Benchmarking of Academic Departments using Data Envelopment Analysis (DEA)

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Outline

- Introduction
- Literature Review
- Methodology
- DEA Models
- Case Study
- Conclusions and Future Work

Introduction

- Standard means of evaluating departmental quality
- US News most prominent and widespread assessment
- Important for all stakeholders of universities
- Peer Assessment Score of US News can be subjective
- Efficient use of available resources
- Benchmarking of best practices

Introduction (Benchmarking)

- Benchmarking is defined as the process of comparing practices, procedures, and performance metrics to an established standard or best practice." (Bosso et al., 2010)
- Identifies reference point for comparison
- Measures the gap between the current situation with the aspiration level

Literature Review

Efficiency and Different Methods of Measuring Efficiency	
• Jayamaha and Mula (2011)	• Efficiency analysis conducted in both private and public sector (hotels, sports and banks; education, electricity and military)
• Bezat (2009)	• Non-parametric and Parametric Methods (Data Envelopment Analysis and Stochastic Frontier Analysis)
• Mortimer and Peacock (2002)	• SFA assumes parametric function between inputs and outputs; also treats deviations from production function as random error and inefficiency
• Kuah and Wong (2011)	• SFA finds it difficult to handle multiple inputs and outputs; requires large number of data
• Kuah and Wong (2011)	• DEA easily handles multiple input and output without giving prior weights; useful when study involves different units

Literature Review (Cont'd)

DEA Methodology	
Charnes, Cooper and Rhodes (1978)	Called the CCR model defined as a ratio, and works with constant return to scale (CRS)
Banker, Charnes and Cooper (1984)	Called the BCC model, that works with variable returns to scale (VRS)
Abolghasem et. al, (2017)	DEA models can be input or output oriented; input oriented contracts the input as much as possible keeping same level of output, whereas the output oriented is the vice versa

Literature Review (Cont'd)

DEA in Education	
Majority of the published work in education sector using DEA falls under two categories: (i) Studying efficiency of different universities (ii) Studying efficiency of different departments within same university	
Abbott and Doucouliagos (2001); Sagarra, Mar-Molinero and Agasisti (2016); Bayraktar et al. (2013)	Evaluates relative efficiency between different universities in Mexico, Australia and Turkey respectively
Barara and Zotti (2016); Goksen et al. (2015); Kao and Hung (2006); Alwadood et al. (2011); Duguleana and Duguleana (2015)	Evaluates relative efficiency of different departments within same universities
Abdullah et al. (2018)	Implemented slack-based DEA model for benchmarking, to identify improvement opportunities in the department

Literature Review (Cont'd)

Research Gap:

- Which input or set of inputs to add, when an investment budget is given

Objectives:

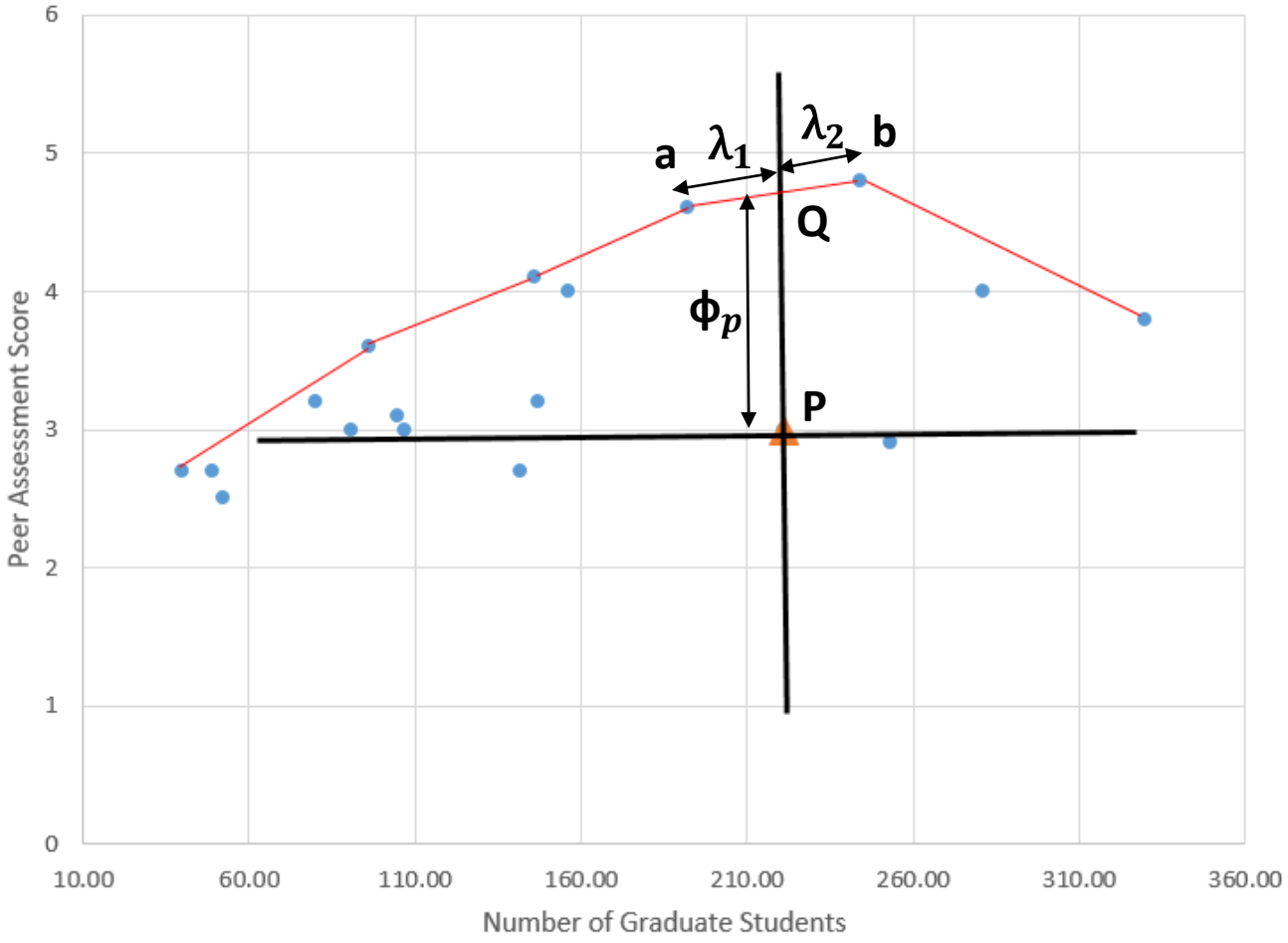
- In this work, output-oriented DEA-BCC models are used
  - To evaluate relative efficiency of the departments different universities
  - To indicate department/s with high efficiency to be used as benchmark for each department under study
  - To understand the possibility of higher output using minimum level of input
  - To provide an investment support model for the leadership for allocating resources to maximize efficiency

Methodology

Data Envelopment Analysis:

- A non-parametric mathematical programming approach
- Measures the relative efficiency of organizational units
- These organizational units are calls Decision Making Units (DMUs)
- DMUs can be different branches of the same bank; different hospitals in the same region; academic departments

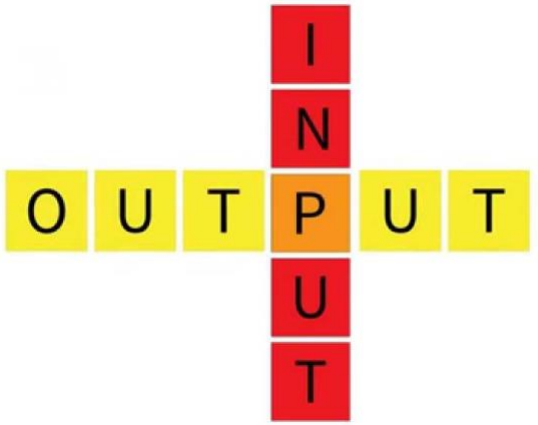
Methodology (Cont'd)



Methodology (Cont'd)

- Output used for the study:
  - Peer Assessment Score

- Inputs used for the study:
  - Number of Faculty
  - Total Research Expenditure Per Faculty
  - Number of Undergraduate Students per Faculty
  - Number of Graduate Students
  - Average H-Index



DEA Models (Efficiency Model)

Table 1.1	**Sets**
N	Set of DMUs (Departments)
I	Set of Inputs
O	Set of Outputs
Table 1.2	**Set of Parameters**
y_{rj}	Amount of output r $\in O$ produced by department j $\in N$
x_{ij}	Amount of input i $\in I$ used by department j $\in N$
Table 1.3	**Set of Decision Variables**
λ_j	Fraction of the j-th department used in the convex linear combination that projects the department under study into the efficiency curve
ϕ_p	Proportional increase (growth rate) of the output for the department under study

DEA Models (Efficiency Model) (cont'd)

max ϕ_p	(1)
Subject to,	
$\sum_{j \in N} y_{rj} \lambda_j \geq y_{rp} \phi_p, \forall_r \in O$	(2)
$\sum_{j \in N} x_{ij} \lambda_j \leq x_{ip}, \forall_i \in I$	(3)
$\sum_{j \in N} \lambda_j = 1$	(4)
$\lambda_j \geq 0, \forall_j \in N$	(5)
ϕ_p free of sign	(6)

DEA Models (Benchmarking Model)

Table 2.1	Sets
N	Set of DMUs (Departments)
I	Set of Inputs
O	Set of Output
Table 2.2	**Set of Parameters**
y_{rj}	Amount of output r $\in O$ produced by department j $\in N$
x_{ij}	Amount of input i $\in I$ used by department j $\in N$
ϕ_p^*	Growth Factor from the Efficiency Model
Table 2.3	**Set of Decision Variables**
λ_j	Fraction of the j-th department used in the convex linear combination that projects the department under study into the efficiency curve
s_r^+	Slacks for the output r $\in O$
s_i^-	Slacks for the inputs i $\in I$

DEA Models (Benchmarking Model) (Cont'd)

max $\sum_{r\in O} s_r^+ + \sum_{i\in I} s_i^-$	(7)
Subject to,	
$\sum_{j\in N} y_{rj}\,\lambda_j - s_r^+ = y_{rp}\phi_p^*,\ \forall_r \in O$	(8)
$\sum_{j\in N} x_{ij}\,\lambda_j + s_i^+ = x_{ip},\ \forall_i \in I$	(9)
$\sum_{j\in N} \lambda_j = 1$	(10)
$\lambda_j \geq 0,\ \forall_j \in N$	(11)
$s_r^+ \geq 0,\ \forall_r \in O$	(12)
$s_i^- \geq 0,\ \forall_i \in I$	(13)

DEA Models (Investment Model)

Table 3.1	Sets
N	Set of DMUs (Departments)
I	Set of Inputs
I^*	Set of Inputs to be added
O	Set of Output
Table 3.2	**Set of Parameters**
y_{rj}	Amount of output r ∈ O produced by department j ∈ N
x_{ij}	Amount of input i ∈ I used by department j ∈ N
w_{ip}	Amount of money needed to increase one unit of input i ∈ I
α_{lip}	Linear effect of adding one input l ∈ I^* to other inputs i ∈ I
c	Investment budget provided to the department
Table 3.3	**Set of Decision Variables**
λ_j	Fraction of the j-th department used in the convex linear combination that projects the department under study into the efficiency curve
ϕ_p	Proportional increase (growth rate) of the output for the department under study
z_{ip}	The input or set of inputs i ∈ I to be added

DEA Models (Investment Model) (cont'd)

max ϕ_p	(14)
Subject to,	
$\sum_{j \in N} y_{rj} \lambda_j \geq y_{rp} \phi_p, \forall_r \in 0$	(15)
$\sum_{j \in N} x_{ij} \lambda_j \leq x_{ip} + \sum_{l \in I^*} z_{ip} \alpha_{lip}, \quad \forall_i \in I$	(16)
$\sum_{l \in I^*} w_{ip} z_{ip} \leq c$	(17)
$\sum_{j \in N} \lambda_j = 1$	(18)
$\lambda_j \geq 0, \forall_j \in N$	(19)
ϕ_p free of sign	(20)
$z_{ip} \in Z^+ U \{0\}$	(21)

Case Study

- Data of 18 university departments were collected
- The departments are given names from Department 1 to Department 18
- 5 inputs and 1 output for each university was considered
- Data for the Inputs were collected from American Society for Engineering Education (ASEE) website
- The data for the output were collected from the US News rankings for 2019

ASEE

BEST GRAD SCHOOLS U.S.News & WORLD REPORT ENGINEERING 2019

Case Study (Data Table)

	Inputs					Output
Department (DMUs)	Number of Faculty	Research Expenditure/Faculty	Undergraduate Students/Faculty	Number of Graduate Students	H-Index	Peer Assessment Score
Department 1	61	$173,339.21	21.72	244	33.40	4.8
Department 2	28	$259,818.25	15.11	192	24.18	4.6
Department 3	30	$803,591.83	19.00	146	14.75	4.1
Department 4	27	$333,101	28.70	281	22.90	4
Department 5	25	$106,837.72	17.52	156	20.90	4
Department 6	30	$471,900	21.33	330	16	3.8
Department 7	27	$102,499.96	10.04	96	17.47	3.6
Department 8	10	$82,800	48.10	147	22.82	3.2
Department 9	14	$161,428.57	16.86	80	13.38	3.2
Department 10	11	$103,000	19.45	105	27.38	3.1
Department 11	15	$147,025.60	32.13	221	16.25	3
Department 12	19	$280,0009.63	26.53	91	15.29	3
Department 13	14	$76.986.36	21.79	107	14.20	3
Department 14	18	$668,817.56	9.11	253	14.57	2.9
Department 15	15	$100,567.20	14.73	49	14.33	2.7
Department 16	11	$127,578.18	16.91	40	13.33	2.7
Department 17	13	$289,758.92	36.38	142	18.86	2.7
Department 18	10	$87,937.50	31.10	52	18.57	2.5

Case Study (Results from the Efficiency Model)

Department (DMU)	Efficiency	Reference Set	λ for each Department in the Reference Set
Department 1	1	1	1
Department 2	1	2	1
Department 3	1	3	1
Department 5	1	5	1
Department 7	1	7	1
Department 8	1	8	1
Department 9	1	9	1
Department 10	1	10	1
Department 13	1	13	1
Department 14	1	14	1
Department 15	1	15	1
Department 16	1	16	1
Department 18	1	18	1
Department 6	0.98	3, 9, 2	0.46, 0.36, 0.18
Department 11	0.90	9, 8, 5, 2	0.68, 0.17, 0.10, 0.05
Department 4	0.90	2, 9, 3	0.88, 0.08, 0.04
Department 12	0.88	9, 7, 2	0.62, 0.33, 0.05
Department 17	0.82	8, 9, 2	0.50, 0.43, 0.07

Case Study (Results from the Benchmarking Model)

DMU	Number of Faculty	Research Expenditure/Faculty	Undergraduate Students/Faculty	Number of Graduate Students	H-Index
Department 6	6	$0	3.82	199	0
Department 11	0	$0	9.83	116	0
Department 4	0	$66,630	13.3	100	0
Department 12	0	$153,390	11.48	0	0
Department 17	0	$202,490	15.54	39.92	1.19

Case Study (Results from the Investment Model)

	Assistant Professors	Associate Professors	Professors	Chairs	Graduate Students
Approximate cost of hiring/adding one unit	$95,000	$102,000	$120,000	$150,000	$35,000
Average H-index	8.40	16.87	30.78	40	-
Approximate Research Fund Brought	$150,000	$300,000	$500,000	$1000,000	-

- Data from Department 12 was considered for the results of the Investment Model
- It is assumed that the Department 12 is given an investment budget of $500,000 (Parameter "c" of the Investment Model)
- Parameter w_{ip} and α_{lip} needs to be determined before running the model

Case Study (Results from the Investment Model) (Cont'd)

w_{ip} (Cost of adding one additional unit)							
Assistant Professor	**Associate Professor**	**Professor**	**Chair**	**Research Expenditure/Faculty**	**Undergraduate Students/Faculty**	**Graduate Students**	**Average H-Index**
$95,000	$102,000	$120,000	$150,000	$102,000	(-)$418,000	$35,000	$150,000

- To increase Research Expenditure/Faculty by $1,000, cost of hiring an Assistant Professor is required
- To increase Undergraduate Students/Faculty by 1 unit, 19 new undergraduates are required with each paying tuition fees of $22,000
- To increase Average H-Index by 1 unit, cost of hiring a Chair is required

Case Study (Results from the Investment Model) (Cont'd)

α_{lip} (Matrix), which is the linear effect of adding one input on the department under study to all other inputs of the Department

	Assistant Professor	Associate Professor	Professor	Chair Professor	Research Expenditure /Faculty	Undergraduate Students /Faculty	Number of Graduate Students	H-Index
Assistant Professor	1	0	0	0	-$6,500	-1.33	2	-0.34
Associate Professor	0	1	0	0	$1,000	-1.33	4	0.08
Professor	0	0	1	0	$11,000	-1.33	5	0.77
Chair Professor	0	0	0	1	$36,000	-1.33	6	1.24
Research Expenditure /Faculty	0	0	0	0	1	0	0	0
Undergraduate Students /Faculty	0	0	0	0	0	1	0	0
Number of Graduate Students	0	0	0	0	0	0	1	0
H-Index	0	0	0	0	0	0	0	1

Case Study (Results from the Investment Model) (Cont'd)

- Once all the parameters are determined:
  - It is important to understand what the Department wants
  - Set up the boundary points based on the need and capacity of the department

- For Department 12:
  - Total hiring of faculty members were restricted to at most 2
  - Also, hiring of each kind of faculty members were at most 2
  - Undergraduate Students/Faculty was limited to maximum 2 units
  - Hiring of Graduate Students given a high boundary of maximum 5
  - Average H-Index constrained to maximum of 0.5

- Model gives optimized resource allocation:
  - To hire one Assistant Professor
  - To hire one Professor
  - Hire five Graduate Students
  - Increase H-Index by 0.5

(1*$95,000+1*$120,000+5*$35,000+0.5*$150,000)
= $465,000 <= $500,000

Case Study (Sensitivity Analysis)

- Helps to analyze change in output with changes in one of the inputs
- Better informed decisions can be taken based on it
- Department 12 was the department under study for the Sensitivity Analysis

Name	Final Value	Shadow Price	Constraint Right Hand Side	Allowable Increase	Allowable Decrease
Number of Faculty	15	0.018	15	3.13	1.27
Research Expenditure Per Faculty	147.02	0.00066	147.02	12.97	8.25
Undergraduate Students per Faculty	22.30	0	32.13	0	9.83
Number of Graduate Students	104.17	0	221	0	116.83
Average H-Index	16.25	0.013	16.25	3.22	1.02

Conclusions and Future Work

Conclusions:

- Benchmarking departmental performance essential for continuous improvement
- Efficiency analyses (Efficiency Model) to identify how well the resources are utilized
- Benchmarking Model to identify higher output with minimum level of inputs
- Investment Model to provide support system for improved resource allocation

Future Developments:

- More university departments to conduct the analysis
- Stochastic Frontier Analysis to find statistical significance of inputs and output
- Including number of faculty in National Academy of Engineering and Fellow of different academic societies (IISE; ASME)
- Non-linear effects of adding one input to the department

Research Outcomes

- Alam, T., González, A. H., & Raman, S. (2019). *Benchmarking of Academic Departments using Data Envelopment Analysis (DEA).* Manuscript in preparation.

- Alam, T., González, A. H., & Trafalis, T. (2019*). Evaluating Soccer Players' Performance using Data Envelopment Analysis (DEA).* Manuscript under review, Athens Journal of Sports.

THANK YOU

QUESTIONS?