{k=1}^{K} z^t_k pi^{t-1}_k,$$

Energy Efficiency Index (EEI)

- We measure energy efficiency change similarly, using the energy efficiency index (EEI),

$$EEI(\tau, \tau+1) = \frac{D_{ex}(ex^{\tau}, ox^{\tau}, i^{\tau-1}, y^{\tau}, u^{\tau})}{D_{ex}(ex^{\tau+1}, ox^{\tau+1}, i^{\tau}, y^{\tau+1}, u^{\tau+1})},$$

- EEI values greater than one indicate improvements to energy efficiency.

Environmental Performance Index (EPI)

- To measure environmental performance, we construct quantity indexes for both desirable and undesirable outputs.
- Our desirable quantity index is written as

$$Q_y(\tau, \tau+1) = \frac{D_y^{\tau+1}(x^{\tau+1}, i^{\tau}, y^{\tau+1}, u^{\tau+1})}{D_y^{\tau}(x^{\tau}, i^{\tau-1}, y^{\tau}, u^{\tau})}.$$

Environmental Performance Index (EPI)

For pollution emissions, we measure feasible contractions, given inputs, investment, and production output with

$$D_u^{\tau}(x^{\tau}, i^{\tau-1}, y^{\tau}, u^{\tau}) = sup\{\delta : (x^{\tau}, i^{\tau-1}, y^{\tau}, \frac{u^{\tau}}{\delta}) \in T^{\tau}\}.$$

- $\delta \geq 1$ and $\delta = 1$ at the frontier.

Pollution Output Distance Estimation

$$
\begin{aligned}
(D_u(x^t,\, i^{t-1},\, y^t,\, u^t))^{-1} = min\,\delta & \\
s.t. \quad & y^t_{k'm} \leq \sum_{k=1}^{K} z^t_k y^t_{km},\; m = 1,\, \ldots,\, M, \\
& x^t_{k'n} \geq \sum_{k=1}^{K} z^t_k x^t_{kn},\; n = 1,\, \ldots,\, N, \\
& \delta u^t_{k'j} = \sum_{k=1}^{K} z^t_k u^t_{kj},\; j = 1,\, \ldots,\, J, \\
& ei^{t-1}_{k'} \geq \sum_{k=1}^{K} z^t_k ei^{t-1}_k, \\
& pi^{t-1}_{k'} \geq \sum_{k=1}^{K} z^t_k pi^{t-1}_k, \\
& z^t_k \geq 0,\; k = 1,\, \ldots,\, K,
\end{aligned}
$$

Environmental Performance Index (EPI)

The corresponding pollution quantity index is

$$Q_u(\tau, \tau+1) = \frac{D_u^{\tau+1}(x^{\tau+1}, i^{\tau}, fy^{\tau+1}, u^{\tau+1})}{D_u^{\tau}(x^{\tau}, i^{\tau-1}, y^{\tau}, u^{\tau})}.$$

- Note that $Q_u(\tau, \tau+1) < 1$ indicates improvement.

Environmental Performance Index (EPI)

- We then construct the EPI as the ratio of good to bad quantity indexes, following Färe et al. (2006; 2010) as,

$$EPI(y^{\tau}, y^{\tau+1}, u^{\tau}, u^{\tau+1}) = \frac{Q_y(\tau, \tau+1)}{Q_u(\tau, \tau+1)}.$$

- An EPI value greater than 1 indicates a relative increase in goods to bads.

Application to Swedish Manufacturing Firms

We apply our environmental investment network technology and associated performance index framework to an unbalanced panel of 66 firms from Sweden's Pulp and Paper manufacturing sector, for the years 2002 - 2008.

Our data includes at the plant level:

- Expenditures for standard production and energy inputs
- Expenditures for environmental management practices and environmental investments
- Emissions of CO_2, SO_2, and NO_X

Application to Swedish Manufacturing Firms

- Capital and Output are measured in M 2008 SEK.
- Environmental Investments and Expenditures are measured in 1,000s 2008 SEK.

Table : Summary Statistics, 2002 - 2008

Variable	Median	Mean	Min	Max
Capital	642.20	1,484.56	9.47	6,979.91
Labor	478.00	644.00	42.00	3,938.00
Energy (MWH)	369,113.40	824,521.40	1,202.45	6,319,466.00
EnvExp	9,200.00	18,082.05	80.00	146,660.00
Env. Inv.	1,962	17,646.02	0.00	291,460.00
Output	120,679.70	191,158.50	5,333.55	1,228,211.00
CO_2 (T)	20,176.53	34,681.72	14.99	236,158.90
SO_2 (T)	22.50	50.73	0.00	353.19
NO_X (T)	32.53	87.87	0.02	515.88

Index Results

Table : Industry Geometric Means by Year

Year	Malm.	EffCh.	TechCh.	EEI	EPI	Qy	Qb
03 - 08	0.989	1.027	0.964	1.114	0.937	1.027	1.096
03 - 04	1.021	1.028	0.994	1.026	1.207	1.028	0.852
04 - 05	0.969	0.945	1.025	1.005	0.755	0.944	1.251
05 - 06	0.984	0.976	1.008	0.870	0.987	0.978	0.992
06 - 07	1.011	1.085	0.932	1.174	0.998	1.083	1.085
07 - 08	1.004	0.999	1.006	1.058	1.045	0.999	0.956

- The Malmquist means indicate a slight overall decline in productivity, driven more by a decrease in Technology.
- The EEI results indicate general improvements to energy efficiency; the EPI indicates an overall decline to environmental performance, due largely to the 2004 - 2005 period.

Industry Trends

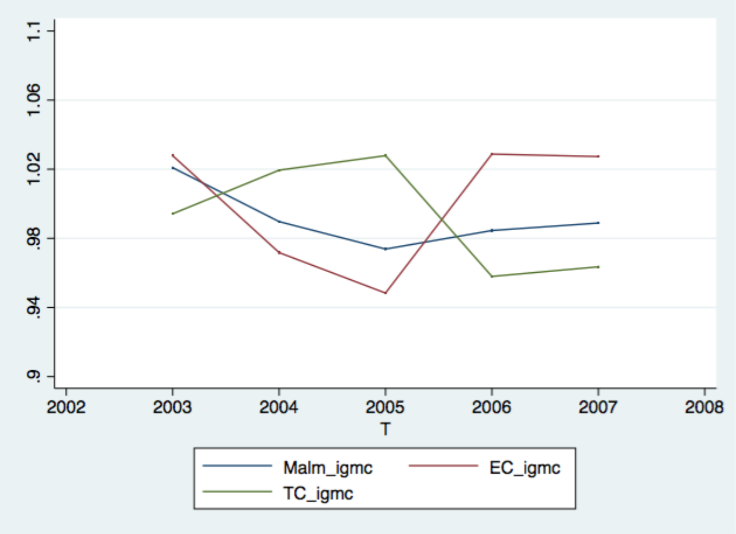

Figure : Malmquist Industry Cumulative Geometric Means

Industry Trends

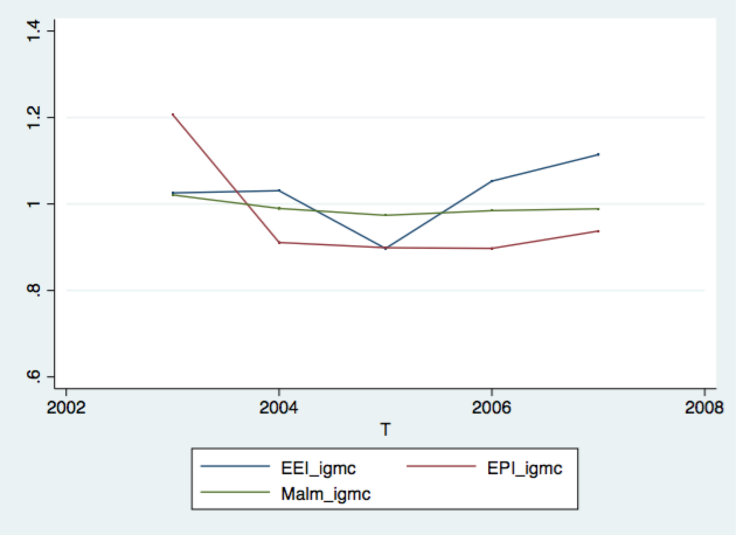

Figure : Malmquist, EEI and EPI Cumulative Geometric Means

Index Results at the Plant Level

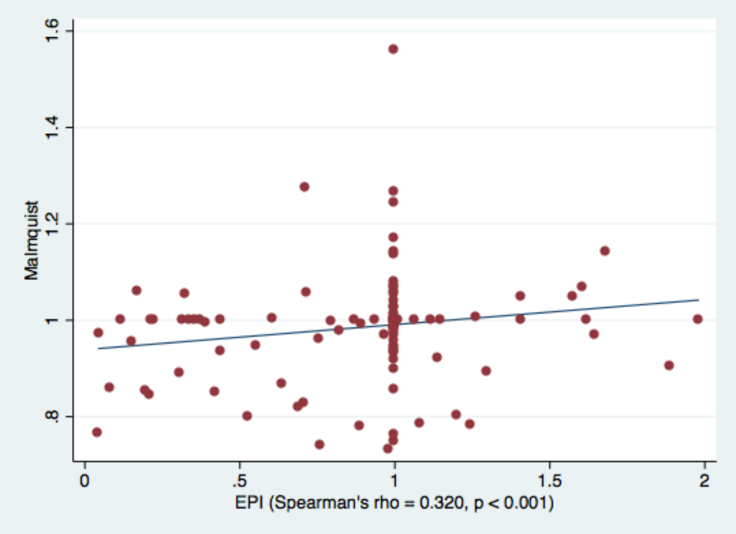

Figure : EPI and Malmquist Results at the Plant Level

Index Results at the Plant Level

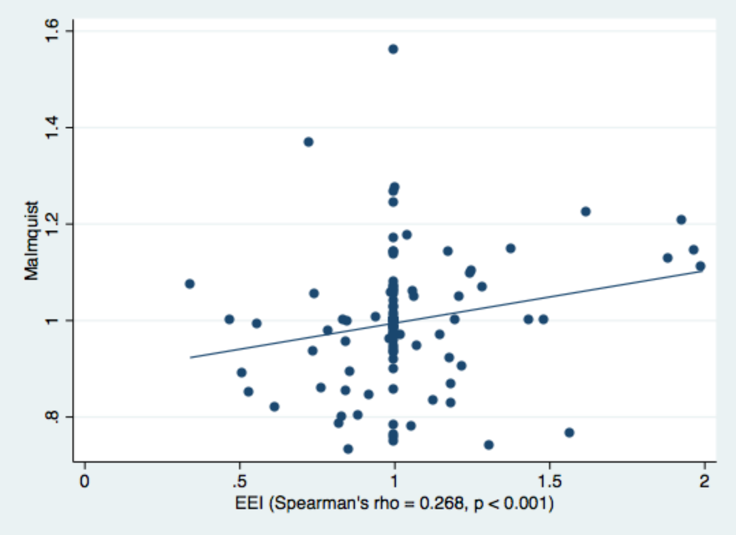

Figure : EEI and Malmquist Results at the Plant Level

Index Results at the Plant Level

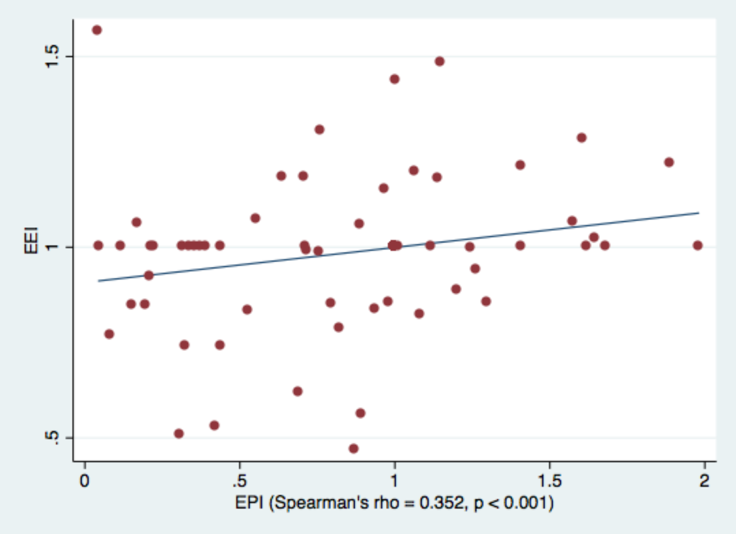

Figure : EEI and EPI Results at the Plant Level

Conclusion

We develop a network technology representation to measure energy efficiency, environmental performance and productivity change, accounting for intertemporal investment decisions.

For firms in Sweden's pulp and paper sector, we find:

- General improvements to energy efficiency
- Overall decline in environmental performance
- Slight decline to overall productivity
- Positive relationship between energy efficiency, environmental performance, and productivity

Conclusion

To our knowledge, this is the first study to include environmental investments in a network environmental technology framework.

Future extensions include:

- Integrating the investment network with an abatement technology network.
- Incorporate dynamic optimization, to estimate optimal investment time paths, for both environmental and production objectives.