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The Measurement of Port Efficiency

by

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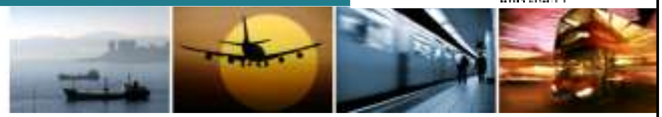

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Defining 'Efficiency'

- ***Technical Productivity*** **relates to the** ***physical*** **amount of** ***all input factors*** **used in the production process, measured by the simple ratio of output over input. Increasing** ***Productivity*** **need not be economically efficient - trade-off with other valuable resources.**
- ***Economic Productivity*** **relates to the** ***value of all inputs*** **used to produce a given output.**
- ***Efficiency*** **(*technical* and/or *economic*) relates to the difference between the actual, relative to the ideal, level of (*technical* and/or *economic*) productivity.**
- ***Scale efficiency*** **refers to the difference between actual, relative to the ideal, production size.**

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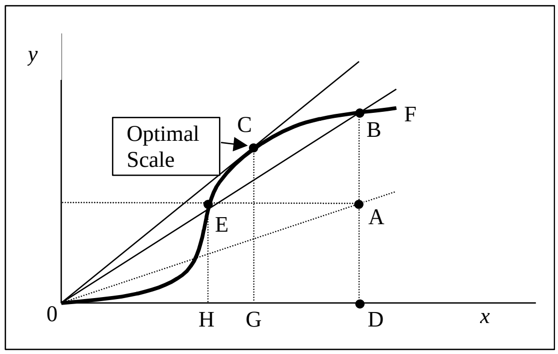
A Refresher in Elementary Economics: Technical Efficiency and Production Functions



Source: Derived from Coelli et al (1998, p. 5)

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Characteristics of Production Frontiers

- **Production functions represent the industry situation at current levels of technology.**

- **The function is defined as a frontier. i.e. it is not based on an average of individual players that comprise the industry. The term ‘Frontier’ emphasises the top level of performance for the industry; a level to which individual players already perform or may aspire.**

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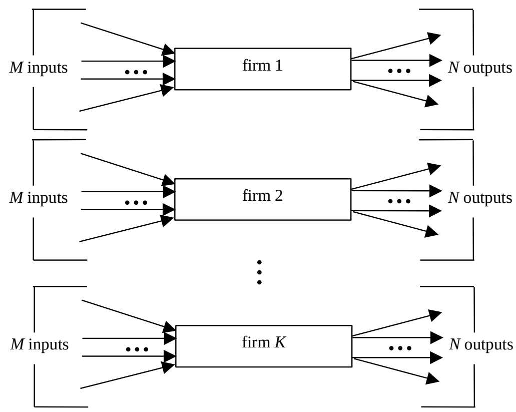
Characteristics of Production Frontiers



Source: drawn by the author

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Characteristics of Production Frontiers

- **Players on the frontier are benchmark performers from the perspective of both productivity and efficiency.**
- **A cost function perspective is also feasible. Any analysis must choose between and output vs Input-oriented approach.**
- **For Ports, most studies are output-oriented; lumpy investments + management focus on increasing throughput.**

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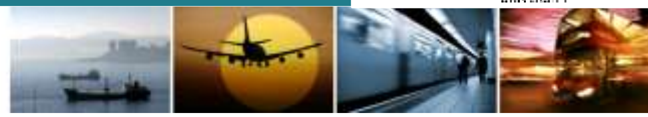

Why Measure Productivity and Efficiency

- **Quantifying the scope for efficiency savings in the use of resources and/or for augmenting output**
- **Determining the most suitable benchmark**
- **Identifying good operating practices**
- **Quantifying the marginal rates of substitution between factors of production**
- **Determining the most efficient operating scale**

This may benefit:

- **Individual firms – management can influence sources of productive efficiency to improve matters and their competitive position**
- **Industry – how far can output be increased simply through efficiency gains to compete with overseas industries**
- **Macroeconomy – in terms of providing a criterion by which economic systems may be compared and the decision made as to which to adopt**

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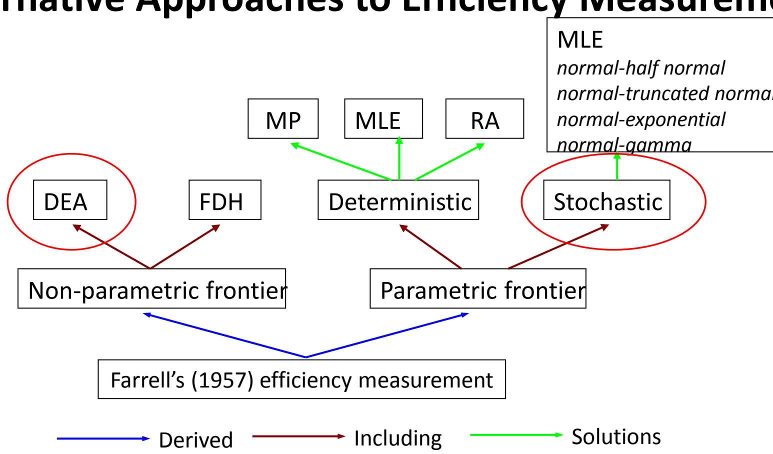
Alternative Approaches to Efficiency Measurement



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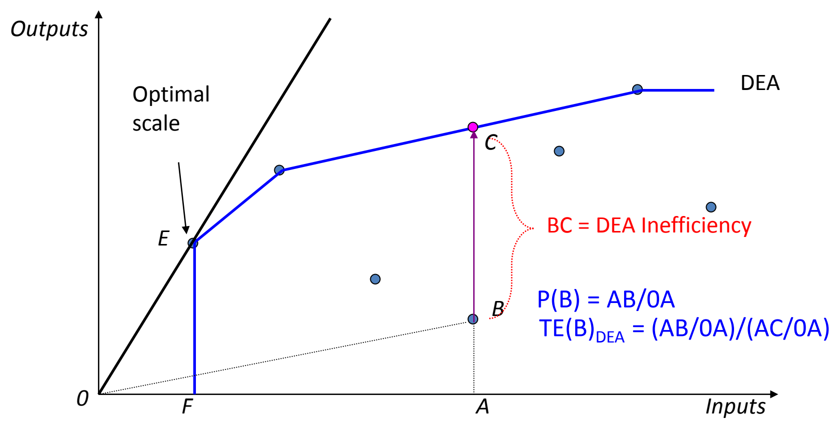
Introduction to DEA



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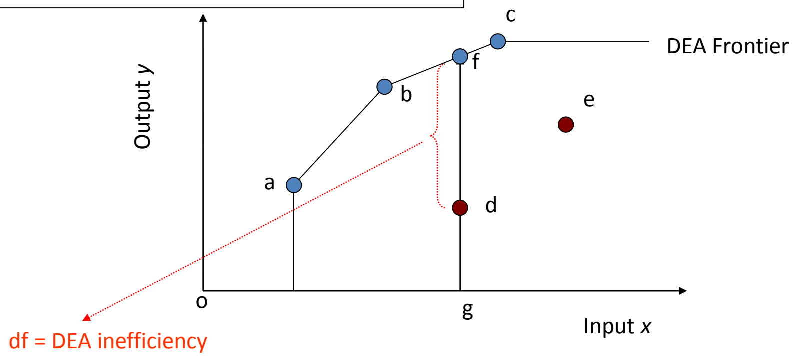
Introduction to SFA

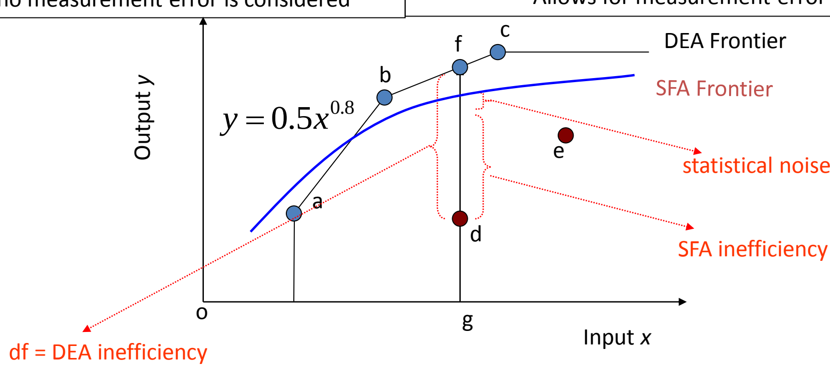
Models	Assumptions	Efficiency Component
The Normal-Half normal model	• $v_k \sim iid\ N(0,\sigma_v^2)$ • $u_k \sim iid\ N^+(0,\sigma_u^2)$ • *v_k and u_k are distributed independently of each other and of the regressors*	$E[u_k \vert \varepsilon_k] = \frac{\sigma\lambda}{(1+\lambda^2)}\left[\frac{\phi\left(\frac{\varepsilon_k\lambda}{\sigma}\right)}{\Phi\left(-\frac{\varepsilon_k\lambda}{\sigma}\right)} - \frac{\varepsilon_k\lambda}{\sigma}\right]$
The Normal-Exponential model	• $v_k \sim iid\ N(0,\sigma_v^2)$ • $u_k \sim iid$ exponential • *v_k and u_k are distributed independently of each other and of the regressors*	$E[u_k \vert \varepsilon_k] = (\varepsilon_k - \theta\sigma_v^2) + \frac{\sigma_v\phi\left[\frac{(\varepsilon_k - \theta\sigma_v^2)}{\sigma_v}\right]}{\Phi\left[\frac{(\varepsilon_k - \theta\sigma_v^2)}{\sigma_v}\right]}$
The Normal-Truncated normal model	• $v_k \sim iid\ N(0,\sigma_v^2)$ • $u_k \sim iid\ N^+(\mu,\sigma_u^2)$ • *v_k and u_k are distributed independently of each other and of the regressors*	$E[u_k \mid \varepsilon_k] = \left(\frac{\varepsilon_k\lambda}{\sigma} + \frac{\mu}{\sigma\lambda}\right)$
The Normal-Gamma model	• $v_k \sim iid\ N(0,\sigma_v^2)$ • $u_k \sim iid$ gamma • *v_k and u_k are distributed independently of each other and of the regressors*	$E[u_k \mid \varepsilon_k] = \frac{h(p+1,\varepsilon_k)}{h(p,\varepsilon_k)}$ $h(p,\varepsilon_k) = E[z^p \mid z > 0, \varepsilon_k]$ $z \approx N[-(\varepsilon_k + \sigma_v^2/\sigma_u), \sigma_v^2]$

Note: $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}$, $\lambda = \sigma_u/\sigma_v$, $\varepsilon_k = v_k - u_k$, *and* $\Phi(\bullet)$ *and* $\phi(\bullet)$ *are the standard normal cumulative distribution and density functions.*

DEA
non-parametric, piecewise linear frontier
no measurement error is considered



DEA	SFA
non-parametric, piecewise linear frontier	Parametric frontier with a particular functional form
no measurement error is considered	Allows for measurement error



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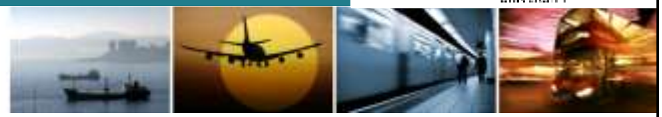

Applications of DEA

Martinez-Budria *et al* (1999) - Spanish Port Authorities 1993-97
Tongzon (2001) 4 Australian and 12 other international container ports 1996
Valentine and Gray (2001) 31 of the top 100 container ports 1998.
Itoh (2002) 8 international container ports in Japan 1990-1999.
Barros (2003,2004) Portuguese port industry 1999 and 2000.
Barros and Athanassiou (2004) Portuguese and Greek seaports, 1998-2000.
Bonilla et al (2004) Spanish port system 1995-1998
Park and De (2004) Korean seaports , 1999.
Turner et al (2004) North American ports 1984 to 1997
Estache et al (2004) Mexico's 11 main ports, 1996-1999.
Cullinane et al (2005) world's top 30 container ports, 2001
Barros (2006) Italian ports, 2002 to 2003.
Rios and Gastaud Macada (2006) 23 container terminals in the Mercosur region, 2002-2004.
Cullinane and Wang (2006) 69 European container terminals, 2003.
Liu (2008) 10 Asia-Pacific ports, 1998-2001.
Hung, Lu and Wang (2010) Asian container ports, 2007.

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•Cullinane, K.P.B. (2010) Revisiting the Productivity and Efficiency of Ports and Terminals: Methods and Applications, in C. Grammenos [Ed.] *Handbook of Maritime*

Applications of SFA

Liu (1995) 28 U.K. ports, 1983-1990.
Banos-Pino et al (1999) 27 Spanish container ports, 1985-1997.
Notteboom et al (2000) 36 European container terminals, 1994.
Coto-Millan et al (2000) 27 Spanish ports, 1985-1989.
Estache et al (2002). Mexican ports, 1996–99.
Cullinane, Song and Gray (2002) major container ports in Asia, 1989-1998.
Cullinane and Song (2003) Korean and UK container terminals, 1979-1996.
Tongzon and Heng (2005) selected container terminals around the world, 2000.
Barros (2005) Portuguese ports between, 1990-2000.
Cullinane and Song (2006) European container ports, 2003.
Gonzalez and Trujillo (2008) Spanish container ports, 1990-2000.
Yan et al (2009) world's major container ports, 1997-2004.

For a comprehensive review of all these works, see:

Cullinane, K.P.B. (2010) Revisiting the Productivity and Efficiency of Ports and Terminals: Methods and Applications, in C. Grammenos [Ed.] *Handbook of Maritime Economics and Business*, Informa Publications, London, 907-946.

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Characteristics of Port Efficiency Studies

- All such studies are data-driven.
- Data used tends to be generally available and proprietary and, therefore, relatively cheap and easy to collect – hence, the focus on containers.
- Since individual port efficiency estimates are all estimated relative to the rest of the sample under study, they cannot be compared across studies.
- Only broad conclusions can be compared – e.g. on private sector involvement.
- Although methods appear complex, analysis is comparatively easy – largely black box approaches, with wide availability of both DEA and SFA software.
- Data is the problem.

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Data Issues

- Defining the port sector (industry) whose production function needs to be estimated – i.e. whole ports or terminals, across what cargo types (container, bulk, ro-ro, break-bulk, general cargo, cars etc), over what geographical range (i.e. what is the objective of the analysis – e.g. African ports).
- Over what time period and periodicity – time series, cross-section, panel. Data per annum, per month etc.
- Identification of input and output variables.

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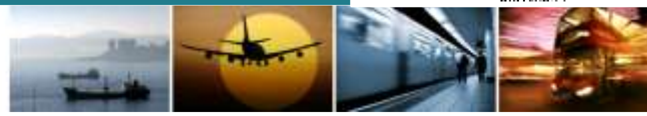

Mainstream Efficiency Variables

Physical Inputs

Capital
- Gantry Cranes
- RTGs
- Straddle Carriers
- Land
- Berthage
- Yardage

Labour
- No. of Employees
- % Mant. vs Manual
- Average Age of workers
- Hours per week
- Idle time

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Mainstream Efficiency Variables

Monetary Inputs

Capital
- Amortised capital Investment
- Equipment cost
- Cost of materials and other direct costs
- Value of land

Labour
- Total cost of management
- Total cost of manual labour
- Administration cost
- Average gross cost per employee

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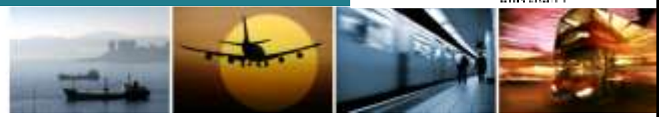

Mainstream Efficiency Variables

Outputs

Physical
- No. of ships handled
- Volume of cargo handled
- Cargo handling rate
- Cargo handled per crane
- Cargo handled per man-hour worked
- Average delays to ships(awaiting berth and at berth)
- Facility utilisation
- Truck turnaround times and queuing

Monetary
- Sales
- Sales growth
- Profits
- Market share
- Profits per employee
- Revenue per m2 of land
- Cargo handled per $

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Contextual (~~Environmental~~) Input Variables

Other, more qualitative influences beyond capital and labour inputs (including external influences) are increasingly treated as 'inputs' to the production process, for example:
- **Ownership structure**
- **Size**
- **Regulatory Changes**
- **Demand variability**
- **Deviation distance**
- **Connectivity and Accessibility**

Potential New Output Variables

Environmental impacts as negative outputs of the production process
Effectiveness variables – e.g. customer satisfaction

- Greater influence over port choice decision and competiveness
- Needs to be tailor-made

Time in port of both ships and cargo as the output of the port production process

- Need to control for congestion time to focus solely on handling efficiency
- Better reflection of inventory costs to shippers
- Allows for choice aspect of transhipment ports where speed of transit to feeders is primary concern to port choice decision maker, rather than cargo handling efficiency at berth.

Conclusions

- Conventional efficiency estimation based on the frontier approach and applying DEA and SFA models is relatively straightforward.
- These models are sufficiently flexible to allow a number of useful variations to have been developed.
- The efficiency outcomes from such models are limited, however, by the fact that they depend intrinsically upon the composition of the database analysed and, as such, results cannot be compared between applications.
- A major issue is the quality and availability of data to drive the empirical models and efficiency estimations.

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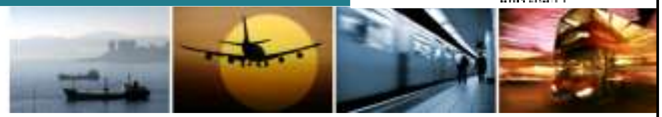

Conclusions

- Any prescriptive set of efficiency indicators must start with the easy and cheap to collect input/output variables.
- These should be supplemented by qualitative contextual input variables, including customer satisfaction and other effectiveness-related data, which is feasible to collect on a systematic basis.
- Time in port as an output of port production may be a reasonable proxy for effectiveness criteria.
- There is an increasing need to account for environmental performance – perhaps as a negative output of production provides a valid route.
- Any systematic and sustainable performance evaluation must be based on data which is economic to collect on a continuous basis.