



Welcome to the International DEA Symposium

Dear Delegates,

It is my great pleasure to extend a warm welcome to everyone on behalf of The University of Queensland and in particular, UQ Business School. Over the next few days I hope many new research collaborations and friendships will be struck helped by the friendly atmosphere we take for granted as residents of Brisbane.

We have a range of presentations spanning banking, power generation, health care, tertiary education and DEA methodology. I trust everyone will freely share their expertise with the others in the informal environment of knowledge exchange we have tried to create. The strong presence of student delegates is truly inspiring and signals the growth DEA has enjoyed since the last time we met at UQ back in year 2000. I believe the 'Student Forum' on the last day will greatly benefit the aspiring students of DEA by exposing their work to expert opinion - hopefully before submission for a degree.

I would like to take this opportunity to thank the sponsors for providing the funds required to make this symposium happen, as well as the keynote speakers who will share their expertise and insight with the rest of us. I also gratefully acknowledge the assistance extended by Trevor Findlay, Mamiza Haq, Jemma King and Danielle Burke of UQ Business School.

I wish all the delegates a very pleasant stay in Queensland and I hope that you will take back home fond memories and some sharpened knowledge.

On behalf of the organising committee,

Necmi Kemal AVKIRAN

Sponsors: Faculty of Business, Economics & Law; UQ Business School; Centre for Efficiency & Productivity Analysis



PROGRAM

International DEA Symposium *Pushing the Envelope*

27-29 September 2010

Venue: The University of Queensland, St Lucia Campus, Brisbane, Australia

Symposium web site: <http://www.users.on.net/~necmi/symposium/>

Enquiries: n.avkiran@business.uq.edu.au

General information for delegates

- The maximum presentation time including questions, answers and discussion is **40mins**. Shorter presentations are also acceptable.
- Abstracts and slides for keynote speakers will be placed at the end of this document. **Anyone wanting a copy of a delegate's presentation or paper is requested to email that person directly (please see addresses provided in square brackets in the program).**
- The audience is requested to **leave all comments to the end of a presentation**. Questions of clarification may be put to the author during the presentation.
- Please bring your PowerPoint slides on a USB memory stick.
- Since there are no parallel sessions, all delegates are advised to come prepared in case a last minute cancellation happens.
- Keynote speakers are kindly requested to act as discussants for other keynote speakers.
- Guidelines for those acting as a discussant for regular delegates:
 - Following a presentation, a verbal summary of highlights **not exceeding five minutes** is adequate. Afterwards, please moderate the discussion.
- All the delegates are kindly requested to complete the **best paper prize score sheets** after each presentation; these will be collected twice a day - at lunch time and at the end of the day. *Keynote speakers and conveners do not qualify for this prize.*
- All events, including lunches and Tuesday evening dinner will be held at UQ St Lucia campus.



Monday, 27 September

9:00 – 9:50am: Registration, Building 14, Room 132

9:50 – 10:00am: Opening address by Professor John Mangan, Associate Dean (Research) BEL Faculty

10:00 – 11:00am: Keynote speech by Professor Finn R Førsund, Department of Economics, University of Oslo, “Reflections on the use of DEA: Some fundamental issues”. [finn.forsund@econ.uio.no]

11:15am – 12:45pm

- “Multi-period peer benchmarking of key financial decisions among Japanese regional banks: A tool for identifying deserving bailouts” (N K Avkiran and M Goto) [n.avkiran@business.uq.edu.au] Discussant: D Tripe
- “Developing a WPF-CCR for selecting suppliers in the existence of imprecise data” (M Azadi and R F Saen) [r.farzipoorsaen@griffith.edu.au] Discussant: F R Førsund

1:00 – 2:00pm: Light lunch (courtesy of UQ Business School)

2:30 – 5:00pm

- “Can closing inefficient branches make a bank’s network more efficient?” (D Tripe) [D.W.Tripe@massey.ac.nz] Discussant: N K Avkiran
- “Bank efficiency and risk exposures in East Asian countries” (S G Chan, M Z A Karim) [sokgee@um.edu.my] Discussant: D Tripe
- “Modelling relative efficiency of banks from the perspective of regulators” (M Haq) [m.haq@business.uq.edu.au]



Tuesday, 28 September

10:00 - 11am: Keynote speech by Professor Joe Zhu, Department of Management, Worcester Polytechnic Institute, “DEA game cross efficiency”. [jzhu@WPI.EDU]

11:15am – 12:45pm

- “An autoregressive estimator for semi-parametric models” (R Boueri) [rmiranda@pos.ucb.br] Discussant: J Zhu
- “Improvement targets under uncertain environments by FDH model” (H Morita) [morita@ist.osaka-u.ac.jp] Discussant: J Zhu

1:00 – 2:00pm: Light lunch (courtesy of UQ Business School)

2:30 – 5:00pm

- “The development of a DEA model for analysing the effectiveness of powerline maintenance teams” (R Egelstaff and G Chattopadhyay) [REgelstaff@thiess-services.com.au] Discussant: S Sandu
- “Interplay between economic and environmental productivity: a case study of Australian electricity industry” (S Sandu and D Sharma) [suwin.sandu@gmail.com] Discussant: R Egelstaff
- “Robustness of DEA efficiency estimates” (N K Avkiran and H Morita) [n.avkiran@business.uq.edu.au]

7:00pm: Dinner (courtesy of UQ Business School)



Wednesday, 29 September

10:00 - 11am: Keynote speech by Professor Christopher O'Donnell, School of Economics, The University of Queensland, "DEA Methodology for Measuring and Decomposing Profitability, Productivity and Efficiency". [c.odonnell1@uq.edu.au]

11:15am – 12:45pm, STUDENT FORUM: Presentations *by* students and *for* students

- "The threat and the remedy of contrast variables in PCA-DEA: A consumption efficiency analysis in Malaysia car market" (G Yap, W Rosmanira, Z Isa) [yaplcgrace@yahoo.com] **Discussant:** C O'Donnell
- "Evaluating the efficiency of Vietnamese banking system: An application using data envelopment analysis" (D T Ngo, D Tripe) [T.Ngo@massey.ac.nz] **Discussant:** M Haq

1:00 – 2:00pm: Light lunch (courtesy of UQ Business School)

2:30 – 5:00pm, STUDENT FORUM: Presentations *by* students and *for* students

- "A decomposition of productivity measures for Bangladesh universities" (P Zaman, R Villano, E Fleming) [pzaman@une.edu.au] **Discussant:** S Harrison
- "Do smaller rural hospitals face greater performance constraints than referral hospitals?" (S Harrison, R Villano, E Fleming) [sharris3@une.edu.au] **Discussant:** P Zaman
- Closing session: "Empowering yourself to publish in international refereed journals" (N K Avkiran) [n.avkiran@business.uq.edu.au]

Abstracts in the anticipated order of presentation

(Slides for keynote speakers are provided separately at the end of this document)

Keynote speech by Professor Finn R Førsund, Department of Economics, University of Oslo, Reflections on the use of DEA: Some fundamental issues

Efficiency and productivity studies based on non-parametric frontier production functions is a research strand accumulating an impressive number of publications with contribution from many countries and is the focus of a number of regular specialised meetings and workshops. However, there are some fundamental issues that are not often addressed in publications. It appears that researchers sometimes rush to estimate efficiency and productivity scores, or delve into mathematical intricacies of DEA formulations without adequately reflecting about the meaning and significance of what they are attempting. The fundamental issues that will be discussed include: Can inefficiency be rationalised; the meaning of dynamic efficiency; the nature of the frontier production function concept; the short-run vs long-run view on efficiency; the aggregation level and the method of aggregation; and, how these issues bear on the measurement of efficiency and productivity.

Multi-period peer benchmarking of key financial decisions among Japanese regional banks: A tool for identifying deserving bailouts (N K Avkiran and M Goto)

A relative multi-period analysis of the troubled Japanese regional banks for the period 1998-2007 investigates the levels of dividends, retained earnings, external funding and share performance during good and bad economic times. The methodology captures linkages among yearly financial decisions, thus acknowledging strategic decisions that cover multiple periods. The paper illustrates a new approach using the range-adjusted measure that can guide continuous benchmarking of bank financial performance, as well as help policy-makers monitoring potential misappropriation of bailout funds during financial crises. The findings indicate a potential to adjust levels of debt and equity funding, and substantial room for improvement in share performance.

Developing a WPF-CCR for selecting suppliers in the existence of imprecise data (M Azadi and R F Saen)

In recent years, determining the appropriate supplier has become a crucial strategic consideration in the competitive market. Worst-practice frontier-Charnes-Cooper-Rhodes (WPF-CCR) model is one of the models in data envelopment analysis (DEA). The DEA requires that the values for all inputs and outputs be known exactly. However, this assumption may not be true, because data in many real applications cannot be precisely measured. One of the important methods to deal with such conditions is considering imprecise data in DEA. In this paper, the concept of imprecise data envelopment analysis (IDEA) approach is used to develop WPF-CCR model. A numerical example demonstrates the application of the proposed model.

Can closing inefficient branches make a bank's network more efficient? (D Tripe)

A common rationale for the investigation of the efficiency of bank branches is that X-inefficiencies in individual branches and other operating units contribute to aggregate X-inefficiency across the bank as a whole. Improvement in the efficiency of individual branches within a network is thus seen as a way by which a bank's overall efficiency can be improved. Challenges with such an approach, however, are that there is generally a minimum operational size for branches within a network, and that a branch network also has a geographic dimension, meaning that branches may be established to support the banks' operations in a geographic sense, without regard to short-run costs (or efficiencies). This study uses data from a bank that operates in New Zealand, a country with relatively low population density, and where the geographic scope of a network can be a significant factor in interbank competition. The study is undertaken using slacks-based DEA models, which are preferred because of their ability to identify relatively greater amounts of inefficiency, where it is easier for management to achieve measureable improvements in performance. Particular attention is given to branches with significant inefficiency (less than 80% efficient), and a restructure of which would allow the banks to achieve significant efficiency improvements. The paper goes beyond a mere identification of inefficiency to identifying potential approaches to improving efficiency.

Bank Efficiency and Risk Exposures in East Asian Countries (S G Chan, M Z A Karim)

Globalization and financial liberalization is believed to increase competition in the banking market which calls for financial institutions to be more efficient for their survival. Nevertheless, the increase in competition has speeded up the reallocation of charter value across banks and this creates wide incentives for banks to diversify away from traditional banking activities. Banks engage in greater diversification with the use of off-balance sheet activities and greater involvement in non-interest income activities. The recent subprime crisis proved that the involvement of banks in non-interest income and other off-balance sheet activities coupled with poor risk management leads to failure of major financial institutions worldwide. Banks in the developing economies experienced contractions in credit line and reduction in financial flows as a result of the subprime crisis. This lesson should not be taken lightly by the developing countries even though the effect of subprime crisis is not as overwhelmed as in the developed countries. The use of off-balance sheet activities and also involvement in non-interest income activities has been on the increasing trend. This will possibly create excessive risk to the banking institutions. Hence, this study looks into the effect of off-balance sheet activities and various types of risk (credit risk, interest rate risk, liquidity risk, insolvency risk etc.) on cost and profit efficiency in the East Asian countries for the period 2000 to 2009. By doing so, we can also provide some indication on the risk exposure of banking institutions in the region. To achieve the objectives, in the first stage, we will estimate efficiency scores using slack-based measures based on the Data Envelopment Analysis. In the second stage, we estimate the effect of off-balance sheet activities and risk-exposures on cost and profit efficiency using Tobit regression by controlling for bank size and capital.

Modelling relative efficiency of banks from the perspective of regulators (M Haq)

The world banking sector has encountered serious downturns in the past few decades with the most recent example driven by the U.S. sub-prime mortgage crisis, first recognized in the financial press in 2007. Bank efficiency is a vital issue to regulators and the systemic problems that followed the Global Financial Crisis (GFC) provide further impetus to better understand the importance of bank efficiency. This study examines the efficiency of eight listed Australian commercial banks using super-SBM common frontier for the period 1995-2005. Findings show a mean efficiency score of 0.838, a minimum score of 0.302 and a maximum score of 3.076 (the latter belongs to Bank of Queensland in 2005). Among the big four banks, it is observed that NAB is efficient consecutively from 1998 to 2005, ANZ bank is efficient in 1995, 2001, 2002, 2004 and 2005, Commonwealth bank is efficient in 1995, 1998, 2000, 2003, 2004 and 2005, while Westpac performed efficiently only in 2001 and 2005. Considering the aforementioned maximum score to be an outlier the super-SBM was run again without the Bank of Queensland 2005 data. The findings indicate the new mean efficiency score as 0.817, and the maximum score to be 1.477 (Bank of Queensland in 2000); Sun Corp –Metway Ltd (in 2002) is the least efficient bank. In order to achieve efficiency Sun Corp should emulate NAB. The projections show that SunCorp can increase revenue diversification by 90% by which the bank's idiosyncratic risk can be reduced by 58%. Further, market discipline can be increased by 371%. Nevertheless, depending on the size of the bank it may not be possible for Sun Corp to increase their subordinated debt amount to such an extent.

Keynote speech by Professor Joe Zhu, Department of Management, Worcester Polytechnic Institute, DEA game cross efficiency

We examine the cross efficiency concept in DEA. Cross efficiency links one DMU's performance with others, and has the appeal that scores arise from peer evaluation. However, one set of optimal DEA weights (possibly out of many alternate optima) may improve the cross efficiency of some DMUs, but at the expense of others. We generalize the original DEA cross efficiency concept to game cross efficiency. Specifically, each DMU is viewed as a player that seeks to maximize its own efficiency, under the condition that the cross efficiency of each of the other DMUs' does not deteriorate. We show that the optimal game cross efficiency scores constitute a Nash Equilibrium point.

An autoregressive estimator for semi-parametric models (R Boueri)

The built-in correlation of the efficiency scores produced by DEA methodology generates a problem for the estimation and inference of a second-stage, parametric regression, when those scores are to be utilized as endogenous variables. Furthermore, the unclearness of the subjacent data generating process makes it hard to evaluate the estimators' properties. Simar and Wilson (2007) address these issues and suggest both a coherent data generating processes and a second-stage bootstrap procedure for dealing with the autocorrelation among efficiency scores. What have been ignored is that the correlation pattern of the efficiency scores is known. It is given by the weight vector of the DEA envelop formulation. Thus, it is possible to incorporate the true correlation structure in a feasible estimator. In this paper, such an estimator is proposed. Monte Carlo simulations are performed utilizing a truncated data generating processes with a true multi-output technology and the results are compared with those obtained by least-squares, Tobit and truncated regressions and by the Simar and Wilson bootstrap. The proposed estimator performed very well in terms of efficiency and fairness, being comparable with the Simar and Wilson bootstrap and superior to the others which do not consider the correlation in the efficiency score.

Improvement targets under uncertain environments by FDH model (H Morita)

Data envelopment analysis is a method for measuring the efficiency of decision making units. When there are stochastic variations in data, the efficiency evaluations such as efficiency score, reference units, are also stochastic. The genetic algorithm in uncertain environments (GAUCE) has been proposed to solve a combinatorial optimization problem under uncertainty. We discuss the stochastic evaluation of FDH efficiency in uncertain environments by applying the framework of GAUCE.

The development of a DEA model for analysing the effectiveness of powerline maintenance teams (R Egelstaff and G Chattopadhyay)

Maintenance of 47,000kms of transmission grid power lines in Australia is a big challenge. Systems and infrastructures that were originally developed in the early years of the 20th century are being maintained and expanded rapidly to meet the ever increasing demands of society in the 21st century. The essential service of maintaining an aging energy systems infrastructure under a deregulated environment, and measuring the performance of various teams in many states of different asset configuration, whilst catering for demands on resources, is a challenge to the service providers and asset owners. Current work and measurement practices used by the service providers are mainly based on historical methods with data capture predominantly localised. Unfortunately, the use of inconsistent approaches between power services suppliers for measuring powerline effectiveness has proven neither transparent nor efficient. The consequences will be more complex in the future when the suppliers of energy are going to manage business which will be required to evolve new techniques and practices to meet demands of super grids and smart energy systems. A data envelope analysis (DEA) model is developed and proposed, in this paper, as a promising approach to overcome and resolve the limitations of the current practices. The DEA technique is proposed because the calculations are non-parametric, and can handle more than one input and output. Furthermore, with DEA it is possible to avoid the assumptions of regression analysis and alter the functional forms for measuring the efficiencies of work teams. The result is that the DEA model will assist management experiment with new work techniques and practices and then measure the efficiency and effectiveness as each technique or practice as it is implemented. The outcome of this DEA model is expected to help the power industry develop contracts and monitor performances of services suppliers in a consistent and transparent manner.

Interplay between economic and environmental productivity: a case study of Australian electricity industry (S Sandu and D Sharma)

Australian electricity industry reform, initiated in the mid-1990s, was predicated on the assumption that it would improve industry productivity and provide wide-ranging economic benefits. Opinions however differ on the actual gains from reform. While some argue that economic gains of recent times are directly attributable to reform, others concur that these gains have their origin in the pre-reform era and that reform has merely maintained the status quo. The emerging concern about global warming, and the role of the electricity sector as the dominant source of greenhouse-gas emissions, has imparted yet another dimension to the ongoing debate about the nexus between reform and productivity, namely, the relationship between economic and environmental productivity. This paper develops a perspective on these dimensions, namely, whether the economic gains are a direct consequence of reform or precede it, and what is the interplay between economic and environmental productivity in the context of Australian electricity reform. The paper employs Data Envelopment Analysis (DEA) and Malmquist approaches to evaluate the economic and environmental productivity of the Australian electricity industry for the period 1955 to 2008. Early analyses indicate that electricity industry productivity improvements for the recent years have their origin in the pre-reform era. Also, that there is an inherent tension between economic and environmental productivity. These analyses should be useful for the Australian energy policy analysts and planners as they endeavour to progress electricity reform and design the architecture of the Australian response to contain global warming.

Robustness of DEA efficiency estimates (N K Avkiran and H Morita)

DEA researchers sometimes forget the exploratory nature of the technique. Furthermore, tests of model fit or diagnostics we find in parametric tests do not exist for DEA. This situation implies we are often uncertain about the sensitivity of efficiency estimates to the composition of the efficient frontier. The efficient frontier can, in turn, be sensitive to the choice of variables, where the choice of variables is often driven by managerial focus (expert opinion), experience, production theory, or a combination. Tests of robustness based on various data perturbations frequently report Spearman or Kendall's tau-b rank correlations. Some studies use large Monte Carlo simulations to compare DEA estimates with 'true' efficiency (based on a Cobb-Douglas function). Main data perturbations may include (i) deleting variables while maintaining the degrees of freedom, (ii) re-testing without the DMUs on the original frontier and observing new rankings, and (iii) re-testing with an arbitrarily reduced sample size. We explore the impact of some data perturbations in the context of network DEA.

Keynote speech by Professor Christopher O'Donnell, School of Economics, The University of Queensland, DEA Methodology for Measuring and Decomposing Profitability, Productivity and Efficiency

Profitability change (a measure of value change) can be written as the product of a terms-of-trade index (a measure of price change) and a productivity index (a measure of quantity change). O'Donnell (2008) shows that the productivity index can be further decomposed into indexes of technical change (movements in the production frontier), technical efficiency change (movements towards the frontier), and scale and mix efficiency change (movements around the frontier to capture economies of scale and scope). The O'Donnell decomposition methodology can be applied in any multiple-input multiple-output setting, it makes no assumptions concerning the optimising behaviour of firms or the degree of competition in input or output markets, and it is exhaustive in the sense that it only involves components that can be unambiguously interpreted as measures of either technical change or efficiency change. Implementing the methodology involves estimating the production frontier using stochastic frontier analysis (SFA) or data envelopment analysis (DEA) methods. This paper shows how DEA can be used to decompose profitability change into the product of a terms-of-trade index and a spatially- and temporally-transitive Hicks-Moorsteen productivity index. The productivity index is then decomposed into technical change and various efficiency change components.

The threat and the remedy of contrast variables in PCA-DEA: A consumption efficiency analysis in Malaysia car market (G Yap, W Rosmanira, Z Isa)

Being non-parametric, data envelopment analysis (DEA) suffers from the curse of dimensionality, especially when large sample size is not attainable. Principal component analysis (PCA) is a well-known remedy for dimension reduction. However, the PCA-DEA model has not solved the problem as the contrast variables in principal components muddle up the statistical model of DEA. To illustrate the deficiency in the PCA-DEA model, an empirical dataset on the consumption efficiency in Malaysia car market is used. It is shown that the contrast variables distort the objective function in the linear programming model as variables with positive and negative weights can counterbalance each other. In other words, a car is deemed efficient by loading input variables that associate with negative weights, yet desirable. Modifications are suggested to avoid the contrast variables. This involves performing orthogonal rotation on the retained principal components, identifying the major direction of the eigenvectors, and normalizing the modified principal directions. By taking absolute value of the modified principal directions, components can be constructed as weighted averages of the original variables. As such, by replacing the original variables with the modified components, the classical statistical DEA model can still be met. It is shown that modified PCA-DEA estimators worked well in the consumption efficiency analysis in the context of Malaysia car market. The efficiency estimates thus produced are more discriminating than that of the standard DEA under both constant and variable returns to scale.

Evaluating the efficiency of Vietnamese banking system: An application using data envelopment analysis (D T Ngo, D Tripe)

Over these last twenty years in Vietnam, the financial system in general and the banking system in particular have been transferred from a monopoly system into a diversified system which allows all participants to compete fairly and effectively. Within these past years, the banking system in Vietnam did gradually develop in number of banking institutions, size of the banking sector in the economy, amount of credits for the economy, and amount of other banking services as well. Along with the development of the banking system in number, size, asset value, deposit, credit and debit account, ATM/POS, interest rates, etc. which attracted more and more customers using the banking' services; the efficiency of the banking system also has been increasing. So far, there is still a lack of research on the efficiency of the banking sector in Vietnam over the decades. Several researches were conducted, however, due to the data limitations, these researches were just small steps at the big front gate. This paper, which focuses on evaluating the efficiency of bigger sample size of Vietnamese commercial banks in the year of 2009, tends to make a contribution to this progress. The DEA approach allows this paper to evaluate the efficiency of 22 Vietnamese commercial banks in using their inputs in the year of 2009 (these banks were ranked top in the banking industry in Vietnam – VNR500). After analysing, the research comes to a conclusion that although the efficiency of these banks is averagely high, however, there is still an opportunity to improve this indicator.

A decomposition of productivity measures for Bangladesh universities (P Zaman, R Villano, E Fleming)

The efficiency of universities has attracted strong attention in recent years, not only due to the ever-increasing public funding made available to the universities, but also because universities play a significant role in shaping the future of any nation. In this study, we measure the performance of forty universities in Bangladesh for the period 2003 to 2008 using data envelopment analysis. Using the DPIN program, productivity measures are decomposed into changes in technology, output and input technical efficiency, output and input scale efficiency, and output and input mix efficiency. Total factor productivity was found to have varied widely across the sample. Our preliminary results confirm that universities achieved mean output and input technical efficiency measures for the whole period of 0.72 and 0.78, respectively. Mean output and input scale efficiency measures were 0.83 and 0.76, and mean output and input mix efficiency measures were 0.88 and 0.42, respectively. The relatively low mean input mix efficiency score probably reflects the inflexibility that universities have in adjusting their input mixes to changing student enrolments. Our results also suggest that public universities performed better on average than private universities on all efficiency scores over the study period. This study constitutes a preliminary analysis of efficiency change of Bangladeshi Universities, and we have some concerns with data quality and the availability of data on output variables that are currently being examined with the aim to provide a more suitable data set for analysis in the future.

Do smaller rural hospitals face greater performance constraints than referral hospitals? (S Harrison, R Villano, E Fleming)

The Federal Government's increased focus on public hospital care and its efficiency has required more in-depth analysis of public hospital performance over time. This paper focuses on New South Wales (NSW) public acute care hospitals, looking at efficiency scores and technology gaps among four categories of NSW hospitals. A balanced panel data set comprises six years of New South Wales health service comparison data for 1993/94 to 1997/98 and 2007/08. It is decomposed and analysed in four categories: Principal Referral, Major Referral, District/Regional and Community hospitals. Data envelopment analysis is used to obtain technical efficiency scores for each category to estimate individual production frontiers. A metafrontier is then constructed, encompassing each category's individual production frontiers, allowing a measure of the metatechnology ratio to be calculated. Results indicate that the average technical efficiency scores for each category of acute care hospital in NSW are 0.965, 0.921, 0.835 and 0.875 for Principal Referral, Major Referral, District/Regional and Community hospitals, respectively. The average metatechnology ratios for each of these categories are 0.964, 0.966, 0.926 and 0.910. The metatechnology ratios indicate that smaller hospitals (District/Regional and Community hospitals) find it more difficult to operate on the metafrontier due to environmental or technological factors.

Empowering yourself to publish in international refereed journals (N K Avkiran)

This presentation is designed to assist the novice researcher keen on publishing in refereed journals. Those who are passionate about life-long learning, appreciate the world of discovery that opens up in front of them the moment a paper is conceived, and realise publishing is increasingly competitive and challenging, may particularly benefit. The headings of main topics to be covered include, (i) conceiving a publishable paper and writing it, (ii) submitting and handling correspondence, and (iii) responding to the referees.

Reflections on the use of DEA: some fundamental issues

Finn R. Førsund
Department of Economics
University of Oslo

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International DEA Symposium
Pushing the Envelope
27-29 September 2010
Brisbane, Australia

Fundamental issues in DEA

1

Motivation: Pushing the envelope of understanding

- Efficiency measurement a major industry
- Purpose to stimulate thinking about issues and counteract herd behaviour
- Too many papers without reflecting over fundamental issues
- Interactions between theory and data
 - Cooper (2002), application-driven DEA

Fundamental issues in DEA

2

Fundamental issues in need of more reflections

- Rationalising inefficiency
- Dynamic efficiency
- The core benchmark frontier construct
- Salter's dynamic framework for efficiency and productivity measurement
 - Implications for efficiency and productivity measurement
- The Malmquist productivity index

Fundamental issues in DEA

3

Rational behaviour and inefficiency

- The transformation of resources to outputs:
 - The production function is defined as a function that maximises outputs for given level of inputs
- Inefficiency means that the production function is not realised
- Observed inefficiency is difficult to reconcile with rational behaviour

Fundamental issues in DEA

4

Explanations of inefficiency

- Seminal contributions to efficiency studies
 - Farrell (1957)
 - Quality of inputs (labour, capital) and management
 - Aigner and Chu (1968)
 - Varied holdings of capital equipment, ability to adjust
 - Leibenstein (1966)
 - X-efficiency due to varied motivational efficiency of workers
 - Stigler (1976)
 - Plays down the arguments, markets for qualities

Rationalising inefficiency

5

Inside the black box

- The objective function of the firm
 - A firm can be perfectly efficient according to its own objectives
- Agency theory
 - Owners and managers are pursuing different objectives, slack as manager welfare, $W(\pi, s)$
 - Managers and workers are pursuing different objectives, reduced effort as worker welfare, $U(w, e)$,
full effort as benchmark for efficiency

Fundamental issues in DEA

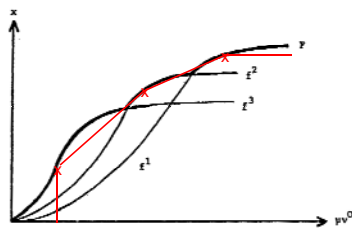
6

- Difficult to specify how goals are to be achieved
 - Public sector services and political goals
- Incomplete information about the production function
 - Diffusion of knowledge
- Putty clay production technology

The fundamental benchmark

- The frontier production function
 - A non-parametric frontier is calculated using LP
 - A stochastic parametric frontier is calculated using statistical estimation procedures
- Efficiency is measured for
 - An individual unit
 - The industry
 - Should be a one-to-one correspondence between the benchmark and the unit under study

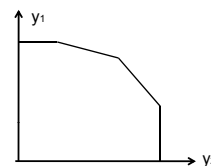
Estimating best practice for individual units



Source: Førsund and Hjalmarsson (1974), Fig. 1

Multi-output, multi-input in DEA

- The textbook case
 - $F(y, x) \leq 0$
 - y outputs, x inputs
- The Frisch system
 - $F^i(y_1, \dots, y_m, x_1, \dots, x_n) \leq 0$
 - $i = 1, \dots, \mu, s = 1, \dots, m, j = 1, \dots, n$
- Degree of assortment:
 - $\alpha = m - \mu$
- The maximal degree
 - $m - 1$
- Pure factor bands, output couplings



Production functions that rationalise inefficiency

- Leif Johansen (1972). *Production functions. An integration of micro and macro, short run and long run aspects.*
 - The crudeness of the concept of the production function, as it is being used in most econometric research, is ... out of proportion with the sophistication of the theories and methods by which it is surrounded (Johansen, 1972, p.1)

The micro foundation of dynamic analysis

- The vintage (putty-clay) model of Leif Johansen (1959), (1972)
 - Production function concepts
 - The micro unit ex ante production function
 - The micro unit ex post production function
 - The industry short-run production function
 - The industry long-run production function
 - The crucial assumptions
 - Standard neo-classical substitution possibilities before investments (putty), but fixed coefficients after investment (clay)

The micro Putty-Clay model

- The ex ante micro unit function at time $t = 0$

$$y_o = f_o(x_1, \dots, x_n, K), f_{oi}' > 0, f_{oK}' > 0, i = 1, \dots, n$$

- The ex post micro unit function at t

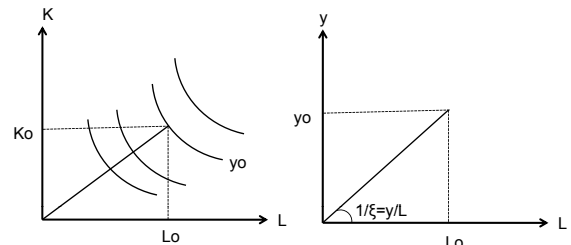
$$y(t, v) = \min \left[\frac{x_1(t, v)}{\xi_1(v)}, \dots, \frac{x_n(t, v)}{\xi_n(v)}, \bar{y}(v) \right], v = \text{vintage}, v \leq t$$

- The “frozen” fabrication (input) coefficients

$$\xi_i(v) = \frac{\bar{x}_i(t, v)}{\bar{y}(v)}, i = 1, \dots, n,$$

$\bar{y}(v)$ = capacity of vintage v , $\bar{x}_i(t, v)$ = capacity input

Ex ante micro – ex post micro



The short-run industry function

- The classical derivation of a production function

$$\text{Max } Y = \sum_{j=1}^N y_j \text{ subject to}$$

$$\sum_{j=1}^N \xi_{ij} y_j \leq \bar{X}_i, i = 1, \dots, n$$

$$y_j \leq \bar{y}_j, j = 1, \dots, N$$

$$Y = \sum_{j=1}^N y_j = F^*(\bar{X}_1, \dots, \bar{X}_n, \bar{y}_1, \dots, \bar{y}_N)$$

$$= F(X_1, \dots, X_n)$$

- Symbols

Y = total industry output

y_j = output of unit j

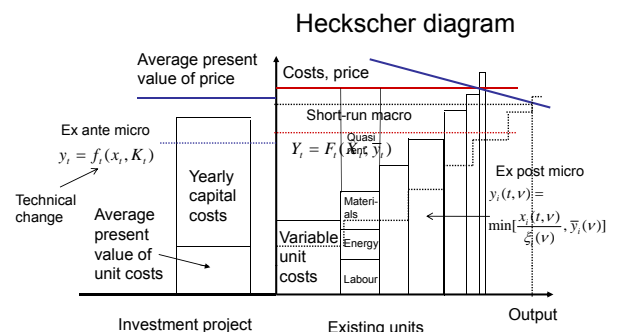
ξ_{ij} = input coefficient for input i in unit j

\bar{X}_i = total given amount of input i

\bar{y}_j = capacity of unit j

$F(\cdot)$ the macro production function

Salter's dynamic analysis



Dynamic efficiency measures

- Dynamics in economics

– Change of variable under study is a function of the level of the variable

– Studying the development over time of a variable

- Dynamic efficiency

– Efficiency for each period over time (static)

– Efficiency of the time path itself (one number covering several periods)

- Dynamic DEA (Färe and Grosskopf, 1996)
 - Disaggregation of a unit into a network of sub-units where one unit produces outputs that are inputs for other units one period later
 - But this is not dynamics in the usual sense
 - No time path is solved for, all time periods may be relabelled to the same period
- Dynamic development of the unit itself
 - Optimal time path of quasi-fixed inputs (capital)
 - Characterisation of the time path using present value of costs based on cost of adjustment (Nemoto & Goto, 1999, 2003)
 - Optimal costs on observed costs (one number)

- Needed: investment theory, dK/dt
- Neoclassical analysis provide
 - Existing K and wanted K
 - But this is not an investment theory (Haavelmo, 1960)
 - Trick: Introduce cost of adjustment
 - But this has a weak empirical foundation
 - Taking resources away from current production
- Another weakness with the Nemoto & Goto approach
 - The benchmark is based on data, but we do not know if any development shown by data actually is optimal

The Malmquist productivity index

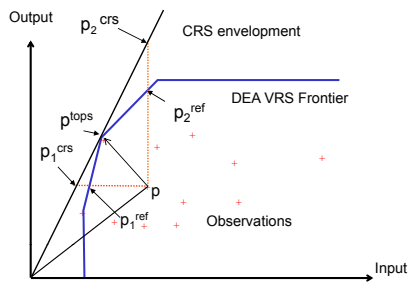
- Caves et al. (1982) definition

$$M_i^t(x_i^t, y_i^t, x_i^{t+1}, y_i^{t+1}) = \frac{E_i^t(x_i^{t+1}, y_i^{t+1})}{E_i^t(x_i^t, y_i^t)}$$

$$i = 1, \dots, J, t = 1, \dots, T$$

$$M_i^{t+1}(x_i^t, y_i^t, x_i^{t+1}, y_i^{t+1}) = \frac{E_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{E_i^{t+1}(x_i^t, y_i^t)}$$

Farrell measures of efficiency

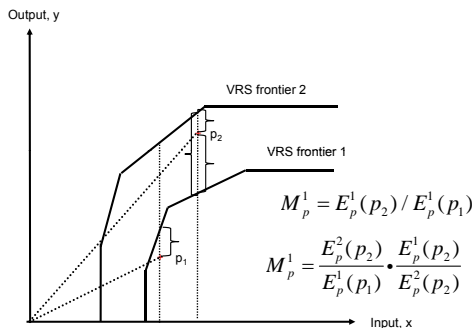


Malmquist index decomposition

- Decomposition into efficiency change and technological shift was first done in Nishimizu and Page (1982)
- Seminal contribution of Färe and Grosskopf et al. (1989, 1992, 1994)
 - Using DEA to estimate piecewise linear technology

$$M_i^t(x_i^t, y_i^t, x_i^{t+1}, y_i^{t+1}) = \underbrace{\frac{E_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{E_i^t(x_i^t, y_i^t)}}_{\text{Efficiency change}} \cdot \underbrace{\frac{E_i^t(x_i^{t+1}, y_i^{t+1})}{E_i^{t+1}(x_i^{t+1}, y_i^{t+1})}}_{\text{Frontier shift}}$$

The Malmquist productivity index



Confusions

- The square root variant of Färe and Grosskopf et al. (1989, 1992, 1994)
- Requires the specification of two benchmark technologies at the same time
- The decomposition of the geometric mean

$$\bar{M}_i^{t,t+1}(x_i^t, y_i^t, x_i^{t+1}, y_i^{t+1}) = \sqrt{\frac{E_i^t(x_i^{t+1}, y_i^{t+1})}{E_i^t(x_i^t, y_i^t)} \cdot \frac{E_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{E_i^{t+1}(x_i^t, y_i^t)}}$$

$$\bar{M}_i^{t,t+1} = \frac{E_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{E_i^t(x_i^t, y_i^t)} \sqrt{\frac{E_i^t(x_i^{t+1}, y_i^{t+1})}{E_i^{t+1}(x_i^{t+1}, y_i^{t+1})} \cdot \frac{E_i^t(x_i^t, y_i^t)}{E_i^{t+1}(x_i^t, y_i^t)}}$$

Desirable index properties

- The identity test: OK
- The proportionality test
 - Doubling of outputs in period t+1 for constant inputs should double the rate of productivity change
 - Doubling the inputs in period t+1 should half the rate of productivity change
- Solution: measuring productivity change at optimal scale of the benchmark technology for each period

The circularity property of an index

- The only important "test" that Fisher's ideal index failed
- The importance for productivity (Gini, 1931)
 - Productivity numbers from different periods can be compared
- The solution: fixed benchmark
 - Berg et al., 1992

$$M_i^s(x_i^t, y_i^t, x_i^{t+1}, y_i^{t+1}) = \frac{E_i^s(x_i^{t+1}, y_i^{t+1})}{E_i^s(x_i^t, y_i^t)}, i = 1, \dots, J, t = 1, \dots, T$$

s benchmark frontier technology

- Circularity does not mean that we cannot measure shifts of the frontier
 - Decomposition maintaining circularity

$$M_i^s(x_i^t, y_i^t, x_i^{t+1}, y_i^{t+1}) = \frac{E_i^s(x_i^{t+1}, y_i^{t+1})}{E_i^s(x_i^t, y_i^t)} = \underbrace{\frac{E_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{E_i^t(x_i^t, y_i^t)}}_{\text{Efficiency change}} \cdot \underbrace{\frac{E_i^s(x_i^{t+1}, y_i^{t+1}) / E_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{E_i^s(x_i^t, y_i^t) / E_i^t(x_i^t, y_i^t)}}_{\text{Frontier shift}}$$

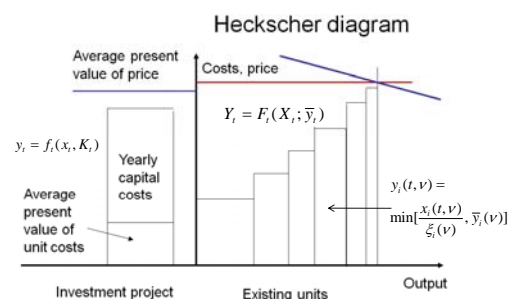
- Both components obey circularity
- Frontier shift for each year is measured relative to the benchmark frontier technology

Arguments against/for circularity

- Färe et al., 2008, p. 551
 - ...we should follow Fisher and use the natural order of time and not worry about circularity.
- Samuelson and Swamy (1974), p. 576
 - Conclusion: So long as we stick to the economic theory of index numbers, the circular test is as required as is the property of transitivity itself.

- Samuelson and Swamy (1974), p. 575
 - Indeed, so enamoured did Fisher become with his so-called Ideal index...that, when he discovered it failed the circularity test he had the hubris to declare "...therefore, a *perfect* fulfilment of this so-called circular test should really be taken as a proof that the formula which fulfils it is erroneous"...
 - Alas, Homer has nodded; or more accurately, a great scholar has been detoured on a trip whose purpose was obscure from the beginning.

The Salter cycle revisited



DEA Game Cross Efficiency

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Cross Efficiency

$$E_{dj} = \frac{\sum_{r=1}^s \mu_{rd}^* y_{rj}}{\sum_{i=1}^m \omega_{id}^* x_{ij}}, d, j = 1, 2, \dots, n$$

For DMU_j , the average of all E_{dj}

$$\bar{E}_j = \frac{1}{n} \sum_{d=1}^n E_{dj}$$

$$\text{Max } \sum_{r=1}^s \mu_r y_{rd} = \theta_d$$

$$\text{s.t. } \sum_{i=1}^m \omega_i x_{ij} - \sum_{r=1}^s \mu_r y_{rj} \geq 0, j = 1, 2, \dots, n$$

$$\sum_{i=1}^m \omega_i x_{id} = 1$$

$$\omega_i \geq 0, i = 1, 2, \dots, m$$

$$\mu_r \geq 0, r = 1, 2, \dots, s$$

Why Cross Efficiency?

- Cross efficiency provides an efficiency ordering among all the DMUs to differentiate between good and poor performers.
- It can eliminate the need for incorporation of additional weight restrictions into DEA, thereby avoiding unrealistic DEA weighting schemes (see Anderson et al. 2002).

Applications

Cross efficiency has been used in a number of different areas.

- It can be used in Multiple Criteria Decision Making (MCDM) to improve discrimination among alternatives (see (Doyle, 1995), (Green & Doyle, 1995), (Sarkis, 2000), (Mavrotas & Trifillis, 2006))
- In ranking candidates in a preferential election (Green et al. , 1996), in the ranking and selection of projects and technologies ((Oral et al. , 1991), (Green et al. , 1996), (Shang & Shueyoshi, 1995)).
- In evaluating the performance of hedge-fund classifications (Gregoriou et al., 2005).
- Other applications are reported in (Sarkis & S.Talluri, 2004), (Chen, 2002), (Ertay & Ruan, 2005).

Problem

- nonuniqueness of the DEA optimal weights possibly reduces the usefulness of cross efficiency (Doyle and Green (1994))
- secondary goals have been proposed for cross efficiency Calculation.
 - Aggressive (benevolent) model formulations to identify optimal weights that not only maximize the efficiency of a particular DMU under evaluation, but also minimize (maximize) the average efficiency of other DMUs.

Cross Efficiency scores are arbitrary in that they depend on a particular set of optimal DEA weights generated by the computer code in use at the time.

Competition

• In many DEA applications, some form of direct or indirect competition may exist among the DMUs

- R&D project proposals

- When DMUs are viewed as players in a game, cross efficiency scores may be viewed as payoffs, and each DMU may choose to take a noncooperative game stance to the extent that it will attempt to maximize its (worst possible) payoff. If one adopts this game-theoretic approach, it may be argued that the existing approaches to cross evaluation suffer shortcomings in regard to these common situations.

Game Cross Efficiency

- For each competing DMU j , a multiplier bundle is determined that optimizes the efficiency score for j , with the additional constraint that the resulting score for d should be at or above d 's estimated best performance, in a cross-efficiency sense.

“chicken and egg” phenomenon

- The problem, of course, arises that we will not know this best performance score for d until the best performances of all other DMUs are known as well.
- To combat this “chicken and egg” phenomenon, we adopt an iterative approach that we shall prove leads to an equilibrium.

DEA Game Cross Efficiency

$$\begin{aligned}
 & \text{Max } \sum_{r=1}^s \mu_r^d y_{rj} \\
 \text{s.t. } & \sum_{i=1}^m \omega_i^d x_{ij} - \sum_{r=1}^s \mu_r^d y_{ri} \geq 0, l = 1, 2, \dots, n \\
 & \sum_{i=1}^m \omega_i^d x_{ij} = 1 \\
 & \alpha_d \times \sum_{i=1}^m \omega_i^d x_{id} - \sum_{r=1}^s \mu_r^d y_{rd} \leq 0 \\
 & \omega_i^d \geq 0, i = 1, \dots, m \\
 & \mu_r^d \geq 0, r = 1, \dots, s
 \end{aligned}$$

- In the algorithm to be developed, this α_d initially takes the value given by the average original cross efficiency of DMU d .
- When the algorithm converges, this α_d becomes the best (average) game-cross efficiency score.

Algorithm

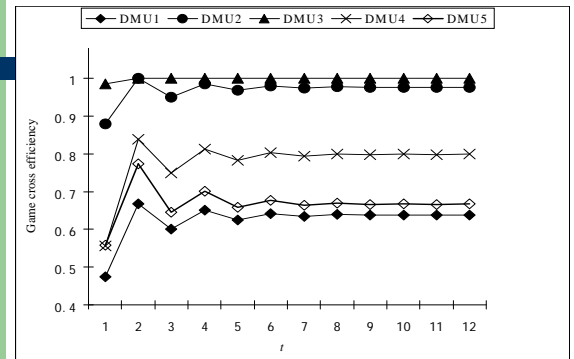
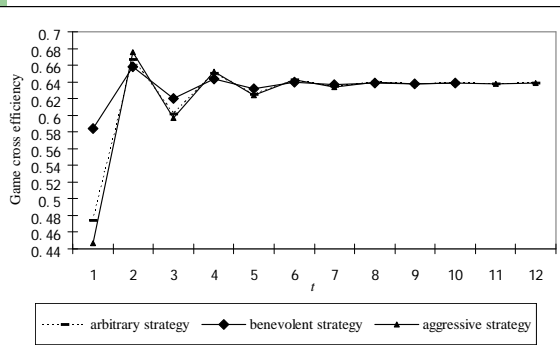
- **Step 1:** Solve CCR model and obtain a set of original average DEA cross efficiency scores Let $t = 1$ and $\alpha_d = \alpha_d^1 = \bar{E}_d$
- **Step 2:** Solve game cross model. Let $\alpha_j^2 = \frac{1}{n} \sum_{d=1}^n \sum_{r=1}^s \mu_{rj}^{d^*}(\alpha_d^1) y_{rj}$
or in a general format $\alpha_j^{t+1} = \frac{1}{n} \sum_{d=1}^n \sum_{r=1}^s \mu_{rj}^{d^*}(\alpha_d^t) y_{rj}$
- **Step 3:** If $|\alpha_j^{t+1} - \alpha_j^t| \geq \varepsilon$ for some j , where ε is a specified small positive value, then let $\alpha_d = \alpha_d^{t+1}$ and go to Step 2. If $|\alpha_j^{t+1} - \alpha_j^t| < \varepsilon$ for all j , then stop. α_j^{t+1} is the best average game-cross efficiency given to DMU j .

Numerical Example

	X_1	X_2	X_3	Y_1	Y_2
DMU ₁	7	7	7	4	4
DMU ₂	5	9	7	7	7
DMU ₃	4	6	5	5	7
DMU ₄	5	9	8	6	2
DMU ₅	6	8	5	3	6

CCR efficiency, Cross efficiencies and Game cross efficiency

	CCR efficiency	Game cross efficiency*	DEA cross efficiency		
			arbitrary	aggressive	benevolent
DMU ₁	0.6857	0.6384	0.4743	0.4473	0.5845
DMU ₂	1	0.9766	0.8793	0.8629	0.9295
DMU ₃	1	1	0.9856	0.9571	1
DMU ₄	0.8571	0.7988	0.5554	0.54	0.71
DMU ₅	0.8571	0.667	0.5587	0.4971	0.6386



Preference Voting

Votes Achieved by Candidates a-f

Candidate	Standing			
	1	2	3	4
a	3	3	4	3
b	4	5	5	2
c	6	2	3	2
d	6	2	2	6
e	0	4	3	4
f	1	4	3	3

Case 1: results: $b(1) = d(1) > c(0.9147) > a(0.8062) > f(0.6704) > e(0.6603)$

Case 2: results after adding two lowly rated candidates:

$b(1.0000) > d(0.9704) > c(0.9011) > a(0.7983) > f(0.6047) > e(0.5893) > g(0.0662) = h(0.0662)$

Conclusion: the order of the candidates does not change!

Conclusions

1. retains the essential peer-evaluation concept of cross evaluation, but at the same time capitalizes on the CCR approach.

2. the iterative approach provided is shown to converge to a Nash equilibrium point.



OPERATIONS RESEARCH

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The DEA Game Cross-Efficiency Model and Its Nash Equilibrium

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DEA METHODOLOGY FOR MEASURING AND DECOMPOSING PROFITABILITY, PRODUCTIVITY AND EFFICIENCY CHANGE

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 International DEA Symposium – Pushing the Envelope!
 27-29 September 2010, Brisbane Australia



BACKGROUND

- O'Donnell, C. J. (2008). An Aggregate Quantity-Price Framework for Measuring and Decomposing Productivity and Profitability Change. *Centre for Efficiency and Productivity Analysis Working Papers WP07/2008*, University of Queensland.
- O'Donnell, C. J. (2010a). "Measuring and Decomposing Agricultural Productivity and Profitability Change." *Australian Journal of Agricultural and Resource Economics* 54(4): 527-560
- O'Donnell, C. J. (2010b). "Nonparametric Estimates of the Components of Productivity and Profitability Change in U.S. Agriculture". *Centre for Efficiency and Productivity Analysis Working Papers WP02/2010*, University of Queensland. (paper presented at NAPW10)

BACKGROUND cont.

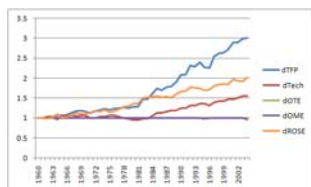
- Profitability change (a measure of value change) can be decomposed into the product of a terms-of-trade index (a measure of price change) and a multiplicatively-complete TFP index (a measure of quantity change):
 $dPROF = dTT \times dTFP$.
- The class of multiplicatively-complete TFP indexes includes Paasche, Laspeyres, Fisher, Tornquist, Hicks-Moorsteen and Lowe TFP indexes, but **not** the Malmquist TFP index of Caves et al (1982).
- **Any** multiplicatively-complete index can be decomposed into measures of technical change and efficiency change: $dTFP = dTech \times dEff$.
- The efficiency change component can be further decomposed into measures of technical, scale and mix efficiency change: $dEff = dOTE \times dOSE \times dRME = dOTE \times dOSME = \dots$ many other decompositions are available.

$dPROF = dTT \times dTFP$



California Agriculture: 1960 - 2004

$dTFP = dTech \times dOTE \times dOME \times dROSE$



California Agriculture: 1960 - 2004

BACKGROUND cont.

This decomposition methodology

- can be applied in **multiple-output multiple-input** settings
- is valid for **general technologies** (including non-convex technologies)
- requires **no assumptions concerning optimizing behaviour**
- requires **no assumptions about the degree of competition** in input or output markets
- is **exhaustive** in the sense that all of the components of TFP change are either measures of technical change or efficiency change (i.e., there are no residual "effects")

Implementing the methodology involves estimating the production frontier.

THIS PRESENTATION ...

- TFP Change in an Aggregate Quantity Framework
- TFP Change and Profitability Change
- Measures of Efficiency
- Decomposing TFP Change
- Implementation Using DEA
- Software
- Examples

TFP CHANGE

TFP is defined as the ratio of an aggregate output to an aggregate input :

$$TFP_{nt} = \frac{Q_{nt}}{X_{nt}}$$

where $Q_{nt} \equiv Q(q_{nt})$ is an aggregate output, $X_{nt} \equiv X(x_{nt})$ is an aggregate input, and $Q(\cdot)$ and $X(\cdot)$ are non-negative and linearly homogeneous aggregator functions. Thus,

$$(1) \quad TFP_{ms,nt} \equiv \frac{TFP_{nt}}{TFP_{ms}} = \frac{Q_{nt}/X_{nt}}{Q_{ms}/X_{ms}} = \frac{Q_{nt}/Q_{ms}}{X_{nt}/X_{ms}} = \frac{Q_{ms,nt}}{X_{ms,nt}}$$

TFP indexes that can be expressed as in (1) are said to be multiplicatively complete (O'Donnell, 2008).

Example - Laspeyres

If we use the price-weighted linear aggregator functions:

$$(2) \quad Q(q_k) = p'_{ms} q_k$$

$$(3) \quad X(x_k) = w'_{ms} x_k$$

then

$$(4) \quad Q^L_{ms,nt} = \frac{Q(q_{nt})}{Q(q_{ms})} = \frac{p'_{nt} q_{nt}}{p'_{ms} q_{ms}}$$

$$(5) \quad X^L_{ms,nt} = \frac{X(x_{nt})}{X(x_{ms})} = \frac{w'_{nt} x_{nt}}{w'_{ms} x_{ms}}$$

and

$$(6) \quad TFP^L_{ms,nt} = \frac{Q^L_{ms,nt}}{X^L_{ms,nt}} = \frac{p'_{nt} q_{nt} / w'_{nt} x_{nt}}{p'_{ms} q_{ms} / w'_{ms} x_{ms}}$$

Example - Malmquist and Hicks-Moorsteen

If we use the distance-based aggregator functions:

$$(7) \quad Q(q_k) = (D^c_0(x_{nt}, q_k) D^c_0(x_{ms}, q_k))^{1/2}$$

$$(8) \quad X(x_k) = (D^c_1(x_k, q_{nt}) D^c_1(x_k, q_{ms}))^{1/2}$$

then

$$(9) \quad Q^M_{ms,nt} = \frac{Q(q_{nt})}{Q(q_{ms})} = \left(\frac{D^c_0(x_{nt}, q_{nt})}{D^c_0(x_{nt}, q_{ms})} \times \frac{D^c_0(x_{ms}, q_{nt})}{D^c_0(x_{ms}, q_{ms})} \right)^{1/2}$$

$$(10) \quad X^M_{ms,nt} = \frac{X(x_{nt})}{X(x_{ms})} = \left(\frac{D^c_1(x_{nt}, q_{nt})}{D^c_1(x_{ms}, q_{nt})} \times \frac{D^c_1(x_{nt}, q_{ms})}{D^c_1(x_{ms}, q_{ms})} \right)^{1/2}$$

and

$$(11) \quad TFP^{HM}_{ms,nt} = \frac{Q^M_{ms,nt}}{X^M_{ms,nt}} = \left(\frac{D^c_0(x_{nt}, q_{nt}) D^c_0(x_{ms}, q_{nt})}{D^c_0(x_{nt}, q_{ms}) D^c_0(x_{ms}, q_{ms})} \times \frac{D^c_1(x_{ms}, q_{nt}) D^c_1(x_{nt}, q_{ms})}{D^c_1(x_{nt}, q_{nt}) D^c_1(x_{ms}, q_{ms})} \right)^{1/2}$$

TFP CHANGE AND PROFITABILITY CHANGE

Profitability is defined as the ratio of revenue to cost:

$$PROF_{nt} = \frac{P_{nt} Q_{nt}}{W_{nt} X_{nt}}$$

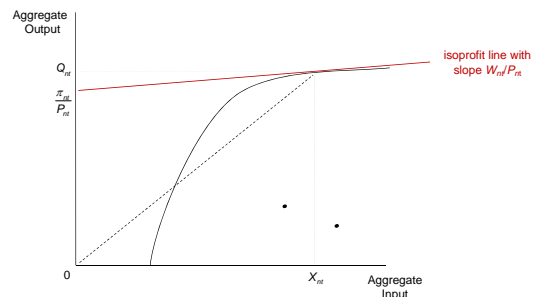
where $P_{nt} \equiv p'_{nt} q_{nt} / Q_{nt}$ and $W_{nt} \equiv w'_{nt} x_{nt} / X_{nt}$ are aggregate output and input prices. Thus,

$$PROF_{ms,nt} = \frac{PROF_{nt}}{PROF_{ms}} = \left(\frac{P_{nt} / P_{ms}}{W_{nt} / W_{ms}} \right) \left(\frac{Q_{nt} / Q_{ms}}{X_{nt} / X_{ms}} \right) = \underbrace{\left(\frac{P_{ms,nt}}{W_{ms,nt}} \right)}_{\Delta TT} \underbrace{\left(\frac{Q_{ms,nt}}{X_{ms,nt}} \right)}_{\Delta TFP}$$

This has important implications for policy ...

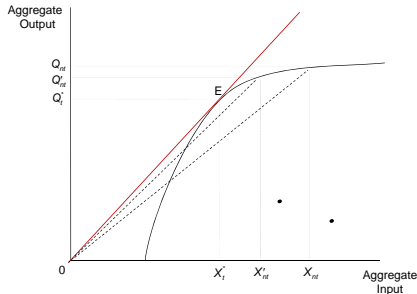
Profitability and TFP

$$\pi_{nt} = P_{nt} Q_{nt} - W_{nt} X_{nt} \Leftrightarrow Q_{nt} = \frac{\pi_{nt}}{P_{nt}} + \frac{W_{nt}}{P_{nt}} X_{nt}$$



Profitability and TFP

$$\pi_{it} = P_{it}Q_{it} - W_{it}X_{it} \Leftrightarrow Q_{it} = \frac{\pi_{it}}{P_{it}} + \frac{W_{it}}{P_{it}}X_{it}$$



$$dPROF = dTT \times dTFP$$



California Agriculture: 1960 - 2004

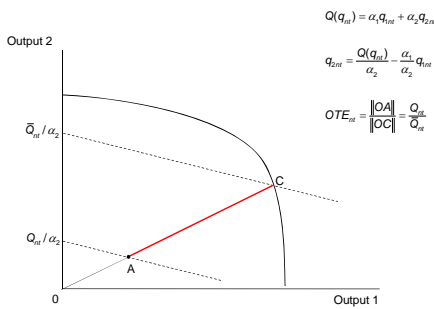
Some Implications

- If profitability levels are constant then productivity change can be measured as the inverse of the change in the terms of trade
- If there is **no technical change** and **no technical inefficiency** then we can still expect to see changes in levels of productivity as rational efficient firms respond to changes in the terms of trade.
- Deteriorations in the terms of trade that result from increased competition in input and output markets (for example) will tend to drive rational **efficient** firms towards points of maximum productivity.
- Rational **efficient** firms who experience similar changes in their terms of trade will tend to exhibit similar patterns of productivity change.
- Regulators can influence productivity outcomes by changing prices and/or by preventing firms from choosing particular input-output combinations.
- **Effective policy-making involves identifying the technical change and efficiency change components of productivity change**

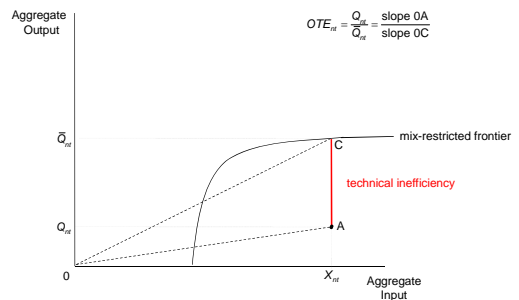
MEASURES OF EFFICIENCY

- **Output-oriented technical efficiency (OTE)** is the difference between observed TFP and the maximum TFP that is possible holding the **inputs fixed** and the **output mix fixed**.
- **Output-oriented scale efficiency (OSE)** is the difference between TFP at a technically efficient point and the maximum TFP that is possible holding the **input mix fixed** and the **output mix fixed**.
- **Output-oriented mix efficiency (OME)** is the difference between TFP at a technically efficient point and the maximum TFP that is possible holding the **inputs fixed**.
- **Residual output-oriented scale efficiency (ROSE)** is the difference between TFP at a mix efficient point and the maximum TFP that is possible using the production technology.
- **Residual mix efficiency (RME)** is the difference between TFP at a scale efficient point and the maximum TFP that is possible using the technology

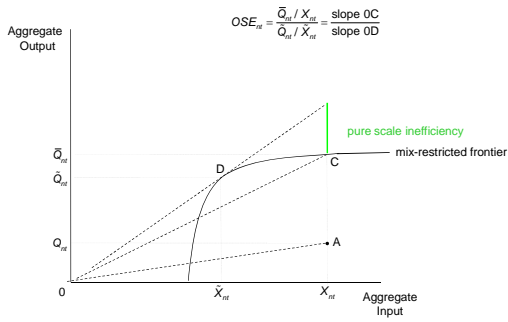
Output-Oriented Technical Efficiency



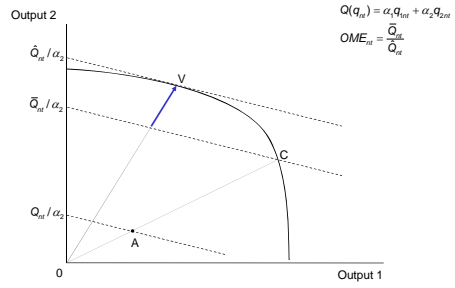
Output-Oriented Technical Efficiency



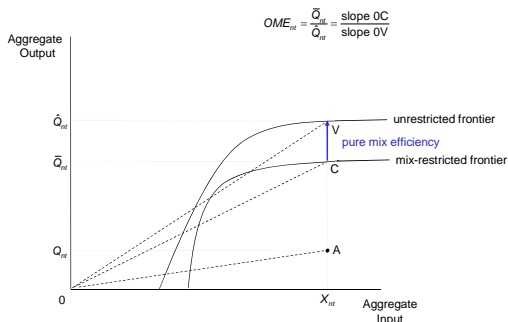
Output-Oriented Scale Efficiency



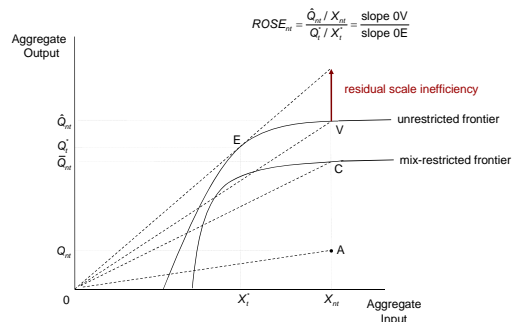
Output-Oriented Mix Efficiency



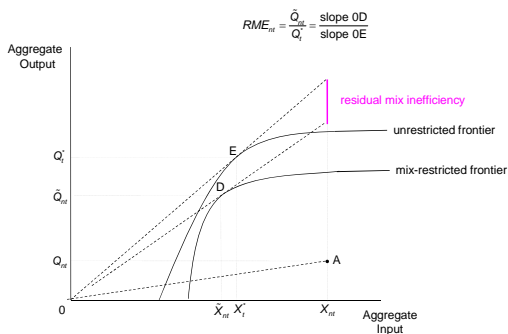
Output-Oriented Mix Efficiency



Residual Output-Oriented Scale Efficiency



Residual Mix Efficiency



TFP Efficiency

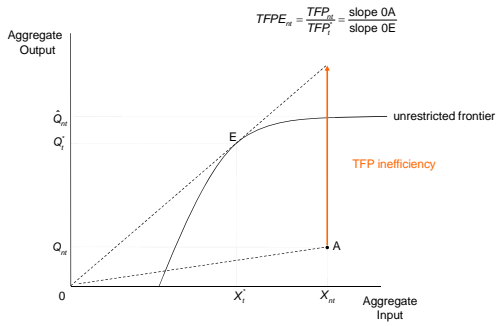
TFP efficiency (TFPE) is defined as the difference between observed TFP and the maximum TFP that is possible using the production technology (O'Donnell, 2008):

$$TFPE_{it} = \frac{TFP_{it}}{TFP_{it}^*}$$

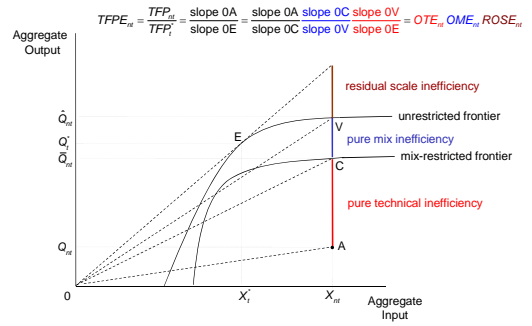
or $TFPE_{it} = OTE_{it} \times OME_{it} \times ROSE_{it}$

or $TFPE_{it} = OTE_{it} \times OSE_{it} \times RME_{it}$

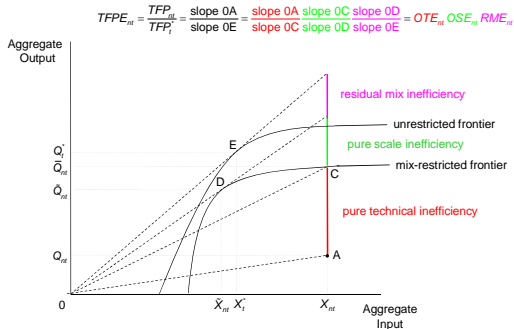
TFP Efficiency



Decomposing TFP Efficiency



Another Output-Oriented Decomposition



DECOMPOSING TFP CHANGE

O'Donnell (2008) shows that any multiplicatively-complete TFP index can be exhaustively decomposed into a measure of technical change and a measure of efficiency change.

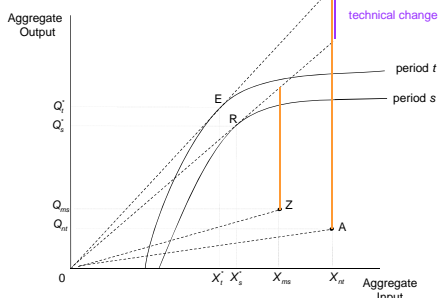
TFP efficiency: $TFPE_{nt} = \frac{TFP_{nt}}{TFP_t} \Leftrightarrow TFP_{nt} = TFP_t \times TFPE_{nt}$

$TFPE_{ms} = \frac{TFP_{ms}}{TFP_s} \Leftrightarrow TFP_{ms} = TFP_s \times TFPE_{ms}$

TFP change: $TFP_{ms,nt} = \frac{TFP_{nt}}{TFP_{ms}} = \left(\frac{TFP_t}{TFP_s} \right) \left(\frac{TFPE_{nt}}{TFPE_{ms}} \right)$

Decomposing TFP Change

$TFP_{ms,nt} = \frac{slope OA}{slope OZ} = \left(\frac{slope OE}{slope OR} \right) \left(\frac{slope OA / slope OE}{slope OZ / slope OR} \right) = \text{Technical change} \times \text{Efficiency change}$



A Finer Decomposition

TFP efficiency: $TFP_{ms,nt} = \frac{TFP_{nt}}{TFP_{ms}} = \left(\frac{TFP_t}{TFP_s} \right) \left(\frac{TFPE_{nt}}{TFPE_{ms}} \right)$

But $TFPE_{nt} = \frac{TFP_{nt}}{TFP_t} = OTE_{nt} * OME_{nt} * ROSE_{nt}$

and $TFPE_{ms} = \frac{TFP_{ms}}{TFP_s} = OTE_{ms} * OME_{ms} * ROSE_{ms}$

So $TFP_{ms,nt} = \frac{TFP_{nt}}{TFP_{ms}} = \left(\frac{TFP_t}{TFP_s} \right) \left(\frac{OTE_{nt}}{OTE_{ms}} \right) \left(\frac{OME_{nt}}{OME_{ms}} \right) \left(\frac{ROSE_{nt}}{ROSE_{ms}} \right)$

Other Decompositions

$$TFP_{ms,nt} = \left(\frac{TFP'_t}{TFP'_s} \right) \left(\frac{OTE_{nt}}{OTE_{ms}} \right) \left(\frac{OSE_{nt}}{OSE_{ms}} \right) \left(\frac{RME_{nt}}{RME_{ms}} \right)$$

$$TFP_{ms,nt} = \left(\frac{TFP'_t}{TFP'_s} \right) \left(\frac{ITE_{nt}}{ITE_{ms}} \right) \left(\frac{IME_{nt}}{IME_{ms}} \right) \left(\frac{RISE_{nt}}{RISE_{ms}} \right)$$

$$TFP_{ms,nt} = \left(\frac{TFP'_t}{TFP'_s} \right) \left(\frac{ITE_{nt}}{ITE_{ms}} \right) \left(\frac{ISE_{nt}}{ISE_{ms}} \right) \left(\frac{RME_{nt}}{RME_{ms}} \right)$$

$$TFP_{ms,nt} = \left(\frac{TFP'_t}{TFP'_s} \right) \left(\frac{OTE_{nt}}{OTE_{ms}} \right) \left(\frac{OSME_{nt}}{OSME_{ms}} \right)$$

IMPLEMENTATION USING DEA

Decomposing TFP indexes into technical change and efficiency change components involves estimating the production frontier. All the usual parametric and nonparametric estimators are available.

- O'Donnell, C. J. (2010a) uses DEA to compute and decompose Hicks-Moorsteen TFP indexes.
- O'Donnell, C. J. (2010b) uses DEA to compute and decompose spatially- and temporally transitive Lowe TFP indexes.

Estimating the Technology

Input- and output-oriented DEA models are underpinned by the assumption that the production frontier is locally linear. In the output-oriented case, this means that for any output vectors in the neighbourhood of the vector q_{nt} , the production frontier takes the form:

$$\eta' q_{nt} = \beta + \phi' x_{nt}$$

where η and ϕ are non-negative and β is unsigned to allow for variable returns to scale. Associated with this frontier is the output distance function (O'Donnell, 2010):

$$D_o^i(x_{nt}, q_{nt}) = \frac{\eta' q_{nt}}{\beta + \phi' x_{nt}} \leq 1.$$

Output-oriented measures of technical efficiency are obtained by choosing values of η , ϕ and β to maximise $D_o^i(x_{nt}, q_{nt}) \equiv OTE_{nt}$. Apart from the non-negativity constraints, the parameters must satisfy $D_o^i(x_{nt}, q_{nt}) \leq 1$ for all $i = 1, \dots, N$ and $r = 1, \dots, t$ and $\eta' q_{nt} = 1$

The Primal Problem

The primal form of the DEA LP is:

- (1a) $D_o^i(x_{nt}, q_{nt})^{-1} = \min_{\beta, \phi, \eta} \beta + \phi' x_{nt}$
 (1b) s.t. $-\eta' q_{nt} + \phi' x_{nt} + \beta \geq 0$ for $i = 1, \dots, N$ and $r = 1, \dots, t$
 (1c) $\eta' q_{nt} = 1$
 (1d) $\eta, \phi \geq 0$.

The Dual Problem

Every normal primal linear program has a dual form with the property that if the primal and the dual LPs both have feasible solutions then the optimized values of the two objective functions are equal. The dual form of the normal maximisation LP (1) is

(2a) $D_o^i(x_{nt}, q_{nt})^{-1} = \max_{\lambda} \lambda$

(2b) s.t. $\lambda q_{nt} - \sum_{i=1}^N \sum_{r=1}^t \theta_{ir} q_{ir} \leq 0$

(2c) $\sum_{i=1}^N \sum_{r=1}^t \theta_{ir} x_{ir} \leq x_{nt}$

(2d) $\sum_{i=1}^N \sum_{r=1}^t \theta_{ir} = 1$

(2f) $\lambda, \theta_{ir} \geq 0$ for $i = 1, \dots, N$ and $r = 1, \dots, t$

Estimating OTE, OSE and OME

The dual problem can be rewritten:

(3a) $\bar{Q}_{nt} / Q_{nt} = \max_{\theta, z} Q(z_{nt}) / Q(q_{nt})$

(3b) s.t. $z_{nt} - \sum_{i=1}^N \sum_{r=1}^t \theta_{ir} q_{ir} \leq 0$

(3c) $\sum_{i=1}^N \sum_{r=1}^t \theta_{ir} x_{ir} \leq x_{nt}$

(3d) $\sum_{i=1}^N \sum_{r=1}^t \theta_{ir} = 1$

(3e) $z_{nt} - \lambda q_{nt} = 0$

(3f) $z_{nt}, \theta_{ir} \geq 0$ for $i = 1, \dots, N$ and $r = 1, \dots, t$

Estimating Maximum TFP

Estimating maximum TFP involves relaxing constraints on mix and levels:

$$\begin{aligned}
 (4a) \quad TFP_i^* &= \max_{\theta_r, z, v} Q(z) \\
 (4b) \quad &\text{s.t.} \quad \sum_{r=1}^N \sum_{t=1}^T \theta_r q_{rt} \geq z \\
 (4c) \quad &v - \sum_{r=1}^N \sum_{t=1}^T \theta_r x_{rt} \geq 0 \\
 (4d) \quad &X(v) = 1 \\
 (4e) \quad &z, v, \theta_r \geq 0 \text{ for } i = 1, \dots, N \text{ and } r = 1, \dots, t
 \end{aligned}$$

SOFTWARE

DPIN is a program for Decomposing Productivity Index Numbers. Available at <http://www.uq.edu.au/economics/cepa/dpin.htm>

Features	30-Day Free Trial	Standard	Professional
Profitability and Terms of Trade Indexes	Yes	Yes	Yes
Hicks-Moorsteen and Fisher Productivity Indexes	Yes	Yes	Yes
Paasche, Laspeyres and Lowe Productivity Indexes	Yes	-	Yes
Technical Efficiency Scores and Indexes (OTE and ITE)	Yes	Yes	Yes
Scale Efficiency Scores and Indexes (OSE and ISE)	Yes	Yes	Yes
Mix Efficiency Scores and Indexes (OME and IME)	Yes	Yes	Yes
Allocative Efficiency Scores and Indexes (RAE and CAE)	Yes	-	Yes
Variable Returns to Scale	Yes	Yes	Yes
Constant Returns to Scale	Yes	Yes	Yes
Technical Regress Allowed	Yes	Yes	Yes
Technical Regress Prohibited	Yes	Yes	Yes
Technical Change Prohibited	Yes	Yes	Yes
Points of Maximum Productivity	Yes	Yes	Yes
Points of Maximum Profitability	Yes	-	Yes
Spatial-Transitivity	Yes	-	Yes
Temporal-and Spatial-Transitivity	Yes	-	Yes
Estimate frontier using moving data window	Yes	-	Yes
Maximum number of firms	10	100	< 2500
Maximum number of observations	20	500	< 5000

EXAMPLES

- O'Donnell (2008) artificial data
- O'Donnell (2010a) FAO agricultural data
- O'Donnell (2010b) USDA agricultural data
- Rice data from Coelli et al (2005)

CONCLUSIONS

- The class of multiplicatively-complete binary TFP indexes includes Paasche, Laspeyres, Fisher, Tornquist, Hicks-Moorsteen and Lowe TFP indexes, but **not** the Malmquist TFP index of Caves et al (1982).
- Any multiplicatively-complete index can be decomposed into measures of technical change and various measures of efficiency change.
- The technical and scale efficiency change components of TFP change are identical for different choices of TFP index number formula
- The technical change and mix efficiency change components vary with different choices of TFP index number formula (Fisher, Hicks-Moorsteen, transitive indexes)
- All the components of TFP change vary with different assumptions about, and different approaches to estimating, the production technology.

POLICY CONCLUSIONS

- Irrespective of whether or not there is any technical change, changes in the terms of trade can be expected to induce changes in levels of profitability and productivity.
- Except in very special cases, the point of maximum TFP does not equal the point of maximum profitability.
- Higher profits will often be associated with lower productivity.
- Policies designed to improve productivity may be misdirected if we fail to understand and properly identify the drivers of productivity change.

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