生產力與效率分析
Productivity and Efficiency Analysis

需求變異下的效率分析
(Demand Effect in PEA)

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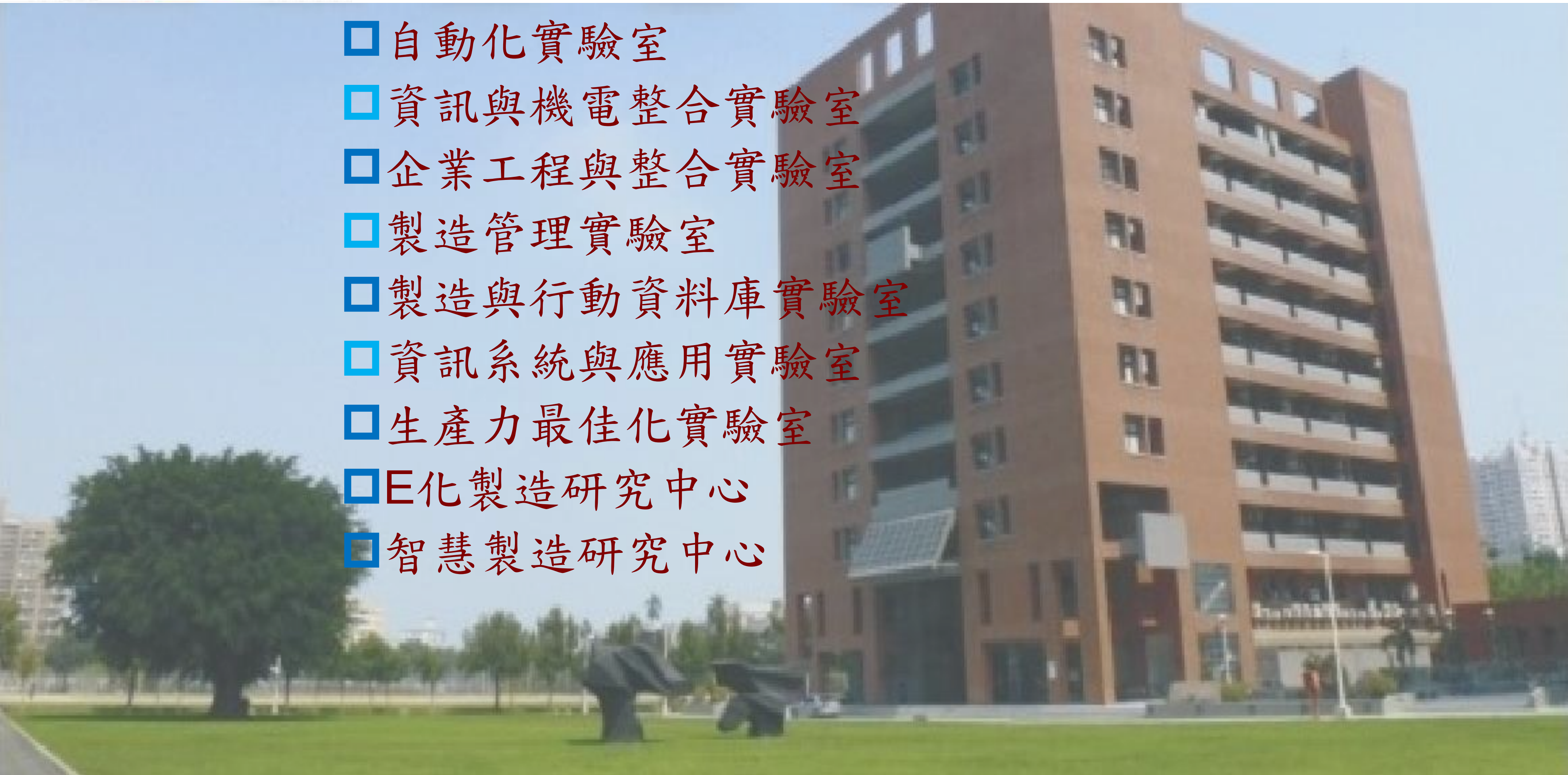

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Outline

- Background and Motivation
- Two-Dimensional Efficiency Decomposition (2DED)
- Effectiveness Measure
- Proactive DEA

Background and Motivation

- In PEA, efficiency analysis is based on the transformation from inputs to outputs; however, outputs are generally affected by "demand".

- Demand fluctuations lead to biased estimates of efficiency.
  - insufficient realized demand will cause measured output to be lower.
  - Efficiency Underestimation

- Panel data: Frontier shifting backward is often attributed to production issues, when in reality it may be a result of demand deterioration. (Lee and Johnson, 2011).

Background and Motivation

- From systemic perspective of a business

Production Unit

Sales Unit

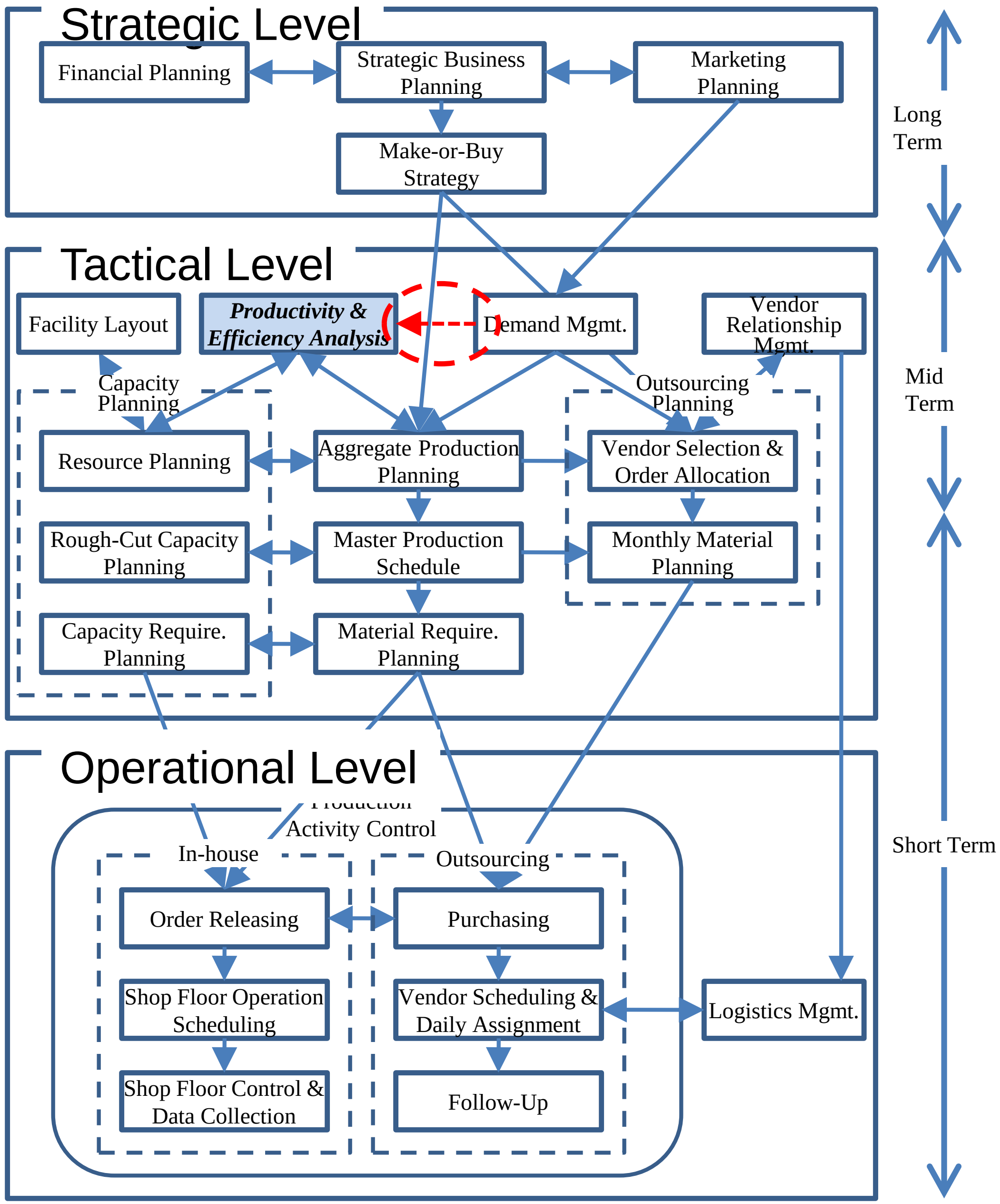
Inputs ⟷ Outputs ⟷ Demand

$$\frac{output}{input} = \text{Efficiency}$$

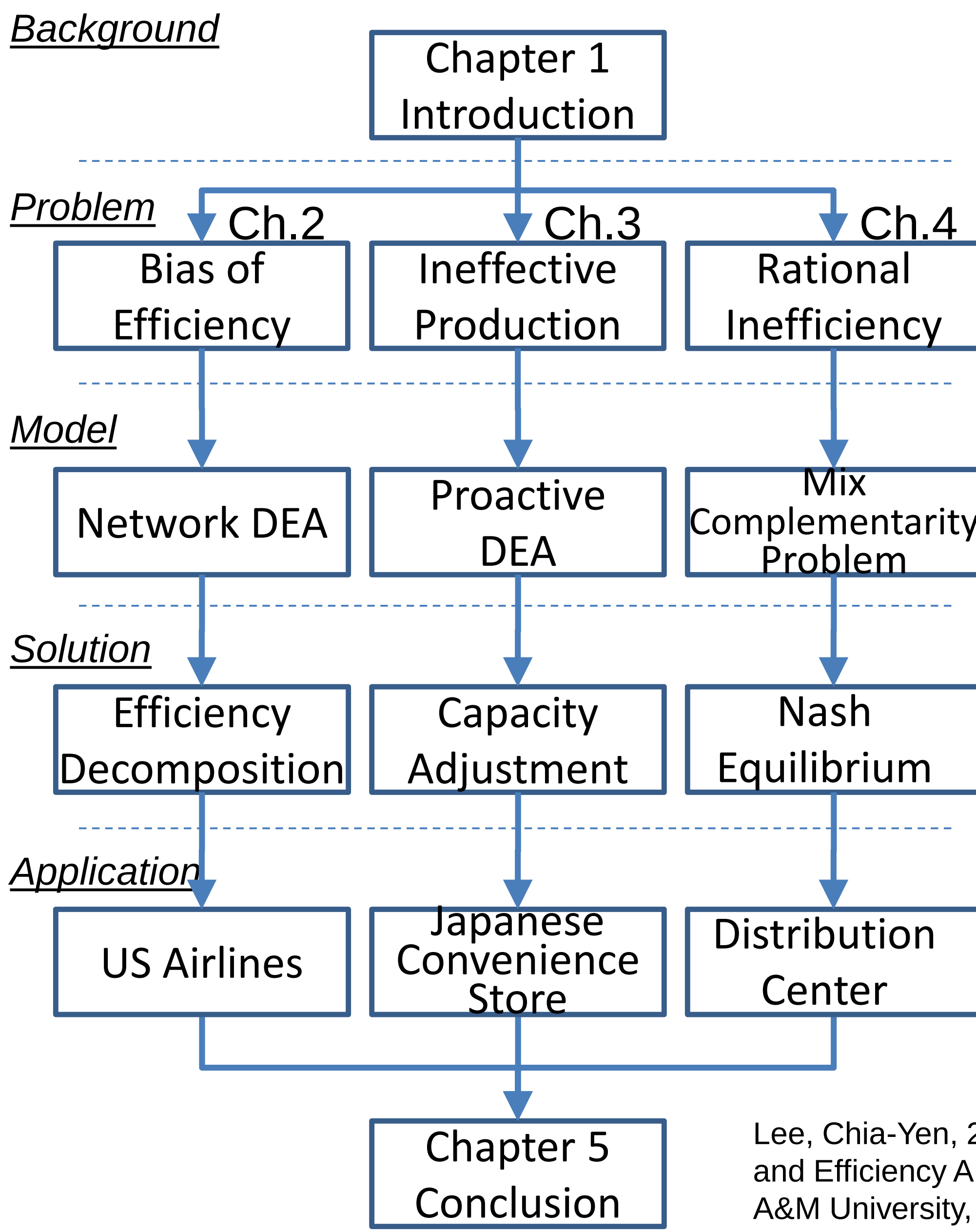
$$\frac{Demand}{output} = \text{Effectiveness}$$

(Lee and Johnson, 2014)

Position of Demand Effect in PEA



Demand Effects in Productivity
and Efficiency Analysis



Lee, Chia-Yen, 2012. Demand Effects in Productivity and Efficiency Analysis. Ph.D. Dissertation in Texas A&M University, USA.

Two-Dimensional Efficiency Decomposition (2DED)

Lee, Chia-Yen and A. L. Johnson, 2012. Two-dimensional Efficiency Decomposition to Measure the Demand Effect in Productivity Analysis. European Journal of Operational Research, 216 (3), 584–593.

2D Efficiency Decomposition (2DED)

- Introduction
- Literature Review
- Research Framework and Methodology
  - Production System Decomposition
  - Two-Dimensional Efficiency Decomposition
    - Efficiency Decomposition of Production Process
    - Efficiency Decomposition of Profitability Change
- Empirical Study- US Airlines Industry
- Conclusion and Future Research

Background and Motivation

- The system is inefficient if its outputs levels are lower than other reference system. However, the reduced actual output can be caused by insufficient demand, that is, demand may bias the efficiency.
- Technical regress is often attributed to production issues when actually it may be a result of demand fluctuation.

Challenges

- How to identify the source of inefficiency?
- How to define the production process with demand component?
- How to measure the technical and profitability efficiency change?

Research Aim

- This study develops an two-dimensional efficiency decomposition of production process and profitability change via network DEA and Fisher Index framework to clarify the sources of inefficiency.

2D Efficiency Decomposition (2DED)

Demand Effect

- Fielding *et al.* (1985): single factor productivity ratio of transportation system and distinguished the production process from the consumption process.
- Lan and Lin (2005) and Yu and Lin (2008): network DEA models to characterize a consumption process.

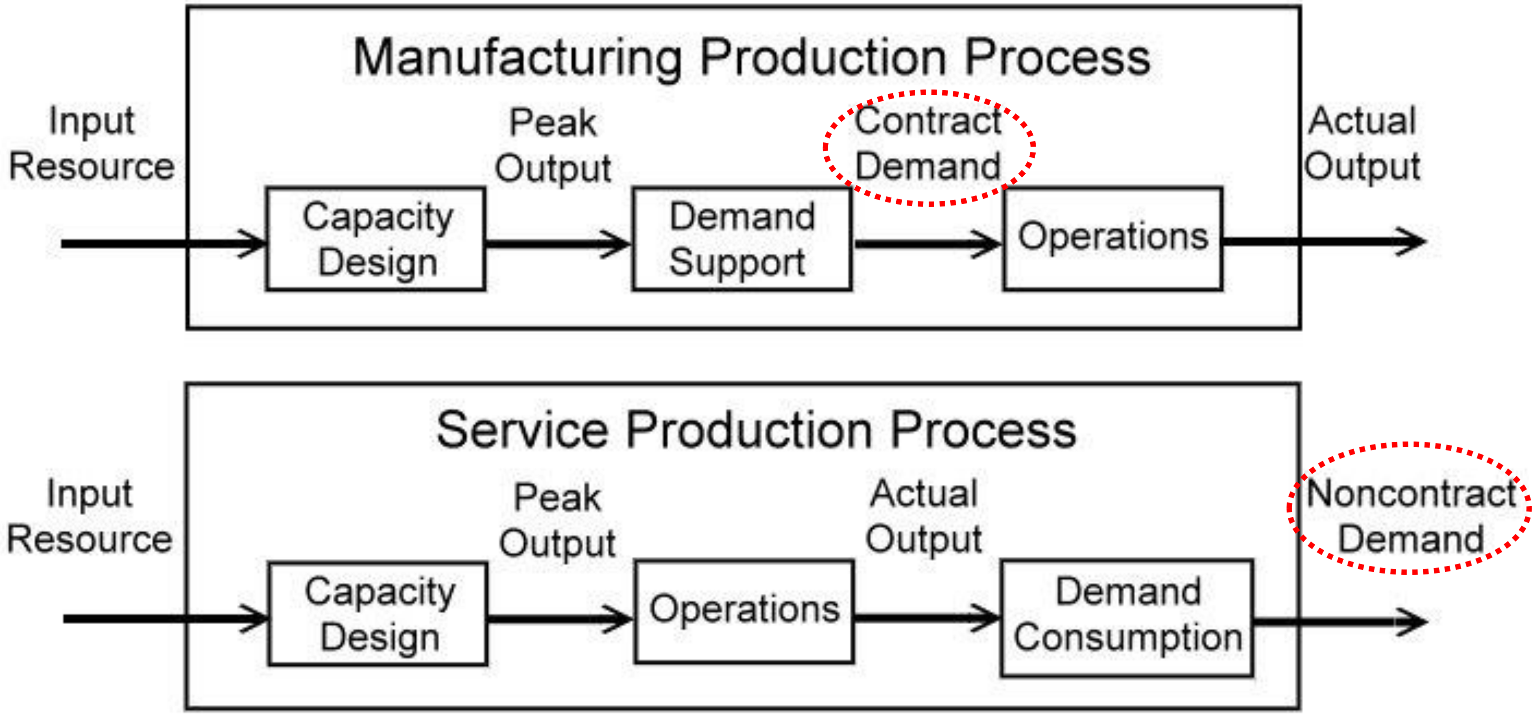
Productivity Change

- Nishimize and Page (1982): total factor productivity change
- Färe *et al.* (1992, 1994): Malmquist productivity index (MPI)
- Ray and Mukherjee (1996): decomposition of Fisher productivity index restricted to the single-output technology.
- Zofio and Prieto (2006): decomposition of Fisher index into Malmquist index with priori weighting parameter of residual allocative term.
- Kuosmanen and Sipiläinen (2009): decomposition of Fisher index the product of five components: change in efficiency, technical change, change in scale efficiency, change in allocative efficiency, and price effect.

(Profitability Eff Change = TechEff x ScaleEff x AllocativeEff)

2D Efficiency Decomposition (2DED)

- Manufacturing system v.s Service system



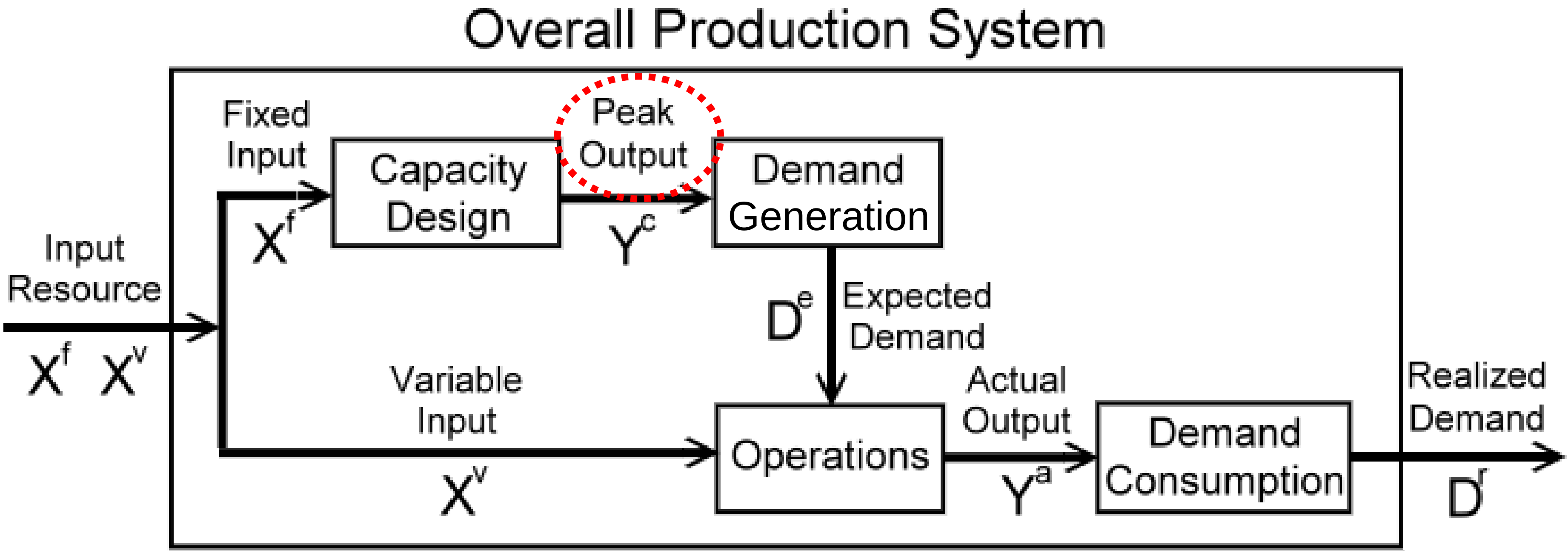
(Lee and Johnson, 2011, IJPR)

- Manufacturing: sales quantities and prices are defined before production due to a longer production lead time (Internal Demand)
- Service: non-storable commodities which once transformed from inputs, must be consumed by customers immediately (External Demand)

2D Efficiency Decomposition (2DED)

Production System Decomposition

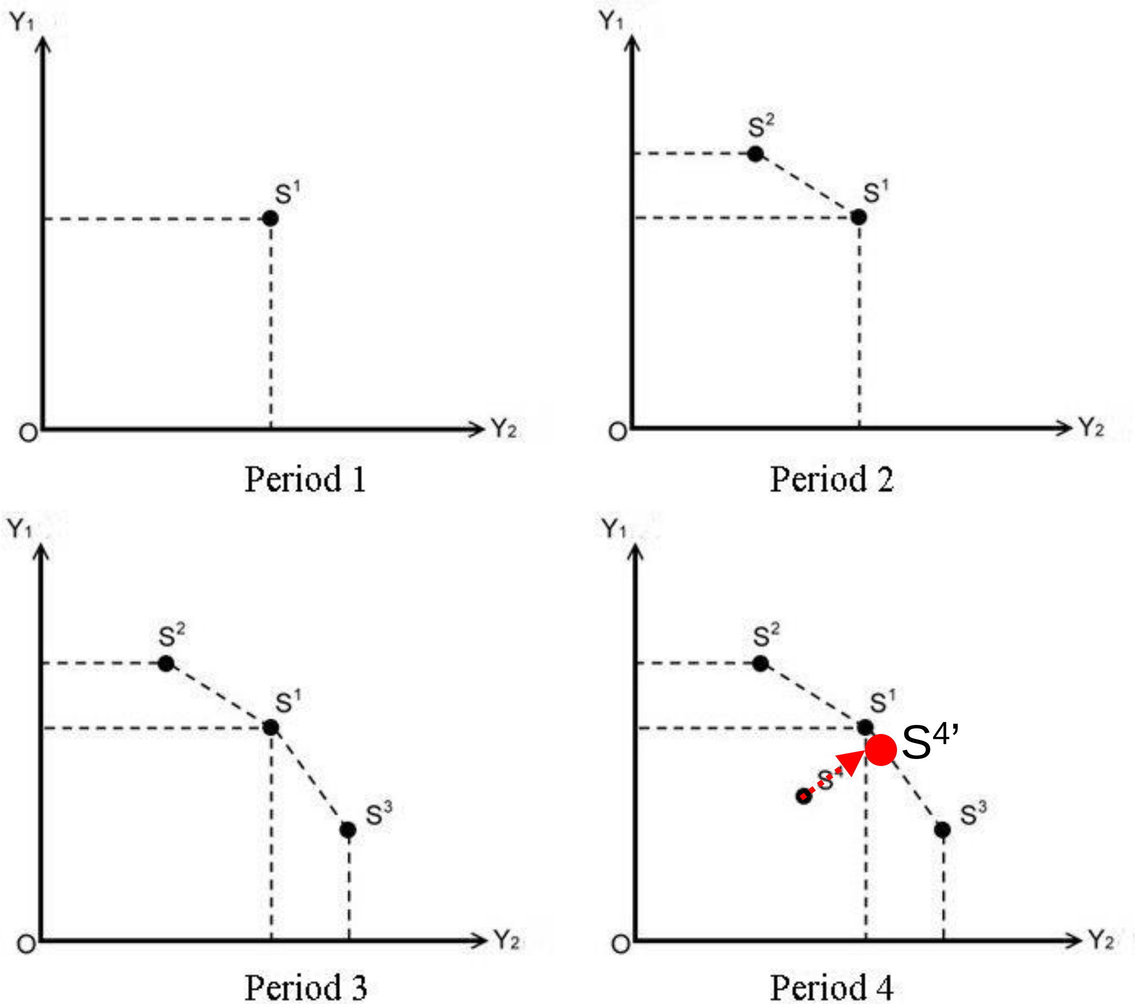
- A Hybrid System of Manufacturing and Service Process



- Four components: capacity design, demand generation, operations, demand consumption
- “Peak output”: historical best production performance needs to be estimated.

2D Efficiency Decomposition (2DED)

Peak Output Estimation



Sequential model

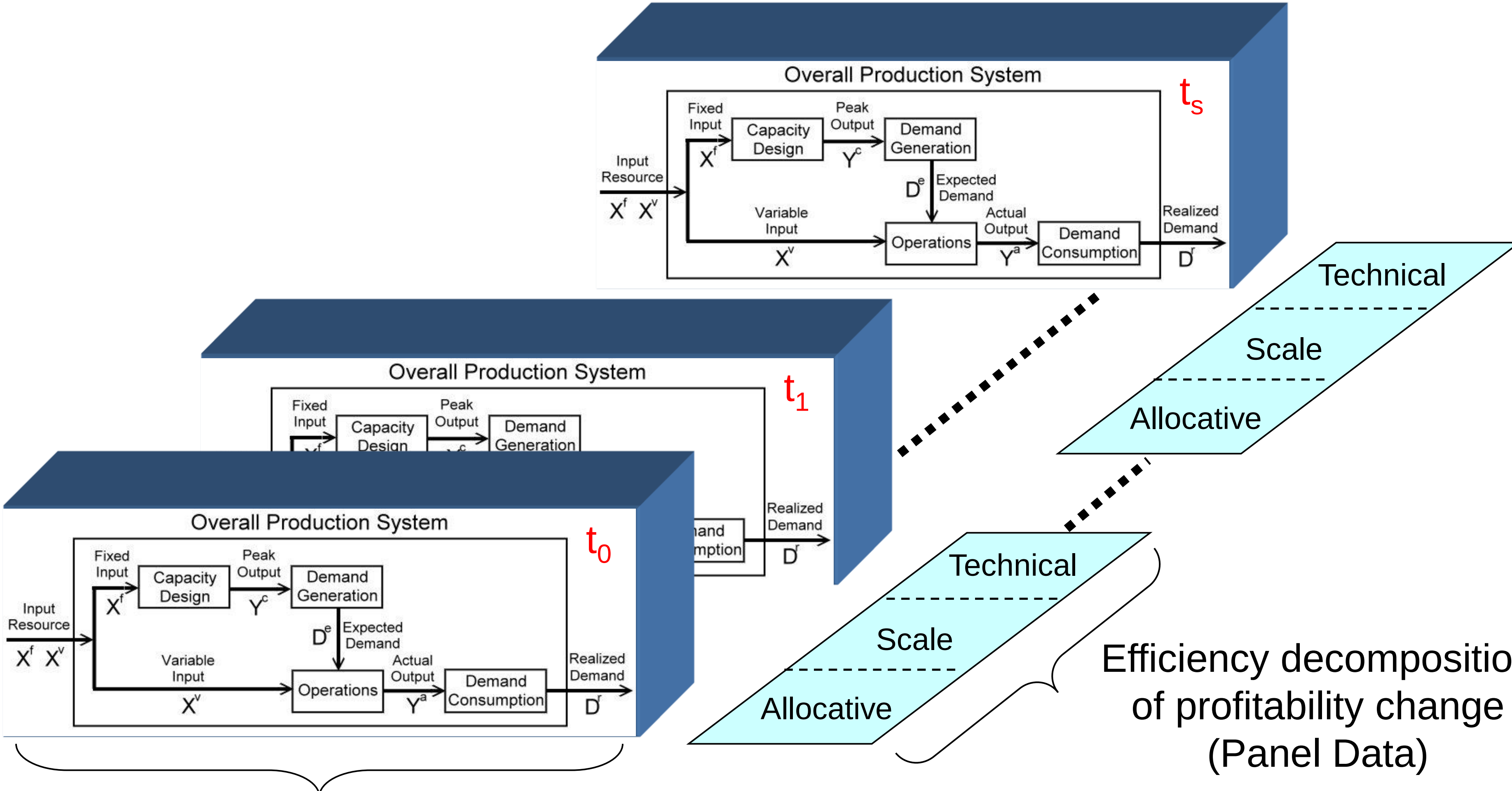
Diewert (1980, 1992),
Pastor and Lovell (2005)

$$
\begin{aligned}
Max \quad & \theta_{rs} \\
s.t. \quad & \sum_{k,t \in \{0,\dots,s\}} \lambda_{kt} X^{f}_{ikt} \le X^{f}_{irs}, \ \forall i \\
& \sum_{k,t \in \{0,\dots,s\}} \lambda_{kt} Y^{a}_{qkt} \ge \theta_{rs} Y^{a}_{qrs}, \ \forall q \\
& \sum_{k,t \in \{0,\dots,s\}} \lambda_{kt} = 1 \\
& \lambda_{kt} \ge 0, \ \forall k, \forall t
\end{aligned}
$$

$$\text{Peak Output} = \theta_{rs} \times Y_{qrs}$$

Diewert, W.E., 1980. Capital and the theory of productivity measurement. The American Economic Review 70 (2), 260–267.
Diewert, W.E., 1992. The measurement of productivity. Bulletin of Economic Research 44 (3), 163–198.
Pastor, J. T., and C.A. Knox Lovell, 2005. A global Malmquist productivity index. Economics Letters, 88 (2), 266-271.

Two-Dimensional Efficiency Decomposition (2DED)



Efficiency decomposition of profitability change (Panel Data)

Efficiency decomposition of production process ← Two-Dimensional Efficiency Decomposition

2D Efficiency Decomposition (2DED)

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Efficiency Decomposition of Production Process

- Relational Network VRS DEA (based on Kao, 2009)

$$E_{rs}^{P} = Max \sum_{q\in Q} u_q^r D_{qrs}^r - u_0^r$$

$$s.t. \sum_{i\in I} v_i^f X_{irs}^f + \sum_{j\in J} v_j^v X_{jrs}^v = 1$$

$$\sum_{q\in Q} z_q^c Y_{qkt}^c - \sum_{i\in I} v_i^f X_{ikt}^f - z_0^c \le 0, \quad \forall k, \forall t \in \{1,\ldots,s\}$$ -Design

$$\sum_{q\in Q} u_q^e D_{qkt}^e - (\sum_{q\in Q} z_q^c Y_{qkt}^c - z_0^c) - u_0^e \le 0, \quad \forall k, \forall t \in \{1,\ldots,s\}$$ -Generation

$$\sum_{q\in Q} z_q^a Y_{qkt}^a - \left(\sum_{q\in Q} u_q^e D_{qkt}^e - u_0^e + \sum_{j\in J} v_j^v X_{jkt}^v \right) - z_0^a \le 0, \quad \forall k, \forall t \in \{1,\ldots,s\}$$ -Operations

$$\sum_{q\in Q} u_q^r D_{qkt}^r - (\sum_{q\in Q} z_q^a Y_{qkt}^a - z_0^a) - u_0^r \le 0, \quad \forall k, \forall t \in \{1,\ldots,s\}$$ -Consumption

$$v_i^f, v_j^v, z_q^c, u_q^e, z_q^a, u_q^r \ge 0, \quad \forall i, \forall j, \forall q$$

2D Efficiency Decomposition (2DED)

Efficiency Decomposition of Production Process

- Efficiency Estimation of Each Component

$$E_{rs}^{D} = (\sum_{q\in Q} z_q^{c*} Y_{qrs}^{c} - z_0^{c*}) / (\sum_{i\in I} v_i^{f*} X_{irs}^{f})$$

$$E_{rs}^{G} = (\sum_{q\in Q} u_q^{e*} D_{qrs}^{e} - u_0^{e*}) / (\sum_{q\in Q} z_q^{c*} Y_{qrs}^{c} - z_0^{c*})$$

$$E_{rs}^{O} = (\sum_{q\in Q} z_q^{a*} Y_{qrs}^{a} - z_0^{a*}) / (\sum_{q\in Q} u_q^{e*} D_{qrs}^{e} - u_0^{e*} + \sum_{j\in J} v_j^{v*} X_{jrs}^{v})$$

$$E_{rs}^{C} = (\sum_{q\in Q} u_q^{r*} D_{qrs}^{r} - u_0^{r*}) / (\sum_{q\in Q} z_q^{a*} Y_{qrs}^{a} - z_0^{a*})$$

Summary

- The proposed network DEA model can decompose the efficiency of production system and separate the demand and production process in efficiency analysis.

2D Efficiency Decomposition (2DED)

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Efficiency Decomposition of Profitability Change

- Kuosmanen and Sipiläinen (2009)

$$\Delta\rho Eff = \rho Eff^{1}(w^{1}, p^{1}; x^{1}, y^{1}) / \rho Eff^{0}(w^{0}, p^{0}; x^{0}, y^{0})$$
$$= \Delta TEff \cdot \Delta SEff \cdot \Delta AEff$$

$$\Delta SEff \equiv \frac{(ISEff^{1} \cdot OSEff^{1})^{1/2}}{(ISEff^{0} \cdot OSEff^{0})^{1/2}}$$

$$\Delta AEff \equiv \left(\frac{IAEff^{1}}{IAEff^{0}} \cdot \frac{OAEff^{1}}{OAEff^{0}} \right)^{1/2}$$

$$ISEff^{t} \equiv \left(\frac{p^{t} \cdot y^{t}}{C^{t}(w^{t}, y^{t})} \right) \Big/ \rho^{t}(w^{t}, p^{t})$$

$$IAEff^{t} \equiv \frac{C^{t}(w^{t}, y^{t})}{w^{t} \cdot (D_{x}^{t}(x^{t}, y^{t}) x^{t})}$$

$$OSEff^{t} \equiv \left(\frac{R^{t}(x^{t}, p^{t})}{w^{t} \cdot x^{t}} \right) \Big/ \rho^{t}(w^{t}, p^{t})$$

$$OAEff^{t} \equiv \frac{p^{t} \cdot (y^{t} / D_{y}^{t}(x^{t}, y^{t}))}{R^{t}(x^{t}, p^{t})}$$

$$\Delta TEff \equiv (\Delta ITEff \cdot \Delta OTEFF)^{1/2}$$
$$\Delta ITEff \equiv D_{x}^{t+1}(x^{t+1}, y^{t+1}) / D_{x}^{t}(x^{t}, y^{t})$$
$$\Delta OTEff \equiv D_{y}^{t+1}(x^{t+1}, y^{t+1}) / D_{y}^{t}(x^{t}, y^{t})$$

$$D_{Input}^{t}(x, y) = \inf\{\theta \mid (\theta x, y) \in \tilde{T}^{t}\}$$
$$R^{t}(x, p) = \max_{y}\{p \cdot y \mid (x, y) \in \tilde{T}^{t}\}$$
$$D_{Outputt}^{t}(x, y) = \inf\{\theta \mid (x, y/\theta) \in \tilde{T}^{t}\}$$
$$\rho^{t}(w, p) = \max_{x,y}\{\frac{p \cdot y}{w \cdot x} \mid (x, y) \in \tilde{T}^{t}\}$$
$$C^{t}(w, y) = \min_{x}\{w \cdot x \mid (x, y) \in \tilde{T}^{t}\}$$
$$\rho Eff^{t}(w^{t}, p^{t}; x^{t}, y^{t}) = \frac{p^{t} \cdot y^{t} / w^{t} \cdot x^{t}}{\rho^{t}(w^{t}, p^{t})}$$

2D Efficiency Decomposition (2DED)

- Empirical Study- US Airlines Industry
- Background
  - Observations: 15 corporations (civil and cargo airlines)
  - Time: 2006 – 2008 (Yearly)
  - Source: Bureau of Transportation Statistics at Research and Innovative Technology Administration
- Data Description
  - Input variables:
    - aircraft fleet size (fixed)
    - fuel (variable)
    - employee (variable)
  - Two products (peak output, expected demand, actual output, realized demand):
    - passenger-miles
    - freight-ton-miles

2D Efficiency Decomposition (2DED)

Efficiency Decomposition Analysis (2008 cross-section)

		System				Design				Generation				Operations				Consumption			
Firm	No.	TE	SE	AE	PE	TE	SE	AE	PE	TE	SE	AE	PE	TE	SE	AE	PE	TE	SE	AE	PE
AirTran Airways	A	0.79	0.87	0.91	0.62	0.92	0.83	0.99	0.76	1	0.91	1	0.91	1	0.76	1	0.76	1	0.91	1	0.91
Alaska Airlines	B	0.81	0.71	0.77	0.44	0.97	0.75	1	0.73	0.94	0.90	0.83	0.7	0.94	0.91	0.97	0.84	0.94	0.90	0.84	0.7
American Airlines	C	0.99	0.72	1	0.71	0.96	0.88	1	0.85	0.99	0.90	1	0.89	1	0.87	1	0.87	0.99	0.90	1	0.89
American Eagle	D	0.66	0.48	0.97	0.31	0.90	0.58	0.90	0.47	1	0.74	1	0.74	1	0.80	1	0.8	1	0.74	1	0.74
Continental	E	0.86	0.85	0.98	0.71	0.86	0.99	0.90	0.77	0.99	1	1	0.98	0.90	0.95	0.92	0.78	0.99	1	1	0.98
Delta Air Lines	F	0.99	0.61	0.98	0.59	0.74	0.71	0.98	0.52	0.99	0.92	0.98	0.89	1	0.88	1	0.88	0.99	0.92	0.98	0.89
ExpressJet airlines	G	1	0.64	1	0.64	1	0.53	1	0.53	1	0.81	1	0.81	1	0.87	1	0.87	1	0.82	1	0.82
Federal Express	H	0.97	0.88	1	**0.86**	1	0.98	1	0.98	0.96	0.96	1	0.96	1	0.89	1	0.89	0.97	0.96	1	0.96
JetBlue Airways	I	0.90	0.78	0.90	0.64	0.86	0.89	0.98	0.75	0.98	0.96	0.94	0.88	0.99	0.87	0.97	0.84	0.98	0.96	0.95	0.88
Northwest Airlines	J	0.77	0.86	1	0.66	0.76	0.99	1	0.75	0.98	0.97	0.97	0.92	0.85	0.93	0.99	0.78	1	0.97	0.98	0.95
SkyWest Airlines	K	0.61	0.64	0.90	0.35	0.46	0.85	0.99	0.39	0.93	0.87	0.95	0.76	1	0.80	1	0.8	0.95	0.87	0.95	0.78
Southwest Airline	L	0.87	0.64	0.86	0.48	0.73	1	0.95	0.69	0.87	0.93	0.85	0.69	1	1	1	1	0.87	0.93	0.86	0.69
United Airlines	M	0.91	0.81	1	**0.74**	1	1	0.98	**0.98**	0.98	0.91	0.99	**0.88**	0.97	**0.87**	1	**0.85**	0.98	0.91	0.99	**0.88**
UPS	N	0.94	0.91	1	**0.86**	1	0.98	1	0.98	0.95	0.96	1	0.91	1	1	1	1	0.94	0.95	1	0.9
US Airways	O	0.74	0.91	0.94	0.63	0.70	0.99	0.95	0.66	0.98	0.99	0.93	0.9	0.87	0.95	0.98	0.81	0.97	0.99	0.94	0.9

2D Efficiency Decomposition (2DED)

- Efficiency Decomposition Analysis (2008 cross-section)

United Airlines	Profitability Efficiency	Technical Eeeiciency	Scale Efficiency	Allocative Efficiency
System	**0.73**	0.97	0.79	0.95
Design	**0.98**	1	0.99	0.99
Generation	**0.88**	0.98	0.91	0.98
Operations	**0.84**	1	**0.85**	0.98
Consumption	**0.88**	0.98	0.91	0.98

2D Efficiency Decomposition (2DED)

Profitability Eff Change of Airlines Industry

Components	2006-2007				2007-2008				2006-2008			
	$\Delta\rho Eff$	$\Delta TEff$	$\Delta SEff$	$\Delta AEff$	$\Delta\rho Eff$	$\Delta TEff$	$\Delta SEff$	$\Delta AEff$	$\Delta\rho Eff$	$\Delta TEff$	$\Delta SEff$	$\Delta AEff$
System	**1.05**	1.00	1.02	1.01	**0.99**	1.02	0.99	0.99	**1.02**	1.01	1.01	1.00
Design	1.05	1.04	1.01	1.00	0.99	0.99	1.00	1.00	1.02	1.01	1.01	1.00
Generation	**0.99**	1.00	1.00	0.99	**0.98**	0.99	1.00	0.99	**0.99**	0.99	1	0.99
Operations	0.99	0.99	1.00	1.00	1.01	1.00	1.01	1.00	1.00	0.99	1.01	1.00
Consumption	**0.99**	1.00	1.00	0.99	**0.99**	0.99	1.00	1.00	**0.99**	0.99	1.00	0.99

2007-2008 economic crisis leads to a downgrade of profitability efficiency change
Source of inefficiency: demand fluctuation

2007-2008 technical regress is mainly caused by demand effect rather than production capability.

2D Efficiency Decomposition (2DED)

Profitability Efficiency Difference

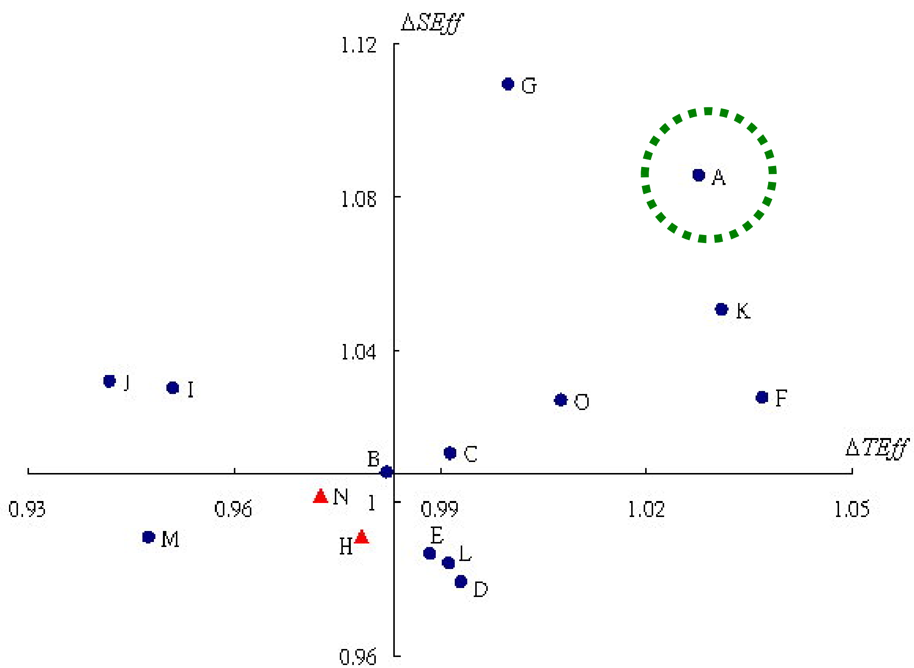
- Civil vs. cargo (Contextual Variable)
- Two-stage methods
  - Efficiency estimation
  - Ordinary least squares (OLS)
    - Dummy variable: 1 indicates cargo; 0 indicates civil airline

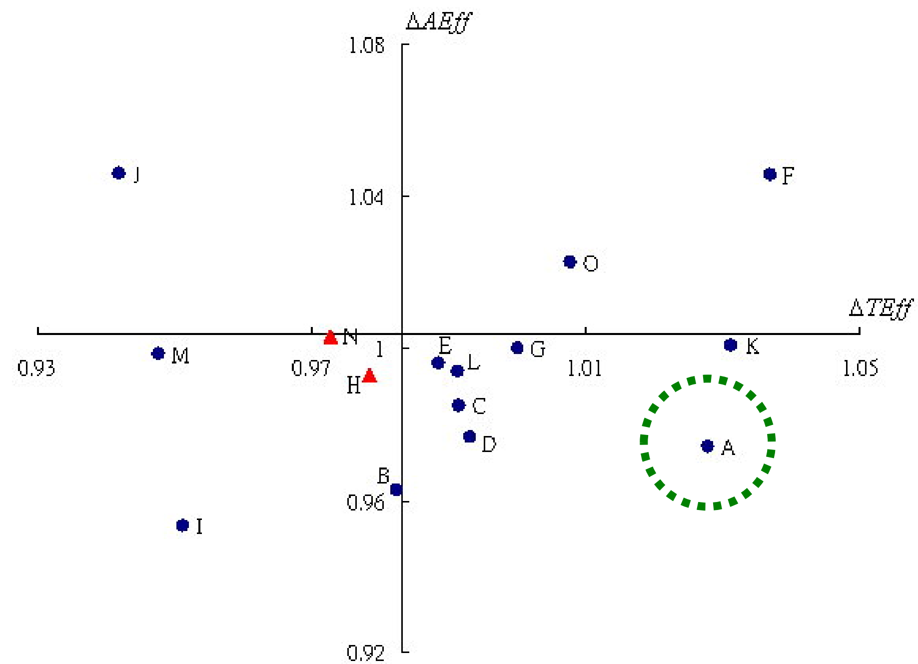
Regression	System	Design	Generation	Operations	Consumption
Intercept	0.59	0.68	0.85	0.81	0.85
Slope	0.21	0.31	0.1	0.02	0.1

- Result
  - Cargo service is 21% more efficient than civil service
  - Efficiency is significantly affected by the capacity design.
  - Reason: lower uncertainty in shipping network

2D Efficiency Decomposition (2DED)

Profitability Eff Change of Individual Corporation





			System				Design				Support				Operations				Consumption			
Firm	No.	Year	$\Delta\rho$	ΔT	ΔS	ΔA	$\Delta\rho$	ΔT	ΔS	ΔA	$\Delta\rho$	ΔT	ΔS	ΔA	$\Delta\rho$	ΔT	ΔS	ΔA	$\Delta\rho$	ΔT	ΔS	ΔA
AirTran Airways	A	06->07	1.1	1.05	1.05	1.01	1.08	1	1.07	1.01	1.06	1.05	1.01	1	0.95	1	0.96	0.99	1.06	1.05	1.01	1
		07->08	1.07	1.01	1.13	0.94	1.03	1.02	1.01	1	1.05	1.05	0.99	1.01	0.96	1	1.02	0.95	1.05	1.05	0.99	1.01
		GM	1.09	1.03	1.09	0.97	1.05	1.01	1.04	1	1.05	1.05	1	1	0.96	1	0.99	0.97	1.05	1.05	1	1

Conclusion

- **Two-Dimensional Efficiency Decomposition** (2DED) for identifying the sources of inefficiency
  - Production system process (4 subprocesses)
    - capacity design, demand generation, operations and demand consumption
  - Profitability efficiency change (3 components)
    - Technical efficiency change, scale efficiency change, allocative efficiency change
    - Fill the gap between profitability efficiency and financial index (Chen and McGinnis, 2007, EJOR)

- Airlines industry 2006–2008
  - Profitability change downgrade between 2007-2008 mainly due to demand fluctuation rather than production capability
  - Separate **demand effect** from production capability

- Duty clarification and resource allocation
  - Capacity design: transportation network design or **industrial engineering division** for capacity and routing planning
  - Demand support: **marketing division** for product pricing and promotion
  - Operations: service and process integration, or the **manufacturing divisions**
  - Demand consumption: **sales division** for sales channels

2D Efficiency Decomposition (2DED)

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Production, Manufacturing and Logistics

Two-dimensional efficiency decomposition to measure the demand effect in productivity analysis

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ABSTRACT

This paper proposes a two-dimensional efficiency decomposition (2DED) of profitability for a production system to account for the demand effect observed in productivity analysis. The first dimension identifies four components of efficiency: capacity design, demand generation, operations, and demand consumption, using Network Data Envelopment Analysis (Network DEA). The second dimension decomposes the efficiency measures and integrates them into a profitability efficiency framework. Thus, each component's profitability change can be analyzed based on technical efficiency change, scale efficiency change and allocative efficiency change. An empirical study based on data from 2006 to 2008 for the US airline industry finds that the regress of productivity is mainly caused by a demand fluctuation in 2007–2008 rather than technical regression in production capabilities.

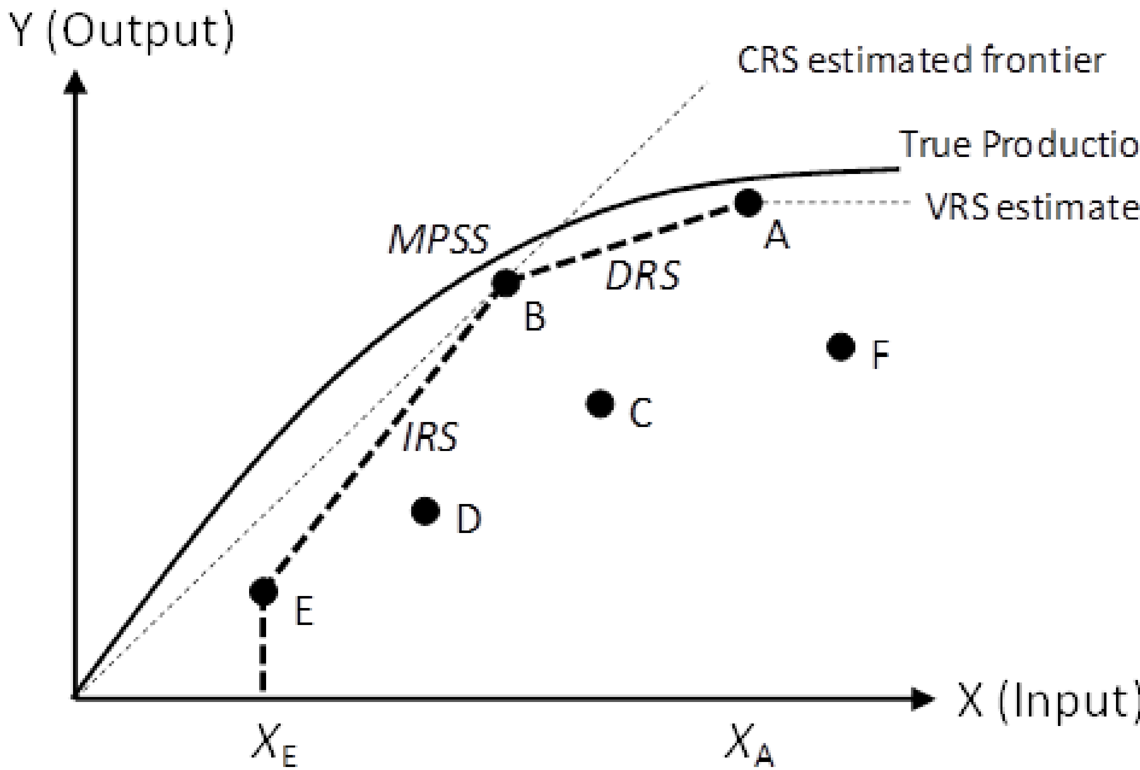
Effectiveness Measure

Lee, Chia-Yen, 2015. Distinguishing Operational Performance in Power Production: A New Measure of Effectiveness by DEA. IEEE Transactions on Power Systems, 30 (6), 3160–3167

PO Lab

- Production Possibility Set (PPS) for DEA

$$\tilde{T} = \left\{(\boldsymbol{x}, \boldsymbol{y}) \middle| \sum_k \lambda_k Y_{jk} \geq y_j, \forall j; \sum_k \lambda_k X_{ik} \leq x_i, \forall i; \sum_k \lambda_k = 1; \lambda_k \geq 0, \forall k\right\}$$



- Efficiency Estimation
  - $D_y(\boldsymbol{x}, \boldsymbol{y}) = \inf\{\theta \,|\, (\boldsymbol{x}, \boldsymbol{y}/\theta) \in \tilde{T}\}$
  - If θ = 1, then the firm is efficient; otherwise it is inefficient when θ < 1.

Real Productivity?

$$\frac{Sales}{Input} = \frac{Sales}{Output} \times \frac{Output}{Input}$$

Productive Effectiveness

Productive Efficiency

Effectiveness Measure

PPOLab

- Efficiency vs. Effectiveness
  - From Organization Management Perspective (Drucker, 1977)
    - Do the right thing → Effectiveness
    - Do the thing right → Efficiency
  - From Production System Perspective (Lee and Johnson, 2015)
    - Generate product sold before overdue or obsolescence → Effectiveness
    - Generate product using inputs & outputs transformation → Efficiency
- The sales-truncated production possibility set (PPS^E)
  - $T = \{(\boldsymbol{x}, \boldsymbol{y}) : \boldsymbol{x} \text{ can produce } \boldsymbol{y}\}$
  - $T^E = \{(\boldsymbol{x}, \boldsymbol{y}^E) : \boldsymbol{x} \text{ can produce } \boldsymbol{y}^E \text{ that will be consumed in current period}\}$

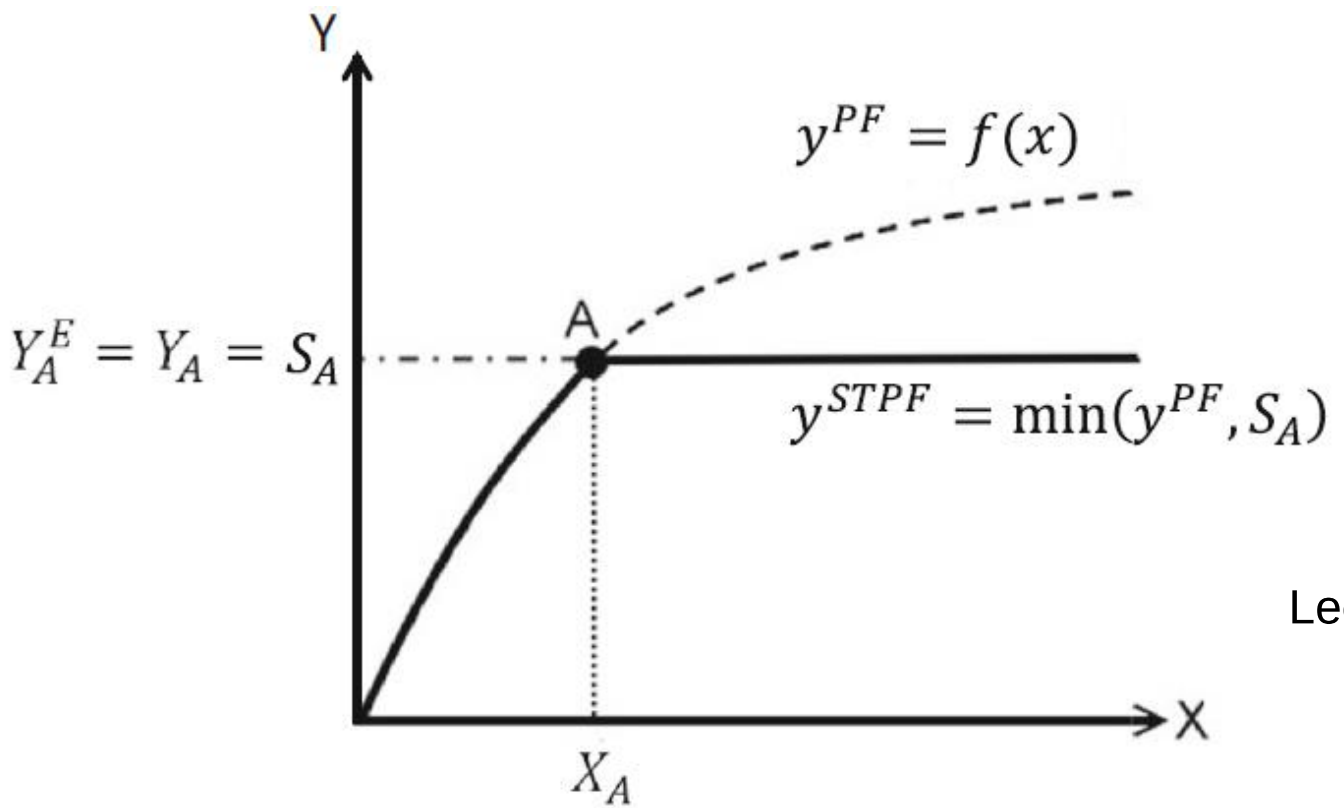
    where

$$Y_{jk}^E = \min\left(Y_{jk}, S_j\right)$$

Effectiveness Measure

- Sales-Truncated Production Function (STPF) and PPS^E
  - $y^{STPF} = \min(y^{PF}, s) = \min(f(\boldsymbol{x}), s)$

$$\tilde{T}^E = \left\{(\boldsymbol{x}, \boldsymbol{y}^E) \middle| \sum_k \lambda_k Y_{jk} \geq y_j^E, \forall j; S_j \geq y_j^E, \forall j; \sum_k \lambda_k X_{ik} \leq x_i, \forall i; \sum_k \lambda_k = 1; \lambda_k \geq 0, \forall k \right\}$$

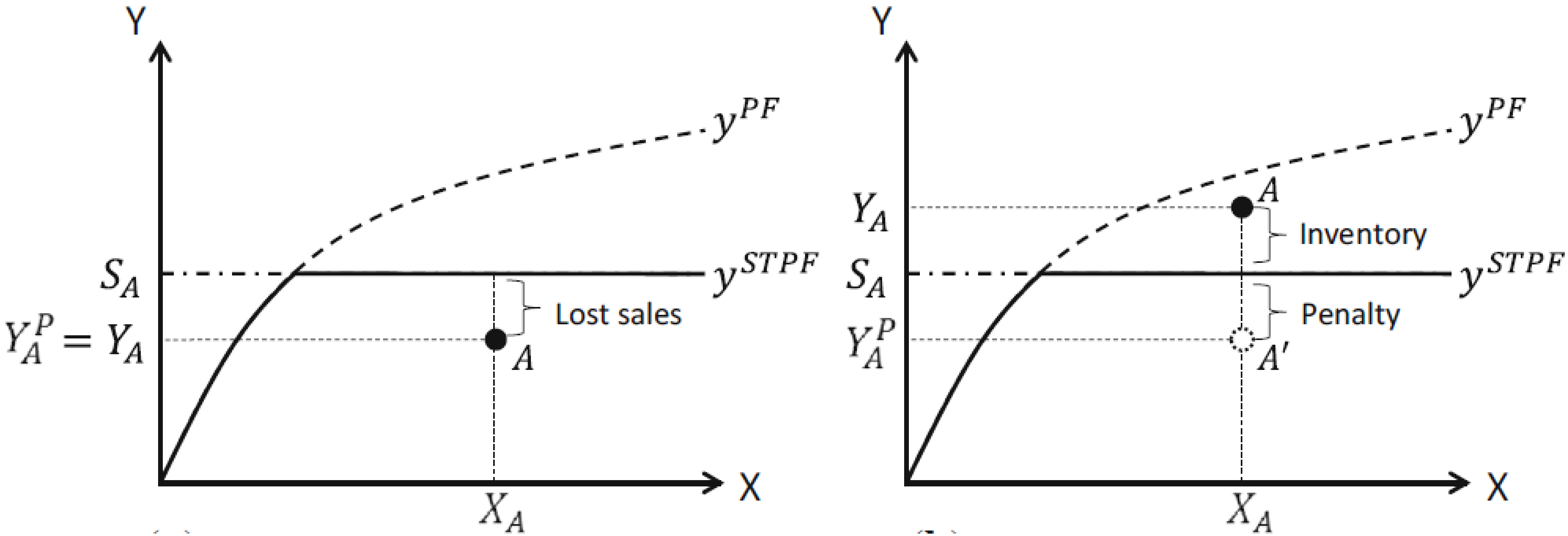


Lee and Johnson (2015)

Lee, Chia-Yen, and A. L. Johnson, 2015. Effective Production: Measuring of the Sales Effect using Data Envelopment Analysis. Annals of Operations Research, 235 (1), 453–486.

Effectiveness Measure

Capacity Shortage and Capacity Surplus



Lee and Johnson (2015)

Penalty

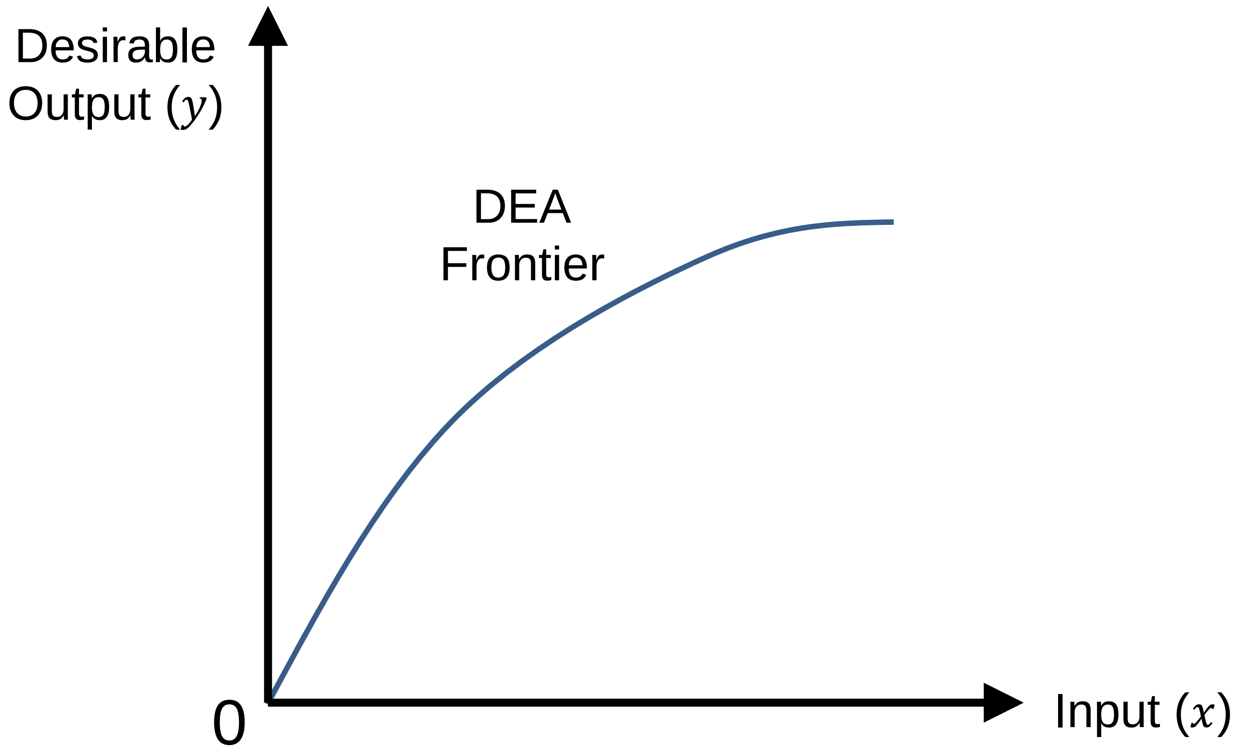
- If $Y_{kj} < S_{kj}$, then the opportunity to sell $S_{kj} - Y_{kj}$ units is lost and we set $Y_{kj}^P = Y_{kj} - \alpha_{kj}(S_{kj} - Y_{kj}) \geq 0$, where $\alpha_{kj}(S_{kj} - Y_{kj})$ is the penalty
- If $Y_{kj} > S_{kj}$, then $Y_{kj} - S_{kj}$ units of inventory are generated and we set $Y_{kj}^P = S_{kj} - \beta_{kj}(Y_{kj} - S_{kj}) \geq 0$, where $\beta_{kj}(Y_{kj} - S_{kj})$ is the penalty

Effectiveness Measure- Undesirable Output

- Energy Market with Undesirable Output (Dakpo et al., 2016)
  - (1) treating the pollution as a free disposable input (Atakelty Hailu & Veeman, 2001), but challenged as it violates the physical laws (Färe & Grosskopf, 2003)
  - (2) data transformation applied to treat the bad outputs as good outputs equivalently (Seiford & Zhu, 2002), but challenged due to undesirable output reduction without any cost (Färe & Grosskopf, 2004)
  - (3) assuming the weak disposability and nulljointness of good outputs and bad outputs (Färe, Grosskopf, Lovell, & Pasurka, 1989) (Färe & Grosskopf, 2009), but violating the law of thermodynamics (Coelli, Lauwers, & Van Huylenbroeck, 2007)
  - (4) the material balance principles requiring knowledge of the technical coefficients between desirable outputs, undesirable outputs and inputs (Hampf & Rødseth, 2014)
  - (5) the use of two sub-technologies (i.e., by-production) (Murty, Robert Russell, & Levkoff, 2012).

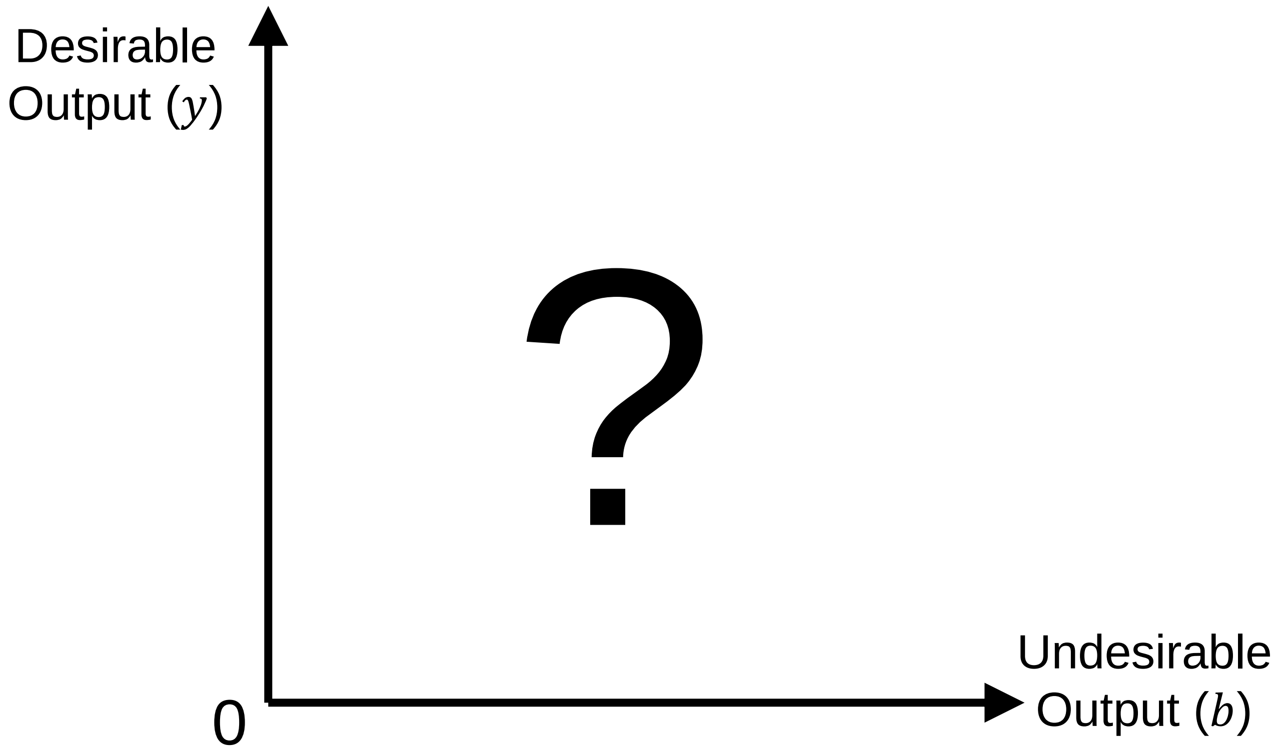
Effectiveness Measure- Undesirable Output

- Input vs. Output



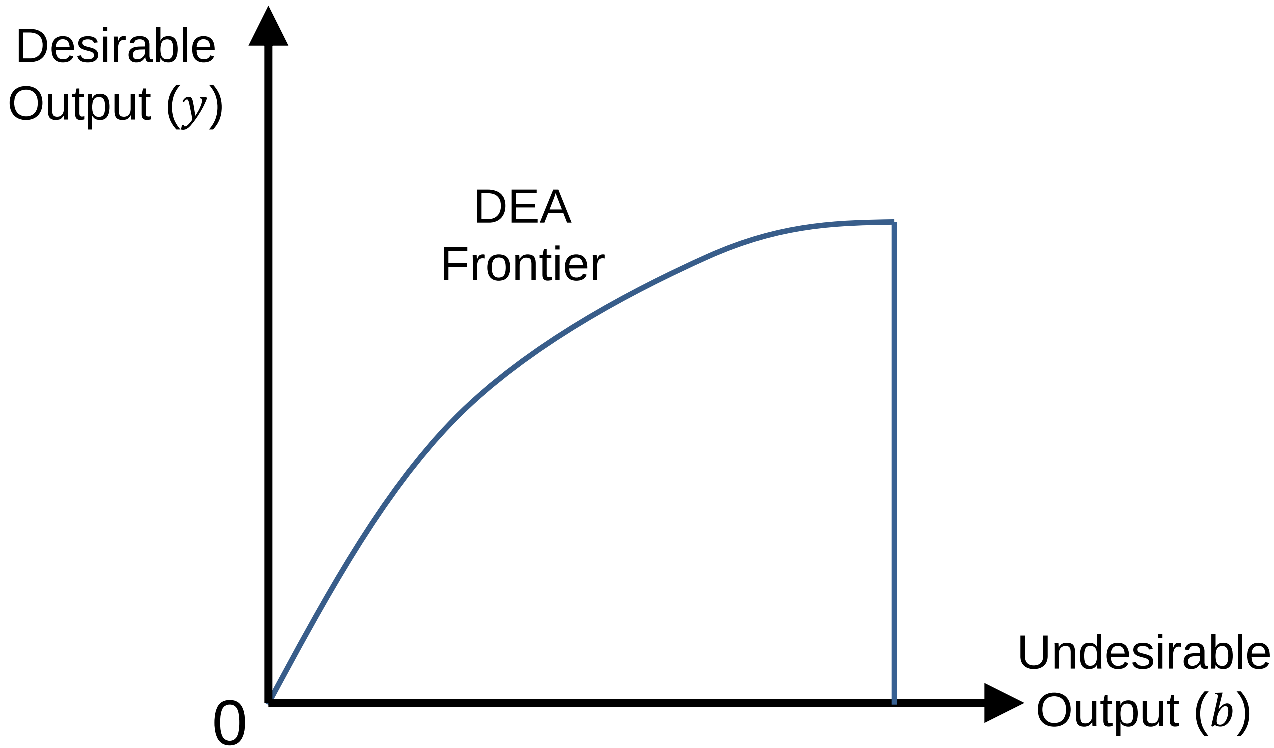
Effectiveness Measure- Undesirable Output

- Good Output vs. Bad Output



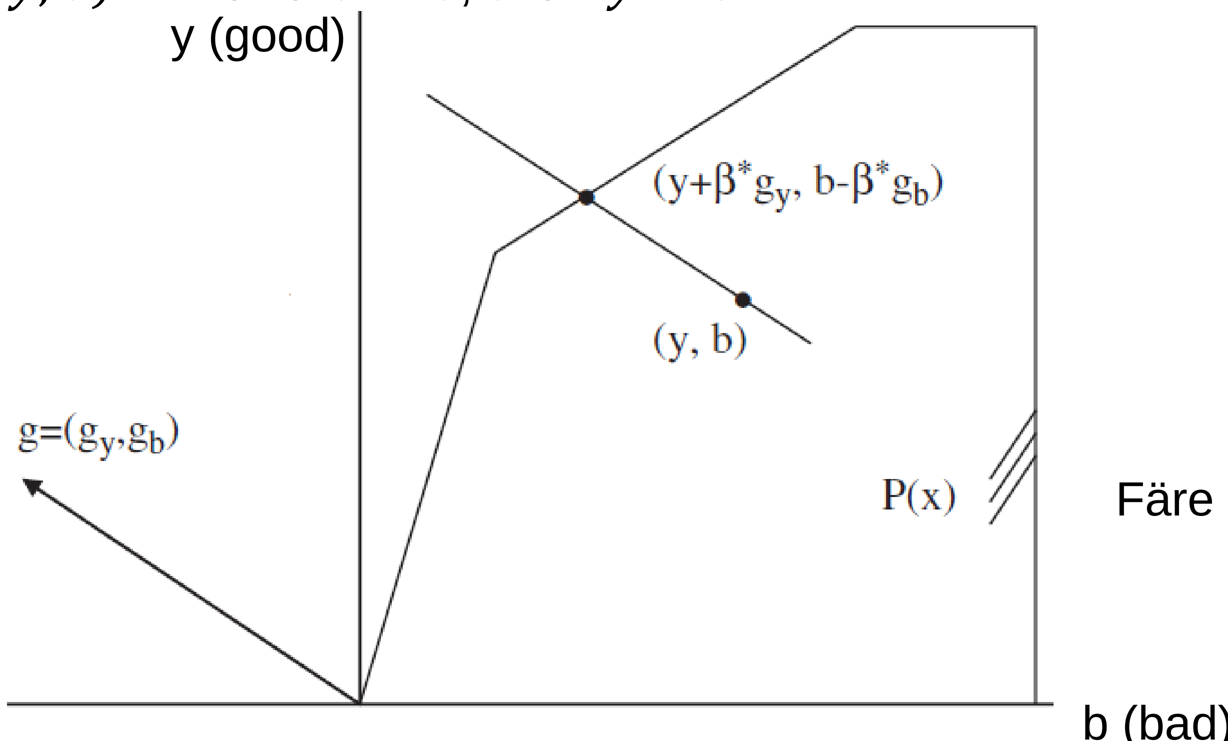
Effectiveness Measure- Undesirable Output

- Good Output vs. Bad Output



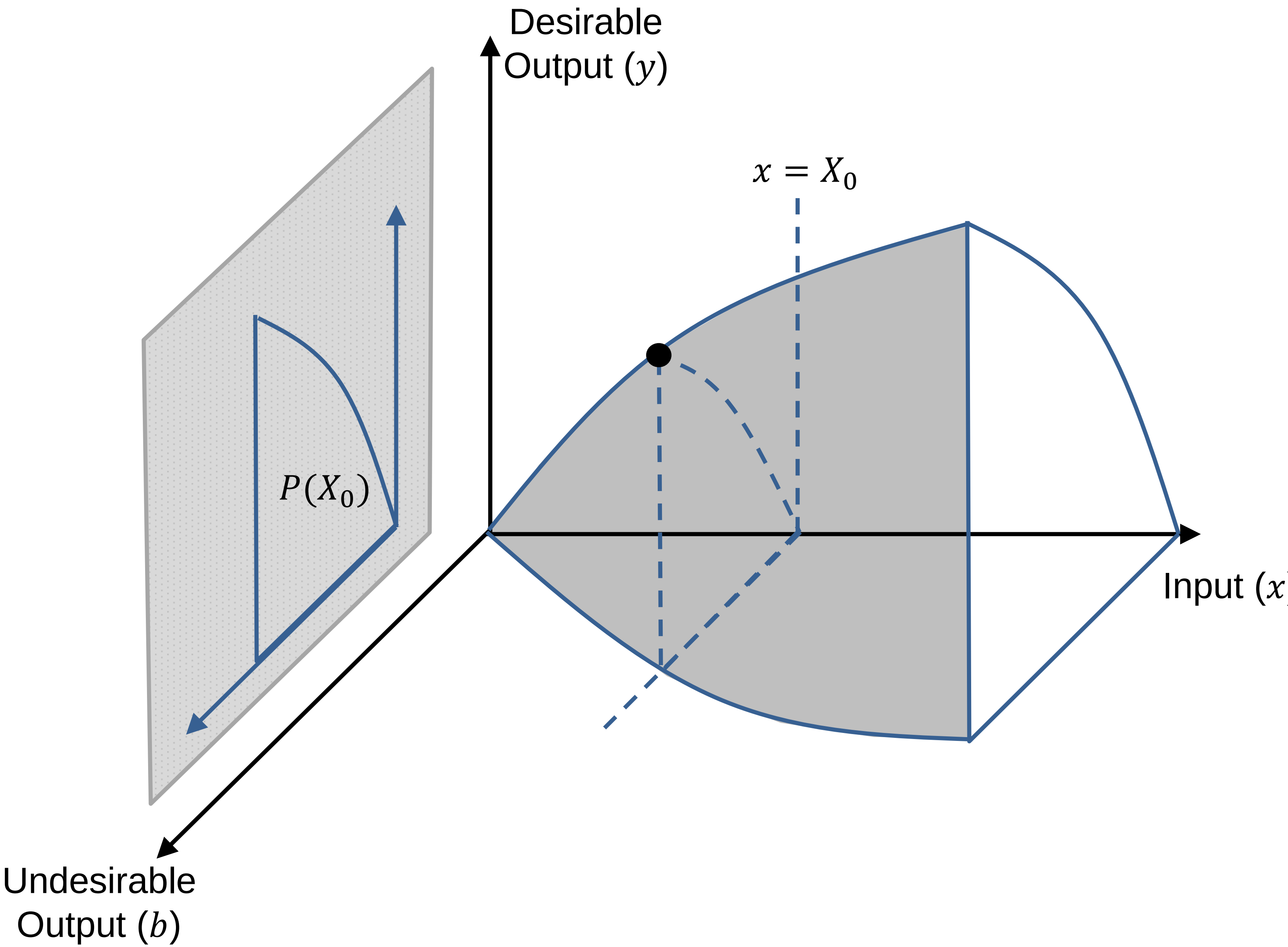
DEA with Undesirable Output

- "Weak Disposability (Fare, Grosskopf, & Pasurkajr, 2007):
  - Free (or strong) disposability of inputs and desirable outputs
    Given $(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b}) \in T$, if $\boldsymbol{x}' \geq \boldsymbol{x}$ and $0 \leq \boldsymbol{y}' \leq \boldsymbol{y}$, then $(\boldsymbol{x}', \boldsymbol{y}', \boldsymbol{b}) \in T$.
  - Weak disposability of desirable outputs and undesirable outputs
    Given $(\boldsymbol{x}, y, \boldsymbol{b}) \in T$ and $0 \leq \rho \leq 1$, then $(\boldsymbol{x}, \rho y, \rho \boldsymbol{b}) \in T$. (Shephard, 1970)
  - Nulljointness of desirable outputs and undesirable outputs
    Given $(\boldsymbol{x}, y, \boldsymbol{b}) \in T$ and $\boldsymbol{b} = 0$, then $y = 0$.



Färe et al. (2007)

DEA with Undesirable Output



Effectiveness Measure

- Podinovski's Convex Technology (Kuosmanen and Podinovski, 2009, AJAE)
  - Directional Distance Function (DDF) with (g_{y_j}, g_{b_q})
  - If θ = 0, then the firm is efficient; otherwise it is inefficient when θ > 0

Efficiency Estimation

$$\text{Max } \theta$$
$$\text{s.t. } \sum_k (\lambda_k + \mu_k) X_{ik} \le X_{ir}, \forall i$$
$$\sum_k \lambda_k Y_{jk} \ge Y_{jr} + \theta g_{y_j}, \forall j$$
$$\sum_k \lambda_k B_{qk} \le B_{qr} - \theta g_{b_q}, \forall q$$
$$\sum_k (\lambda_k + \mu_k) = 1$$
$$\lambda_k, \mu_k \ge 0, \forall k$$

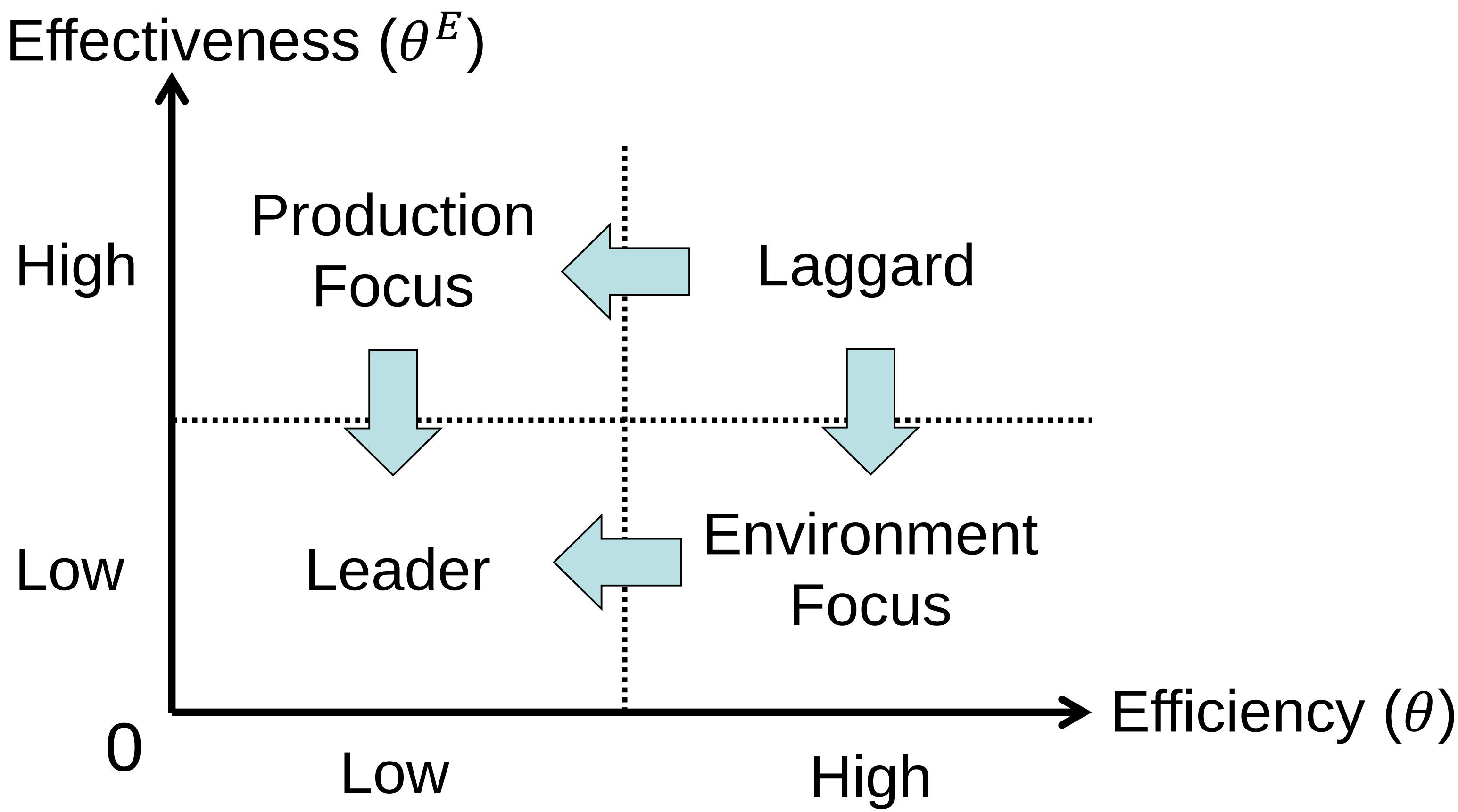
Effectiveness Estimation

$$\text{Max } \theta^E$$
$$\text{s.t. } \sum_k (\lambda_k + \mu_k) X_{ik} \le X_{ir}, \forall i$$
$$\sum_k \lambda_k Y_{jk} \ge Y_{jr}^P + \theta^E g_{y_j}, \forall j$$
$$D_{jr} \ge Y_{jr}^P + \theta^E g_{y_j}, \forall j$$
$$\sum_k \lambda_k B_{qk} \le B_{qr}^P - \theta^E g_{b_q}, \forall q$$
$$\sum_k (\lambda_k + \mu_k) = 1$$
$$\lambda_k, \mu_k \ge 0, \forall k$$

Lee (2015)

Effectiveness Measure

- Efficiency vs. Effectiveness



The lower the better!

Lee (2015)

Effectiveness Measure

Empirical Study (Lee, 2015)

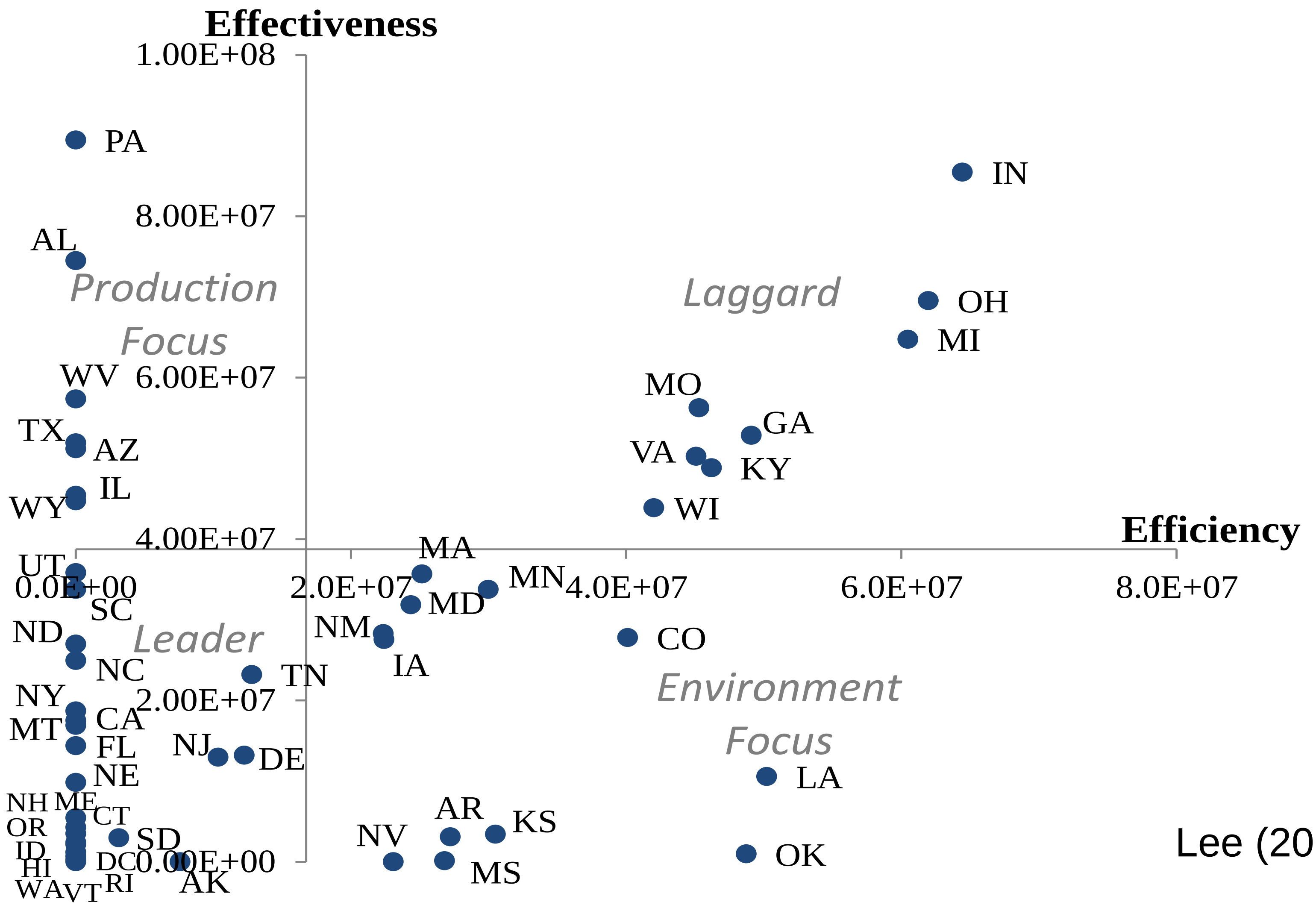
- U.S. state-level power systems operating in 2010
- the performance evaluation before electricity reallocation (B.R.) regulated by the North American Electric Reliability Corporation (NERC) and after electricity reallocation (A.R.)
- Data Source: U.S. Energy Information Administration (EIA)
- Inputs and Outputs
  - nameplate capacity (megawatts, MW)
  - annual amount in tons of coal consumption
  - annual amount in barrels of petroleum consumption
  - annual amount of natural gas consumption in Mcf (thousand cubic feet)
  - annual amount of electricity generated in megawatt-hours (MWh)
  - annual amount in tons of CO_2
  - annual amount in tons of SO_2
  - annual amount in tons of NO_x.
  - The retail sales of electricity (MWh)
  - The emission limits are based on the 1997 Kyoto Protocol describing a 7% reduction commitment from 1990 to 2012.

Effectiveness Measure

State	Efficiency Score	Efficiency Rank	Effectiveness B.R. Score	Effectiveness B.R. Rank	Effectiveness A.R. Score	Effectiveness A.R. Rank	S.P. B.R.	S.P. A.R.	Dereg.
AK	7,575,641	28	9,371	2	9,371	2	L	L	
AL	0	1	74,516,940	49	73,975,840	48	P	P	
AR	27,219,950	38	3,075,796	13	2,283,183	21	E	E	
AZ	0	1	51,175,990	42	51,334,650	43	P	P	
CA	0	1	17,524,320	24	3,205,945	22	L	L	
CO	40,117,750	41	27,784,870	30	177,245	9	E	E	
CT	0	1	3,490,028	15	7,816,946	28	L	L	Y
DC	0	1	210,257	5	87,498	7	L	L	Y
DE	12,242,070	30	13,216,700	21	45,799	5	L	L	Y
FL	0	1	14,368,640	22	86,447,640	50	L	P	
GA	49,109,220	47	52,846,210	44	45,034,600	40	Lag	Lag	
HI	0	1	706,429	7	9,038,993	29	L	L	
IA	22,408,730	33	27,526,000	29	32,871,910	37	E	E	
ID	0	1	1,206,515	9	219,624	11	L	L	
IL	0	1	45,429,080	39	1,958,221	19	P	L	Y
IN	64,439,700	51	85,448,860	50	83,526,080	49	Lag	Lag	
KS	30,492,780	40	3,438,061	14	4,950,186	24	E	E	
KY	46,205,060	45	48,829,420	40	46,716,940	41	Lag	Lag	
LA	50,209,620	48	10,581,890	19	7,610,323	27	E	E	
MA	25,178,220	36	35,679,670	35	99,886	8	E	E	Y
MD	24,346,570	35	31,838,990	32	691,379	16	E	E	Y
ME	0	1	4,255,580	16	5,374,721	25	L	L	Y
MI	60,477,390	49	64,765,180	47	64,650,420	47	Lag	Lag	Y
MN	29,989,090	39	33,756,310	33	63,538	6	E	E	
MO	45,300,500	44	56,265,050	45	54,570,970	45	Lag	Lag	
MS	26,793,410	37	142,808	4	357,017	13	E	E	

Effectiveness Measure

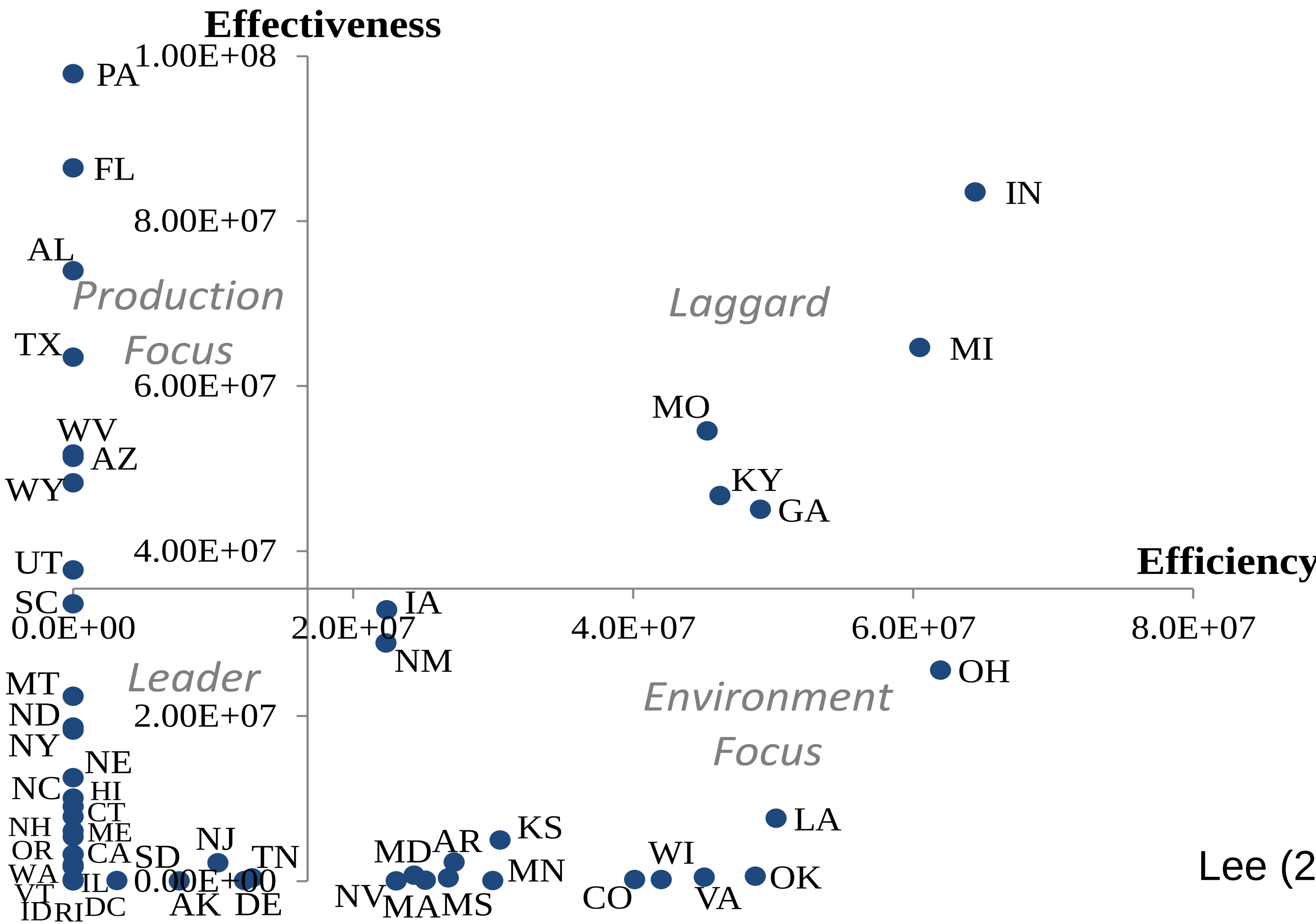
- Strategic position before electricity reallocation (B.R.)



Lee (2015)

Effectiveness Measure

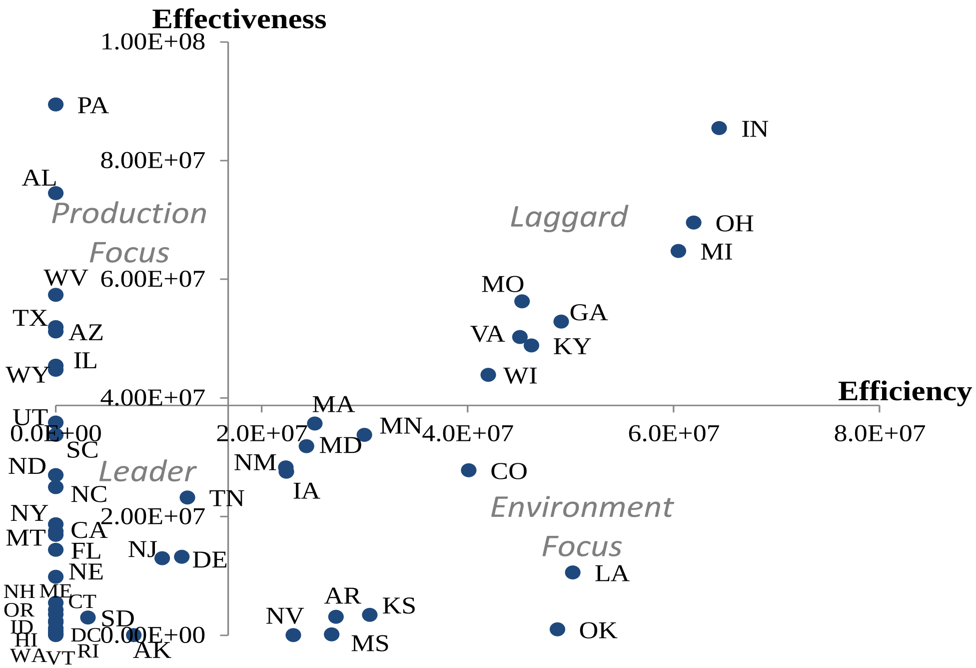
- Strategic position after electricity reallocation (A.R.)



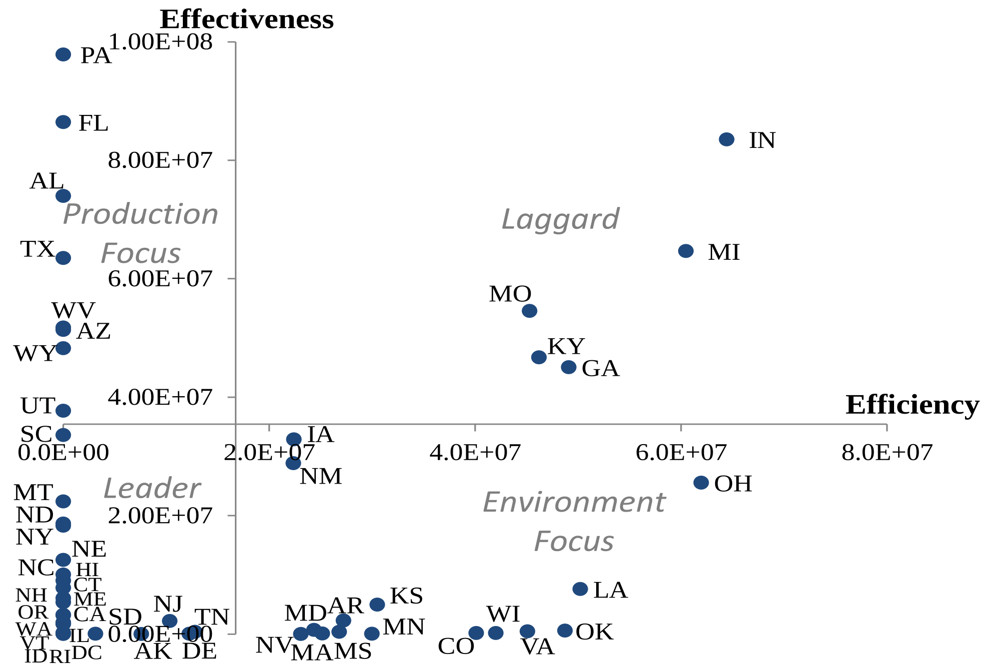
Lee (2015)

- Strategic position

before electricity reallocation (B.R.)



after electricity reallocation (A.R.)



Lee (2015)

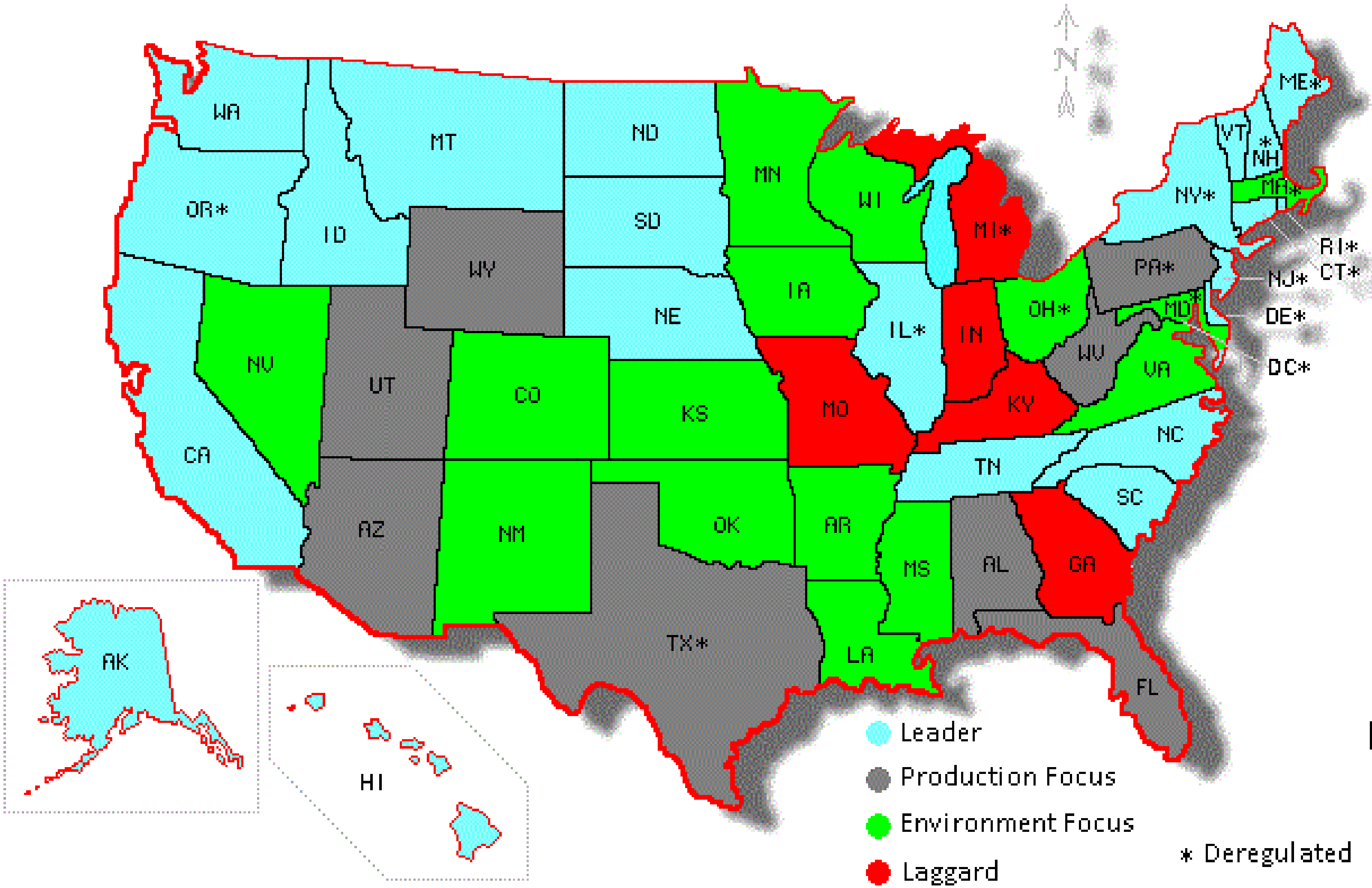
Effectiveness Measure

Managerial Insights

- overall effectiveness of transmission and reallocation increases 8.56%
- 31 states are good in efficiency and 36 states are good in effectiveness B.R.
- Good productive efficiency however, does not guarantee good effectiveness.
- The typical efficiency measure cannot capture the environmental effect to support policy decision.
- For example, the IL state transfers from Production Focus to Leader before and after reallocation. In fact, IL generates more electricity than necessary since there is a power flow from the IL region into the Tennessee Valley Authority (including KT and TN) and the Mid-Atlantic region (including IN, OH, WV) due to efficient electricity generation and demand fulfillment. Thus, IL shows the Production Focus (too much surplus electricity) B.R., but IL becomes the Leader A.R.

Effectiveness Measure

- Strategic position (A.R.)



Lee (2015)

Effectiveness Measure

Conclusion Remarks

- Proposed a new effectiveness measure to capture the consumption effect of good output (i.e., electricity) and environmental regulation of bad outputs (i.e., pollutants) in productivity analysis
- Developed strategic position for identifying the competitive advantage using the metrics of efficiency and effectiveness.
- Conducted an empirical case study of U.S. power plants in 2010
  - while most of the states were efficiently using resources for power generation and effectively matching sales levels to electricity levels generated under environmental regulation
  - current electricity transmission plan increases of 8.56% for effectiveness
  - a reduction of 9.8% for electricity generation indicate the move towards effective frontier benchmarks
  - The sharp increase in SO2 and NOx allowance prices resulting from Clean Air Interstate Rule (CAIR), which required additional SO2 and NOx reductions beginning in 2010, have led to an increase in the expected pollutant control costs in the future and are providing incentives to purchase allowances and bank them for future use

Distinguishing Operational Performance in Power Production: A New Measure of Effectiveness by DEA

Chia-Yen Lee, *Member, IEEE*

***Abstract*—Measuring the efficiency of power plant systems requires capturing fluctuations in the level of sales to customers as well as accounting for the effects of regulatory caps on emissions. This study proposes a novel effectiveness measure considering desirable outputs and undesirable outputs via data envelopment analysis (DEA). The new measure complements typical efficiency measures. We test the validity of the proposed measure with an empirical case study of the fifty U.S. states and the District of Columbia. We find that the current interregional electricity transmission plan increases 8.56% in effectiveness. For the emissions control, we suggest a 9.8% reduction in electricity generation towards an effective production frontier. We conclude that the proposed effectiveness measure's ability to distinguish sales and regulation effects from typical productive efficiency eliminates the bias often found in currently used measures.**

***Index Terms*—Data envelopment analysis (DEA), effectiveness, environmental regulation, power plant, undesirable output.**

I. Introduction

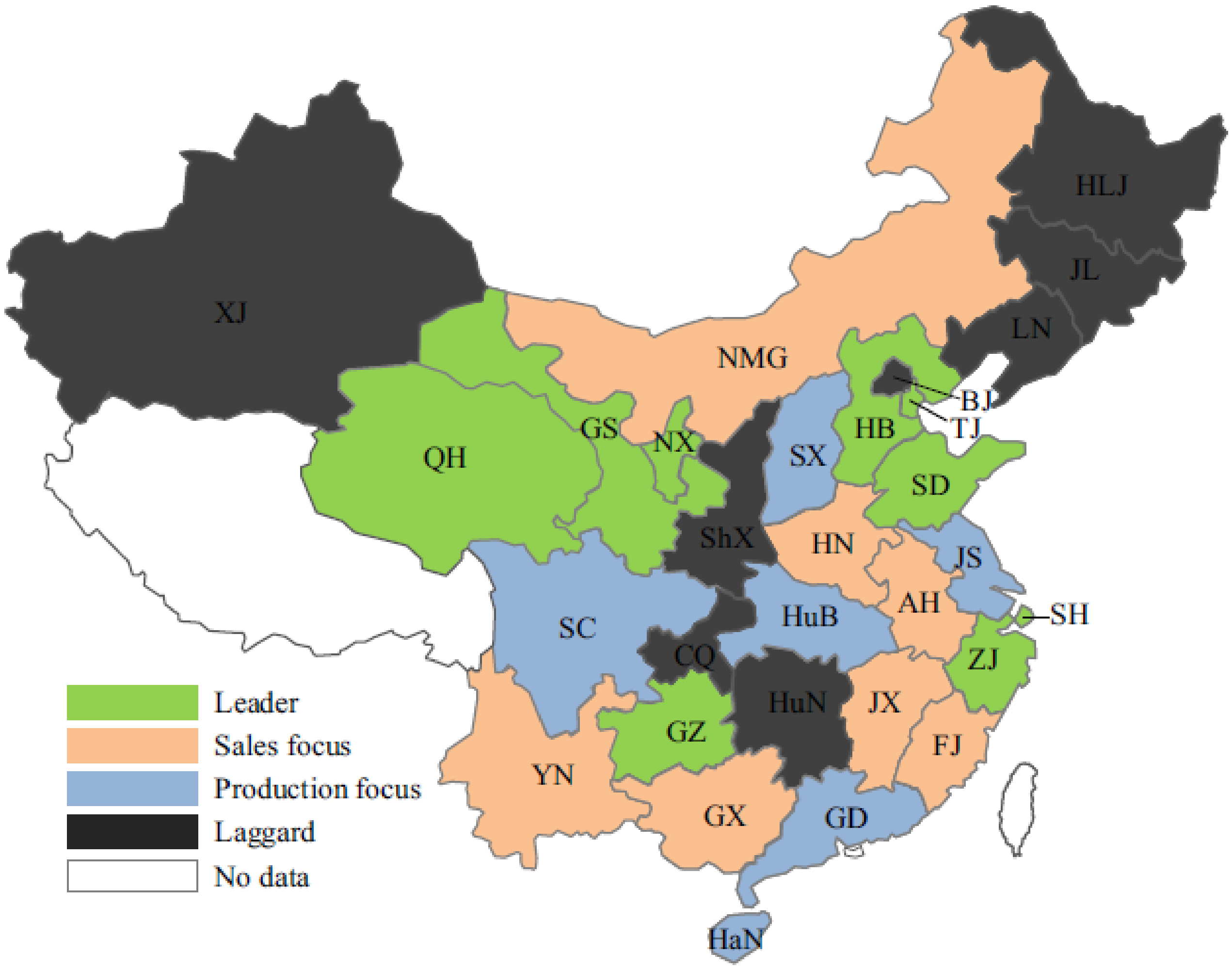
ELECTRIC generation remains a major source of air pollution in the United States. In 2010, U.S. power plants gen-

least as high as other observed production processes, i.e., it produces output levels on the production function.

One example of a study using DEA is Chitkara [4], who employed DEA and the Malmquist productivity index [5] to evaluate the operational inefficiency of the coal-fired generating units owned by the National Thermal Power Corporation of India from 1991 to 1995. He claimed that DEA provided targets for productivity improvement by extensive training of operating personnel, and also indicated that the Ministry of Power should consider a benchmark technique based on the industrial best practice instead of using normative performance standards. Pahwa *et al.* [6] gave a performance analysis of the 50 largest electric distribution utilities in the U.S. in 1997. Their result showed the performance efficiency gaps in the inputs and outputs of inefficient utilities. Based on a sensitivity-based classification of utilities, they developed a gap report to guide productivity improvement. Chien *et al.* [7], who measured the efficiencies of 17 service centers of the Taiwan Power Company (TPC), found that most of the inefficient ones presented increasing returns to scale. The authors proposed reorganization alternatives (e.g., merging the service centers) to improve oper-

Effectiveness Measure

- Strategic position of regional electric power industry in China



Region	Code
Beijing	BJ
Tianjin	TJ
Hebei	HB
Shanxi	SX
Inner Mongolia	NMG
Liaoning	LN
Jilin	JL
Heilongjiang	HLJ
Shanghai	SH
Jiangsu	JS
Zhejiang	ZJ
Anhui	AH
Fujian	FJ
Jaingxi	JX
Shandong	SD
Henan	HN
Hubei	HuB
Hunan	HuN
Gaungdong	GD
Guangxi	GX
Hainan	HaN
Chongqing	CQ
Sichuan	SC
Guizhou	GZ
Yunnan	YN
Shaanxi	ShX
Gansu	GS
Qinghai	QH
Ningxia	NX
Xinjiang	XJ

Wang, Ke, Chia-Yen Lee, Jieming Zhang, and Yi-Ming Wei, 2018. Operational Performance Management of the Power Industry: A Distinguishing Analysis Between Effectiveness and Efficiency. Annals of Operations Research, 268 (1-2), 513-537.

Proactive DEA

Lee, Chia-Yen, and A. L. Johnson, 2014. Proactive Data Envelopment Analysis: Effective Production and Capacity Expansion in Stochastic Environments. European Journal of Operational Research, 232 (3), 537–548.

Proactive DEA

Motivation

- demand fluctuations cause a surplus or shortage of capacity.
  - capacity surplus
  - capacity shortage

"effective" output

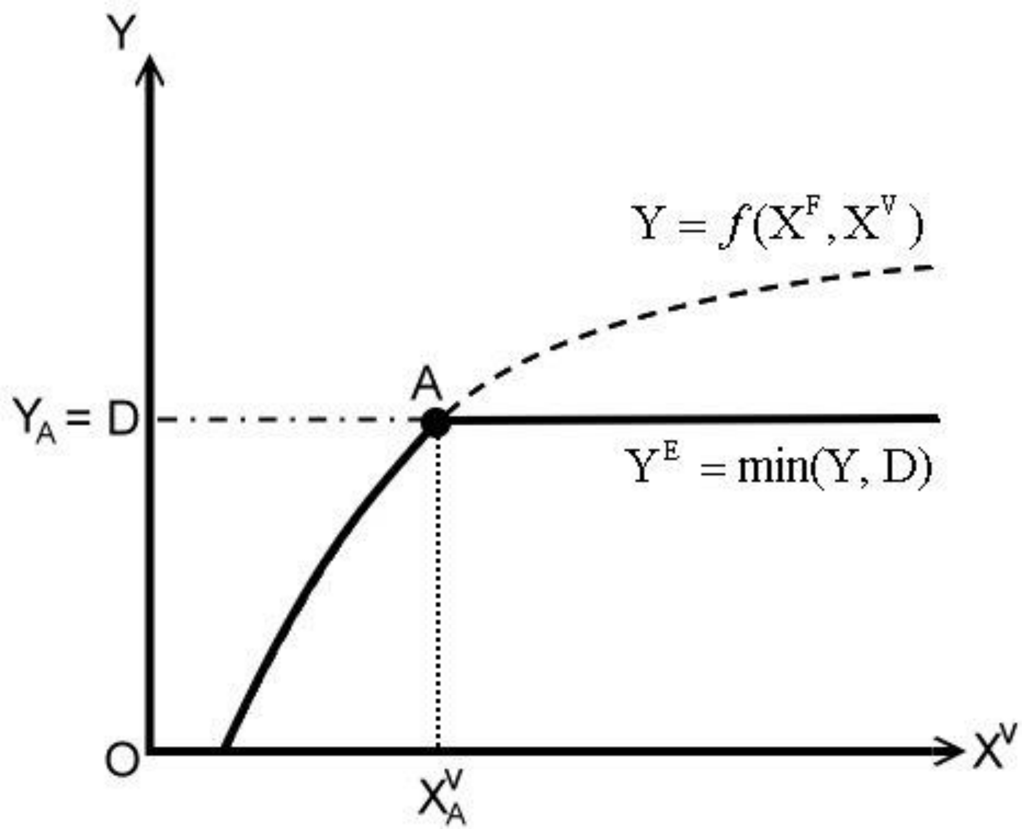
- the output product or service produced and consumed.
- in the short run, firm can change variable input resources to adjust the output level and partly address demand uncertainty.

Research Aim

- This study proposes a short-run capacity planning method, proactive DEA, that adjusts the variable input to control output level for demand satisfaction and quantifies the effectiveness of the production system under demand uncertainty using a stochastic programming DEA (SPDEA) approach.

Proactive DEA

Effective Production



$$Y^E = \min(Y, D) = \min(f(X^F, X^V), D)$$

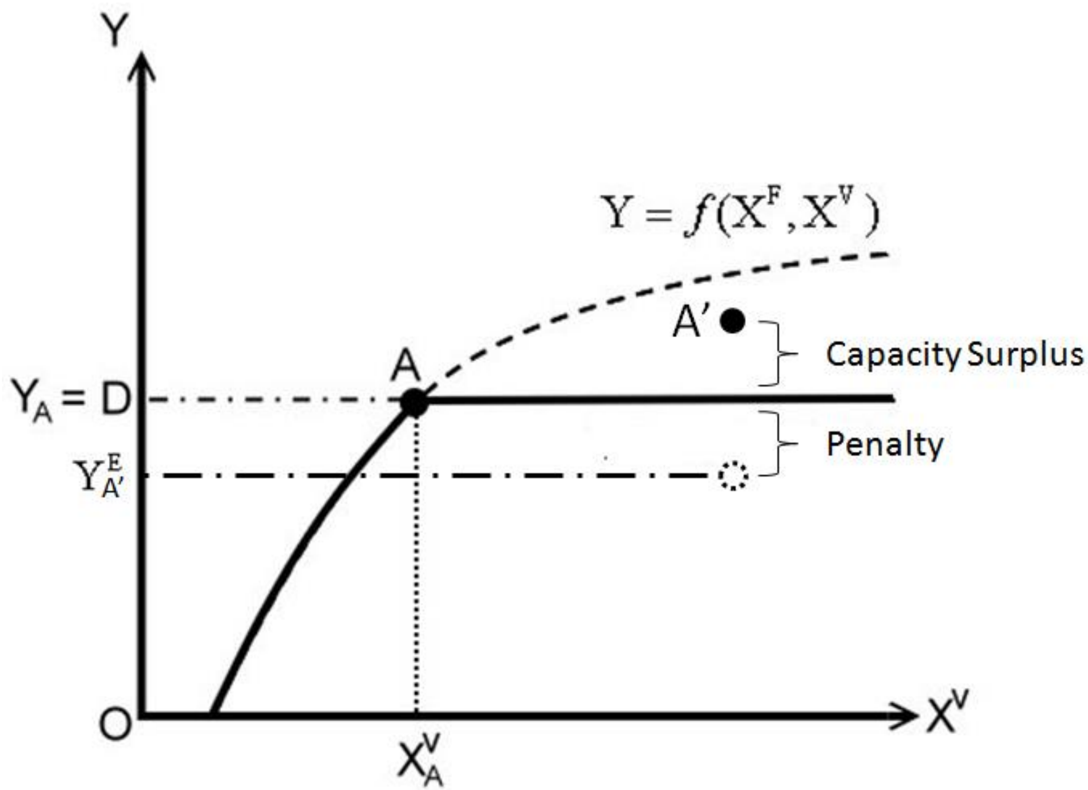
PDLab

- Effective Production
  - capacity shortage

$$\text{If } Y_q \le D_q \text{, then set } Y_q^E = Y_q .$$

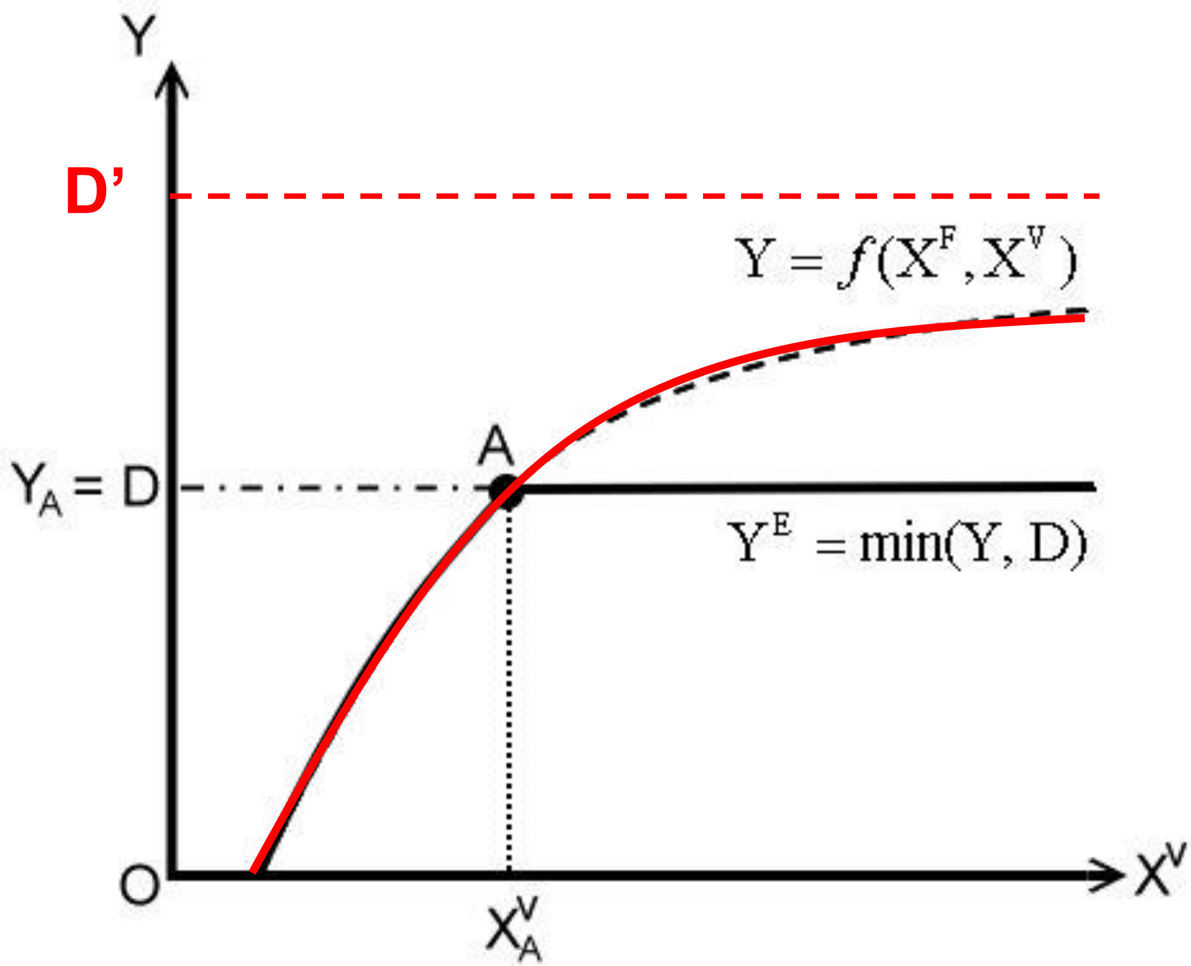
  - capacity surplus (penalty)

$$\text{If } Y_q > D_q \text{, then set } Y_q^E = D_q - \min(Y_q - D_q, D_q) .$$



Effectiveness vs. Efficiency

Proposition: The effectiveness estimate converges to an efficiency estimate as demand increases.



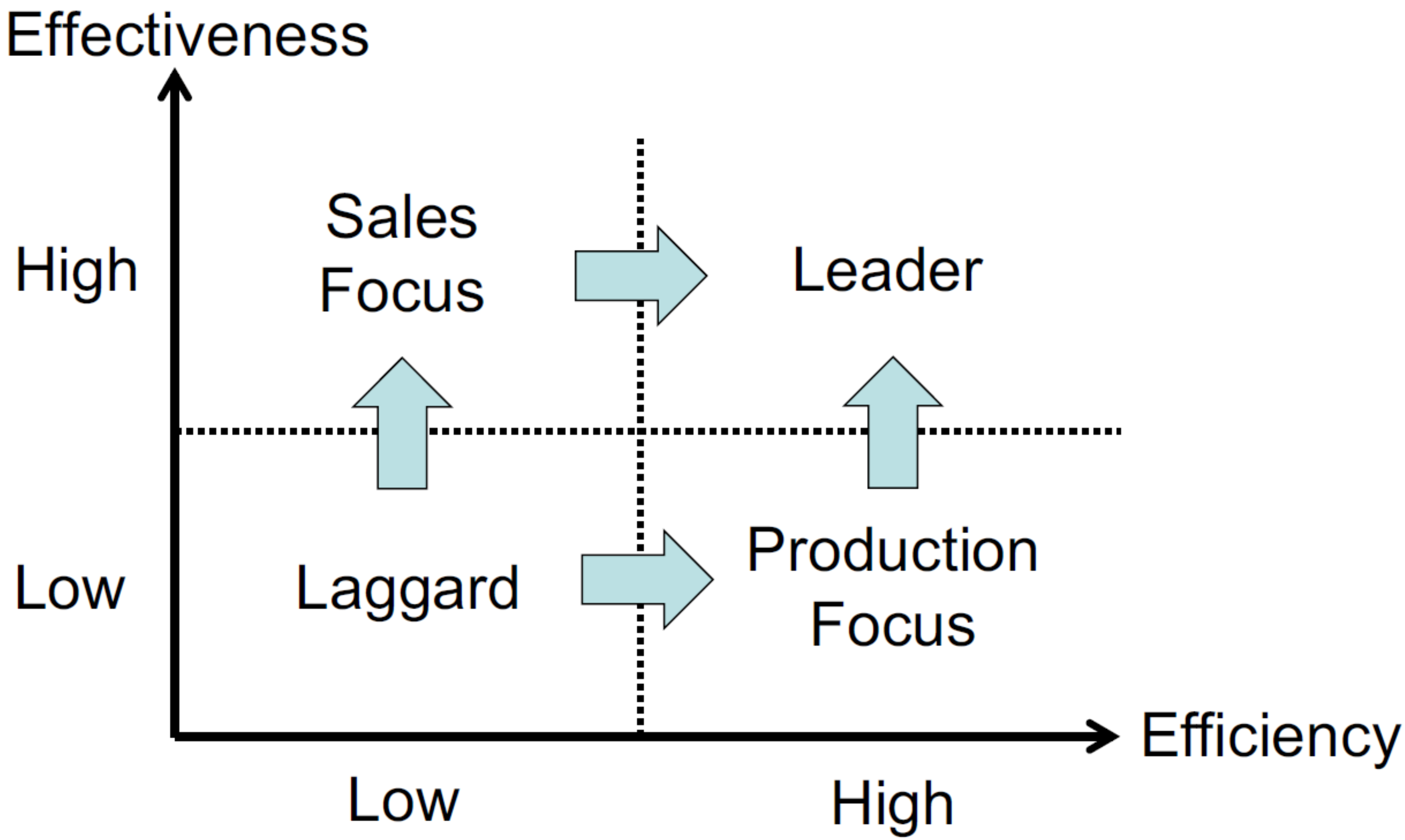
- Production Possibility Set (DEA)

$$\tilde{T} = \{(x, y): \quad \sum_k \lambda_k Y_{qk} \geq Y_q, \quad \forall q$$
$$\sum_k \lambda_k X_{ik}^F \leq X_i^F, \quad \forall i$$
$$\sum_k \lambda_k X_{jk}^V \leq X_j^V, \quad \forall j$$
$$\sum_k \lambda_k = 1$$
$$\lambda_k \geq 0, \quad \forall k \}.$$

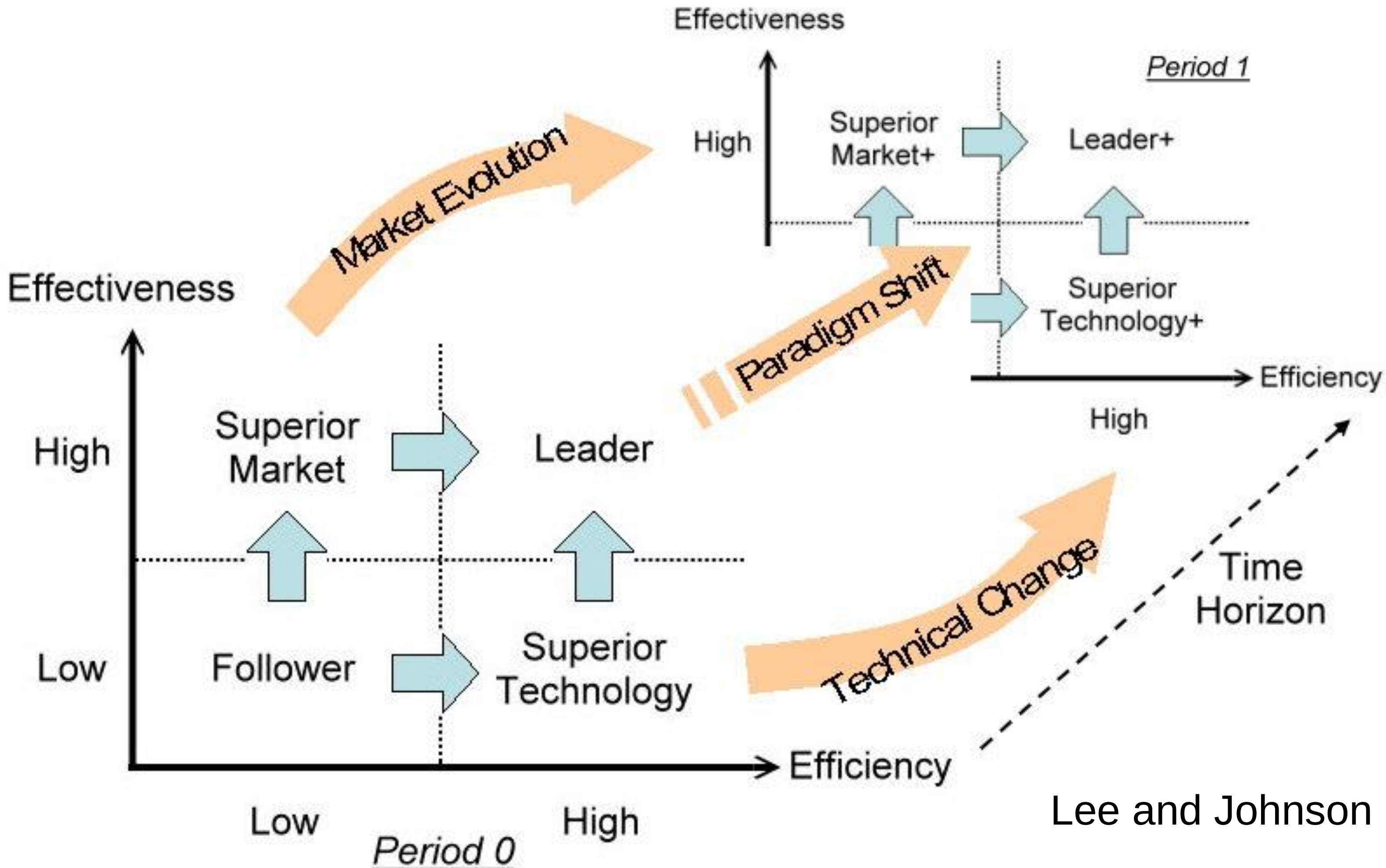
- Truncated Production Possibility Set

$$\tilde{T}^E = \{(x, y^E): \quad \sum_k \lambda_k Y_{qk} \geq Y_q^E, \quad \forall q$$
$$D_q \geq Y_q^E, \quad \forall q$$
$$\sum_k \lambda_k X_{ik}^F \leq X_i^F, \quad \forall i$$
$$\sum_k \lambda_k X_{jk}^V \leq X_j^V, \quad \forall j$$
$$\sum_k \lambda_k = 1$$
$$\lambda_k \geq 0, \quad \forall k \}.$$

- Two-dimensional strategic position between efficiency and effectiveness.



Strategic position and Paradigm Shift



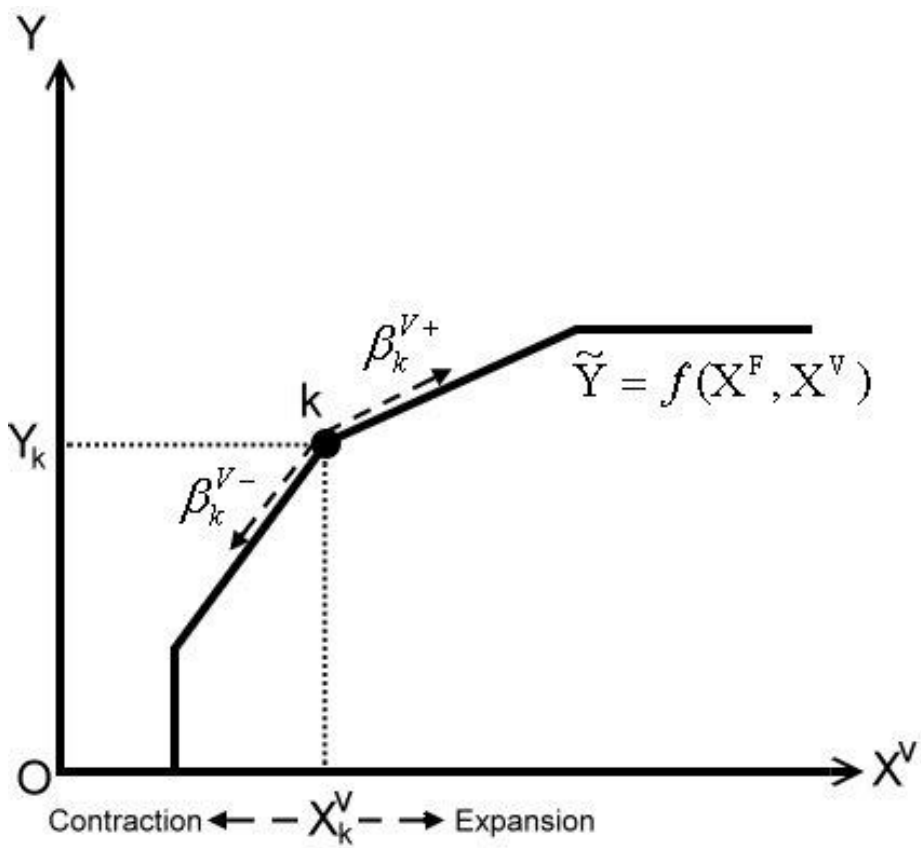
Lee and Johnson (2015)

Lee, Chia-Yen, and A. L. Johnson, 2015. Effective Production: Measuring of the Sales Effect using Data Envelopment Analysis. Annals of Operations Research, 235 (1), 453–486.

- Notation
  - Y_{ks}^{E} the effective output of k^{th} firm in s^{th} scenario
  - D_{ks} the realized demand of k^{th} firm in s^{th} scenario
  - β_{jr}^{V} the marginal product characterized by β_{jr}^{V+} and β_{jr}^{V-} with respect to j^{th} variable input of firm r
  - R_{jr} the parameter of adjustable range
  - u_s , w_s , v_{is}^{F} , v_{js}^{V} , v_{0s} the decision variables associated multipliers
  - d_{jrs} the additional adjustment of variable input characterized by d_{jrs}^{+} and d_{jrs}^{-}
  - y_{rs} the actual output
  - y_{rs}^{E} the effective output
  - $\theta_{rs}^{E} = 1/\mu_{rs}^{E}$ measures production effectiveness

POLab

Variable Input Adjustment and Marginal Product



$$\frac{\partial^+ Y_{q^*r}}{\partial X^V_{j^*r}} = \beta^{V+}_{q^*j^*r} = \text{Min } \; v^V_{j^*}$$

$$s.t. \quad \sum_i v_i^F X_{ir}^F + \sum_j v_j^V X_{jr}^V - \sum_q u_q Y_{qr} + u_0 = 0$$

$$\sum_i v_i^F X_{ik}^F + \sum_j v_j^V X_{jk}^V - \sum_q u_q Y_{qk} + u_0 \geq 0$$

$$u_{q^*} = 1$$

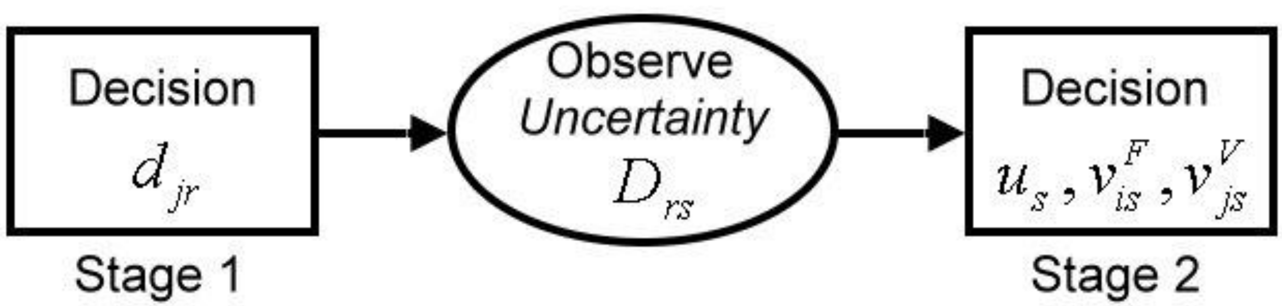
$$v_i^F, v_j^V, u_q \geq 0, \quad u_0 \text{ is free}$$

Podinovski and Førsund (2010)

Proactive DEA

- Two-stage Recourse Stochastic Programming (Birge & Louveaux, 2011)
  - a two-stage decision process including
    - "here-and-now" decisions
    - "wait-and-see" decisions

    by considering the expected recourse function



Birge, J. R., & Louveaux, F. (2011). Introduction to stochastic programming (2nd ed.). New York: Springer Verlag.

POLab

Value of Information and Stochastic Solution

- Expected value of perfect information (EVPI)
- measures the maximum amount a decision maker is willing to pay in return for complete information about the future

$$\mathrm{EVPI} = \mathrm{WS} - \mathrm{RP} = E_{\tilde{D}}\left[\mathrm{Max}\ g(d,\tilde{D})\right] - \mathrm{Max}\ E_{\tilde{D}}\left[g(d,\tilde{D})\right]$$

Value of the stochastic solution (VSS)

- a measure of the quality of the expected value (EV) decision in terms of the recourse problem. Namely, it gives the cost of ignoring uncertainty

$$\mathrm{VSS} = RP - \mathrm{EEV} = \mathrm{Max}\ E_{\tilde{D}}\left[g(d,\tilde{D})\right] - E_{\tilde{D}}\left[g(\bar{d}(\bar{D}),\tilde{D})\right]$$

where $\bar{d}(\bar{D})$ be a EV solution and define the expected result of using the EV solution (EEV)

Scenario-based Programming

Max effectiveness / Min input adjustment

$$\text{Min} \quad M\mu^{E}_{rs} + \sum_{j}(d^{+}_{jrs} + d^{-}_{jrs})$$

DEA formulation

$$s.t. \quad \mu^{E}_{rs} = \sum_{i} v^{F}_{is} X^{F}_{ir} + \sum_{j} v^{V}_{js}(X^{V}_{jr} + d_{jrs}) + w_s D_{rs} + v_{0s}$$

$$u_s(y^{E}_{rs} + \varepsilon) + w_s(y^{E}_{rs} + \varepsilon) = 1$$

$$\sum_{i} v^{F}_{is} X^{F}_{ik} + \sum_{j} v^{V}_{js} X^{V}_{jk} - u_s Y_{ks} + v_{0s} \ge 0, \ \forall k \setminus r$$

$$\sum_{i} v^{F}_{is} X^{F}_{ir} + \sum_{j} v^{V}_{js}(X^{V}_{jr} + d_{jrs}) - u_s(y^{E}_{rs} + \varepsilon) + v_{0s} \ge 0$$

Effective output level

$$y^{E}_{rs} = y_{rs}(1 - z1_{rs}) + [D_{rs} - \min(y_{rs} - D_{rs}, D_{rs})]z1_{rs}$$

$$y_{rs} - D_{rs} < Mz1_{rs}$$

$$y_{rs} - D_{rs} \ge -M(1 - z1_{rs})$$

Capacity expansion

$$y_{rs} = Y_r + \sum_{j} \beta^{V}_{jr} d_{jrs}$$

Marginal product

$$\beta^{V}_{jr} = \beta^{V+}_{jr} z2_{jrs} + \beta^{V-}_{jr}(1 - z2_{jrs}), \ \forall j$$

$$d_{jrs} < Mz2_{jrs}, \ \forall j$$

$$d_{jrs} \ge -M(1 - z2_{jrs}), \ \forall j$$

$$d_{jrs} = d^{+}_{jrs} - d^{-}_{jrs}, \ \forall j$$

Input adjustment range

$$-R_{jr} X^{V}_{jr} \le d_{jrs} \le R_{jr} X^{V}_{jr}, \ \forall j$$

Binary and nonnegative constraints

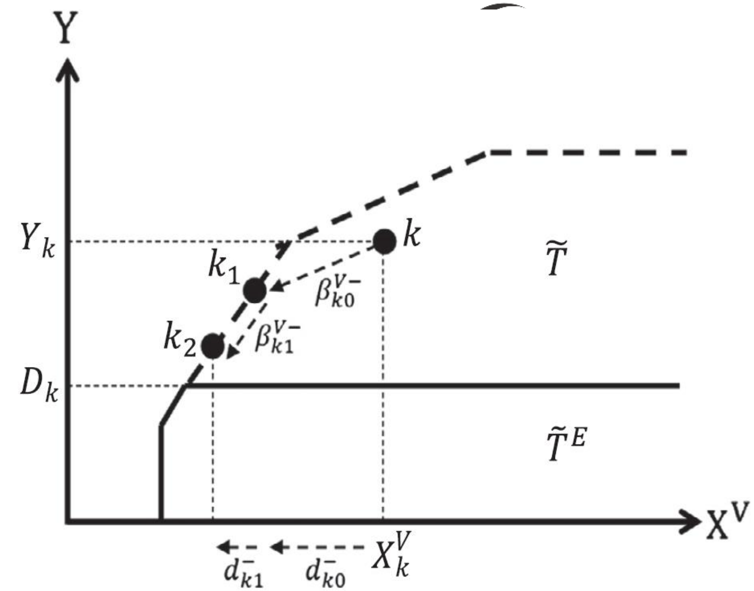
$$z1_{rs}, z2_{jrs} \in \{0,1\}, \ \forall j$$

$$y^{E}_{rs}, y_{rs}, d^{+}_{jrs}, d^{-}_{jrs}, u_s, w_s, v^{F}_{is}, v^{V}_{js} \ge 0, \ \forall i, \forall j$$

Proposed Algorithm

1. For one specific demand scenario D_r, start from specific firm $r = 1$.
2. For $r = 1$ to number of firms.
   2.1 Set step $t = 0$, $X^V_{jrt} = X^V_{jr}$ and $Y_{rt} = Y_r$.
   2.2 Calculate marginal products β^{V+}_{jrt} and β^{V-}_{jrt}.
   2.3 Run scenario-based approach (9.1)–(9.16) and (9.17) to calculate $X^V_{jrt} + d_{jrt}$, $\forall j$ and $Y_{rt} + \sum_{j=1}^{J} \beta^V_{jrt} d_{jrt}$.
   2.4 If $d_{jr} = \sum_t d_{jrt} = 0$, then go to step 2.8; otherwise run output-oriented DEA estimator to calculate efficiency θ^{DEA}_{rt}.[4]
   2.5 If $\theta^{DEA}_{rt} \geqslant 1$, then get θ^E_{rt}, $d_{jr} = \sum_t d_{jrt}$, $\forall j$, and $Y_r = Y_{rt} + \sum_{j=1}^{J} \beta^V_{jrt} d_{jrt}$. Go to step 2.8.
   Else if $\theta^{DEA}_{rt} < 1$ and $d_{jr} = \sum_t d_{jrt} < 0$, then run (10) to hold back the input adjustment on the efficient frontier

$$
\begin{aligned}
\text{Min} \quad & \sum_{j=1}^{J} \left(X^V_{jrt} + d_{jrt} \right) \\
\text{s.t.} \quad & \sum_{k=1}^{K} \lambda_k Y_k = Y_{rt} + \sum_{j=1}^{J} \beta^{V-}_{jrt} d_{jrt} \\
& \sum_{k=1}^{K} \lambda_k X^F_{ik} \leqslant X^F_{ir}, \ \forall i \\
& \sum_{k=1}^{K} \lambda_k X^V_{jk} \leqslant X^V_{jrt} + d_{jrt}, \ \forall j \\
& \sum_{k=1}^{K} \lambda_k = 1 \\
& -R_{jr} X^V_{jr} \leqslant \left(X^V_{jrt} - X^V_{jr} \right) + d_{jrt} \\
& \lambda_k \geqslant 0, \ \forall k
\end{aligned}
\tag{10}
$$



Else run the model (11)

$$
\begin{aligned}
\text{Max} \quad & \sum_{j=1}^{J} \left(X^V_{jrt} + d_{jrt} \right) \\
\text{s.t.} \quad & \sum_{k=1}^{K} \lambda_k Y_k = Y_{rt} + \sum_{j=1}^{J} \beta^{V+}_{jrt} d_{jrt} \\
& \sum_{k=1}^{K} \lambda_k X^F_{ik} \leqslant X^F_{ir}, \ \forall i \\
& \sum_{k=1}^{K} \lambda_k X^V_{jk} \leqslant X^V_{jrt} + d_{jrt}, \ \forall j \\
& \sum_{k=1}^{K} \lambda_k = 1 \\
& R_{jr} X^V_{jr} \geqslant \left(X^V_{jrt} - X^V_{jr} \right) + d_{jrt} \\
& \lambda_k \geqslant 0, \ \forall k
\end{aligned}
\tag{11}
$$

   2.6 Set $X^V_{jr(t+1)} = X^V_{jrt} + d_{jrt}$, $\forall j$ and $Y_{r(t+1)} = Y_{rt} + \sum_{j=1}^{J} \beta^V_{jrt} d_{jrt}$.
   2.7 Set $t = t + 1$ and go to step 2.2.
   2.8 Set $r = r + 1$ and go to step 2.1.

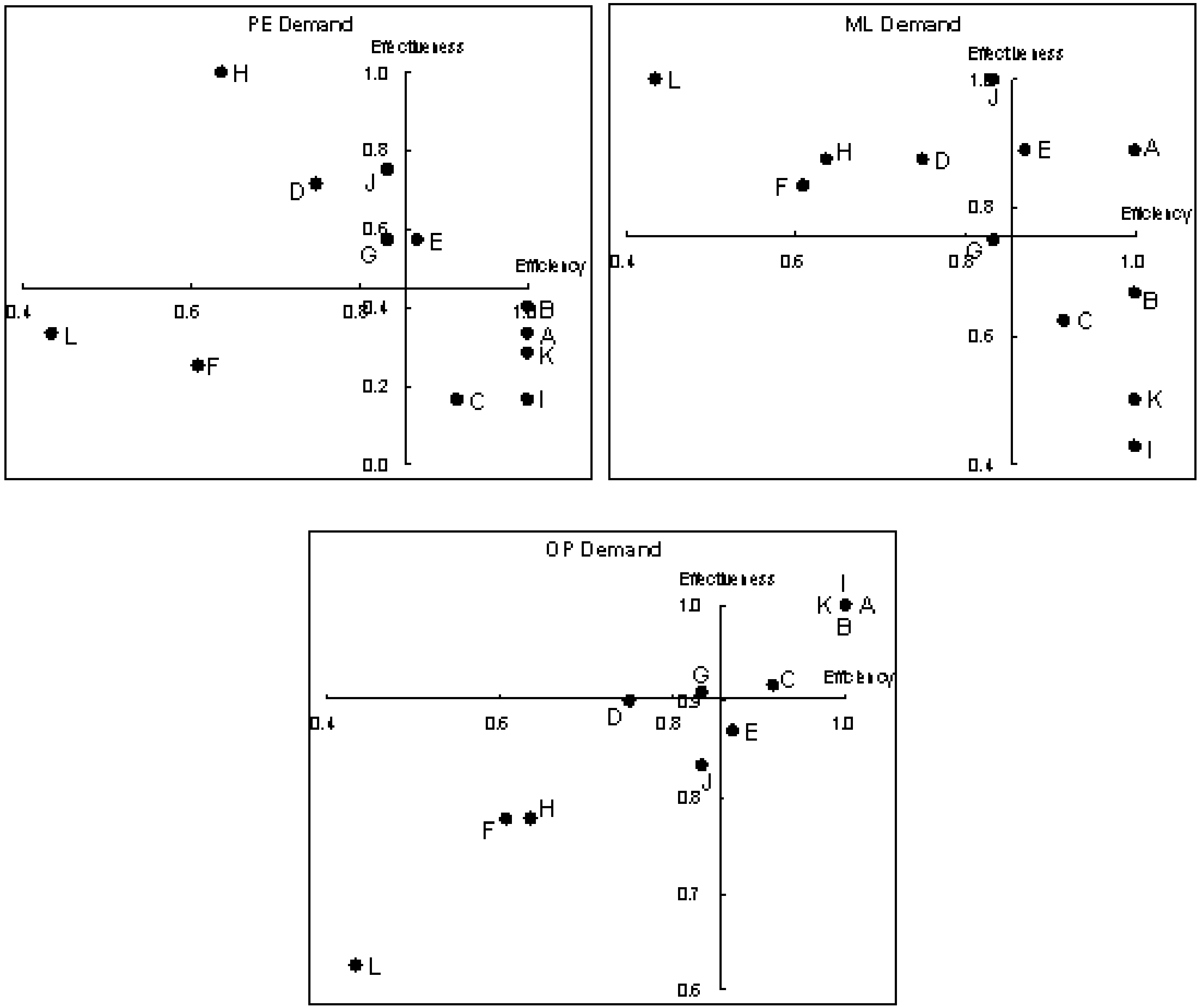
Example Illustration

- 12 firms, 1 fix input, 1 var. input, and 1 output
- Three demand scenarios
- No variable input adjustment

DMU	Fix Input	Var. Input	Actual Output	Pessimistic Demand	Most-likely Demand	Optimistic Demand
A	9	5	10	6	9	12
B	4	7	8	5	6	9
C	4	9	11	6	8	13
D	5	9	9	7	8	10
E	7	7	10	7	9	13
F	6	7	7	4	6	9
G	10	8	10	7	8	11
H	8	6	7	7	8	9
I	5	6	11	6	7	12
J	4.5	10	10	8	10	12
K	4	8	12	7	8	12
L	10	7	5	3	5	8

Proactive DEA

Strategic Position



Empirical Study- Japanese Convenience Store

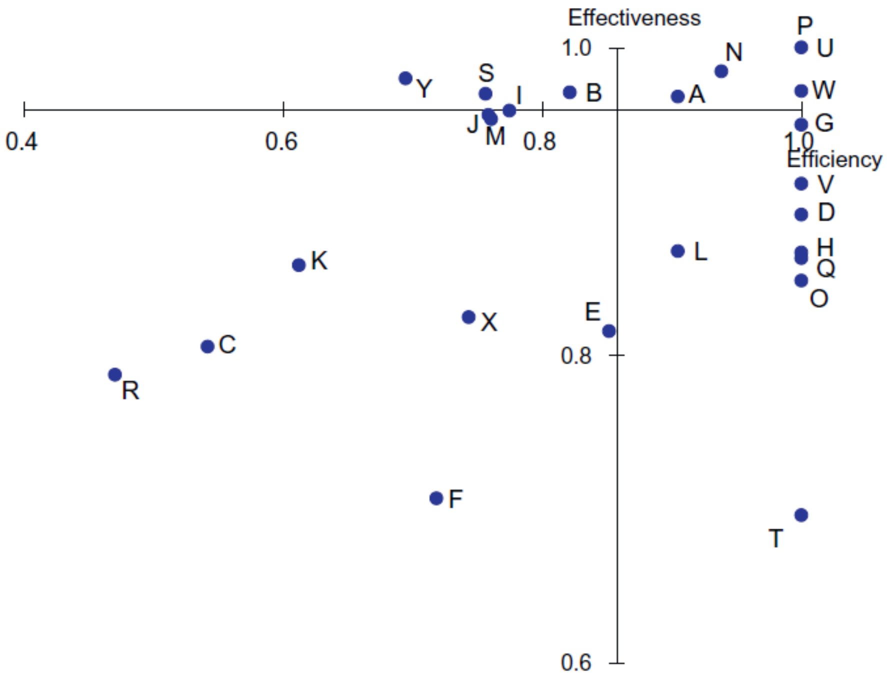
- Background
  - Observations: 25 convenience store chains
    - Product with high turnover rate
    - Hire or layoff employees to address demand fluctuation
  - Time: 1st half of 2003
  - Source: Sueyoshi (2003)

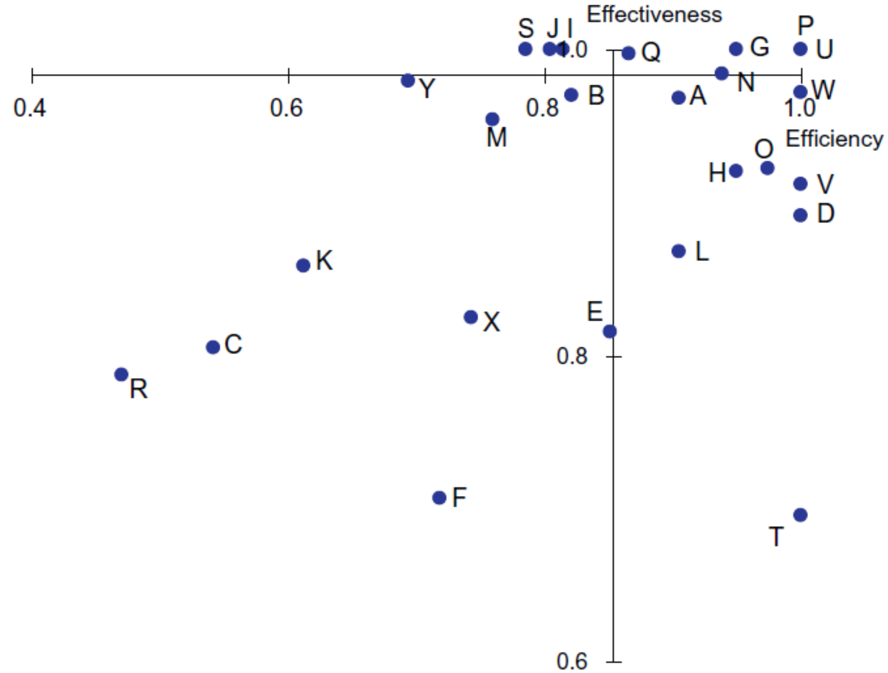
- Data Description
  - Input and output variables:
    - Capital (fixed)
    - Branch (fixed)
    - Employee (variable)
    - Goods (output)
  - Demand scenarios
    - Pessimistic, most-likely, optimistic

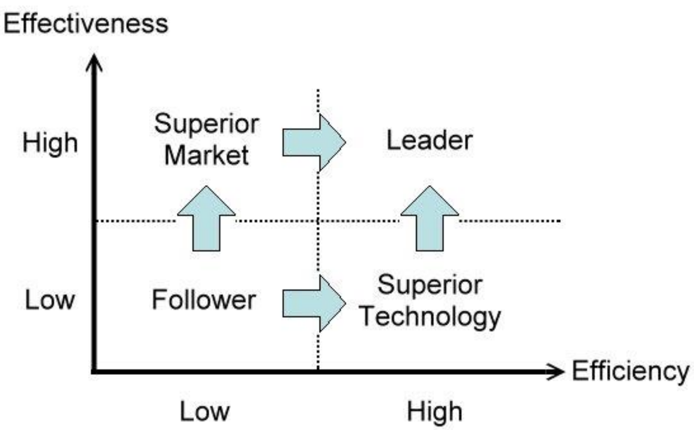
CVS	Efficiency			Effectiveness							
				EV			RP				
	N	Y	Exp.	N	Y	Exp.	N	Y	Exp.	EVPI	VSS
Community Store	1	1	0	1	1	0	0.98	0.99	-23.3	0.00	0.01
Circle K	**0.77**	**0.83**	**133.7**	0.90	1	84	**0.90**	**0.98**	**84**	0.02	**0.08**
Sunkus	0.76	0.78	-141.3	0.92	1	120.5	0.92	0.99	120.6	0.01	0.07
Shop and Life	0.61	0.65	4.9	0.97	1	-1.6	0.95	0.97	-1.5	0.01	0.02
Seicomart	1	1	0	1	1	0	0.98	0.99	-40.4	0.00	0.01
Seven Eleven	1	1	0	1	1	0	1	1	0	0.00	0.00
Daily Yamazaki	1	1	0	1	1	0	**0.98**	**1**	**-152.4**	0.00	0.02
Family Mart	0.76	0.76	0	0.90	1	151.5	0.90	0.98	151.5	0.02	0.08
:											
Avg.	0.857	0.863		0.955	0.98		0.951	0.972			

Proactive DEA

- Strategic Position with pessimistic demand before and after expansion.







Concluding Remarks

- Short-run capacity expansion decision with uncertain demand
  - Production function for short-run capacity expansion
  - Effective production
  - Diminishing marginal product
  - From ex-post evaluation to ex-ante resource planning
- Stochastic programming DEA
  - provides a robust solution and enhances the decision making
- Efficiency vs. effectiveness
  - identify the influence of demand on productivity analysis
  - strategic position and paradigm shift
- Empirical Study
  - Japanese Convenience Store Chains
    - SPDEA provides a robust adjustment of headcount to handle demand fluctuation

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Production, Manufacturing and Logistics

Proactive data envelopment analysis: Effective production and capacity expansion in stochastic environments

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A B S T R A C T

Demand fluctuations that cause variations in output levels will affect a firm's technical inefficiency. To assess this demand effect, a demand-truncated production function is developed and an "effectiveness" measure is proposed. Often a firm can adjust some input resources influencing the output level in an attempt to match demand. We propose a short-run capacity planning method, termed proactive data envelopment analysis, which quantifies the effectiveness of a firm's production system under demand uncertainty. Using a stochastic programming DEA approach, we improve upon short-run capacity expansion planning models by accounting for the decreasing marginal benefit of inputs and estimating the expected value of effectiveness, given demand. The law of diminishing marginal returns is an important property of production function; however, constant marginal productivity is usually assumed for capacity expansion problems resulting in biased capacity estimates. Applying the proposed model in an empirical study of convenience stores in Japan demonstrates the actionable advice the model provides about the levels of variable inputs in uncertain demand environments. We conclude that the method is most suitable for characterizing production systems with perishable goods or service systems that cannot store inventories.

Thanks for your attention!

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