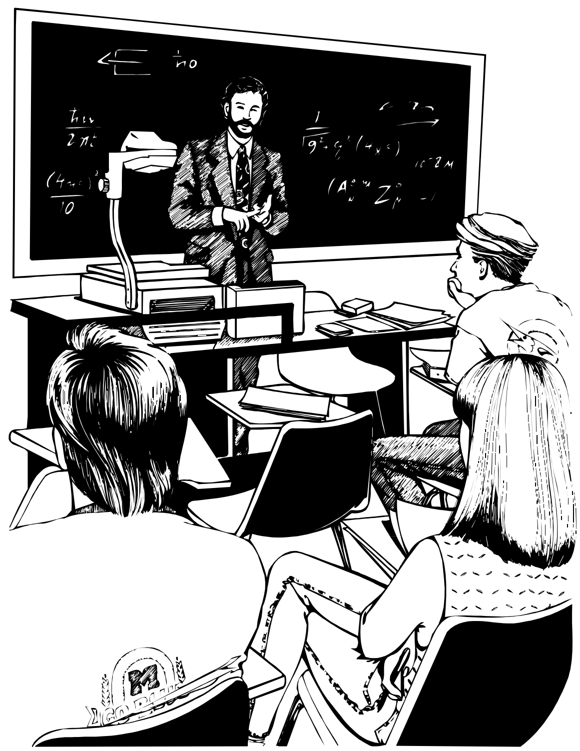
Agribusiness & Applied Economics Miscellaneous Report No. 195 November 2004

A Comparison of Departmental Teaching Efficiency in the College of Agriculture, Food Systems, and Natural Resources: AY2000-AY2004

David K. Lambert



Department of Agribusiness and Applied Economics
Agricultural Experiment Station
North Dakota State University
Fargo, ND 58105-5636

Contact Information

We would be happy to provide a single copy of this publication free of charge. You can address your inquiry to: Carol Jensen, Department of Agribusiness and Applied Economics, North Dakota State University, P.O. Box 5636, Fargo, ND, 58105-5636, Ph. 701-231-7441, Fax 701-231-7400, e-mail cjensen@ndsuext.nodak.edu. This publication also is available electronically at: http://agecon.lib.umn.edu/.

Information on other titles in this series may be obtained from: Department of Agribusiness and Applied Economics, North Dakota State University, P.O. Box 5636, Fargo, ND 58105. Telephone: 701-231-7441, Fax: 701-231-7400, or e-mail: cjensen@ndsuext.nodak.edu.

A Comparison of Departmental Teaching Efficiency in the College of Agriculture, Food Systems, and Natural Resources: AY2000-AY2004

David K. Lambert*

Abstract

Teaching efficiency is investigated for the nine departments in the College of Agriculture, Food Systems, and Natural Resources at North Dakota State University. Using Data Envelopment Analysis, departments are compared to their College peers in converting teaching faculty and teaching funds into three teaching outputs: student credit hours generated, undergraduate majors, and graduate students. Most departments are efficient in the technical conversion of inputs to outputs under variable returns to scale. Scale effects are evident, indicating some departments consistently extract higher average productivity from inputs in servicing undergraduate majors, graduate students, and in generating student credit hours.

Introduction

Data Envelopment Analysis (DEA) was developed by Charnes, Cooper, and Rhodes in a seminal 1978 work that operationalized the efficiency concepts first proposed by Farrell in 1957. DEA is used to compare the efficiency of farms, firms, plants, workers, university departments, and hundreds of other entities sharing common technologies. Specific applications have compared hospitals (Jacobs), agricultural producers in different states and countries (Managi and Karamera, Lambert and Parker, Lambert and Bayda), banks (Drake and Hall), economics departments in British universities (Johnes and Johnes), U.S. brewers (Day, Lewin, Li, and Salazar), public schools (Coates and Lamdin), and sports teams and players (Mazur; Haas).

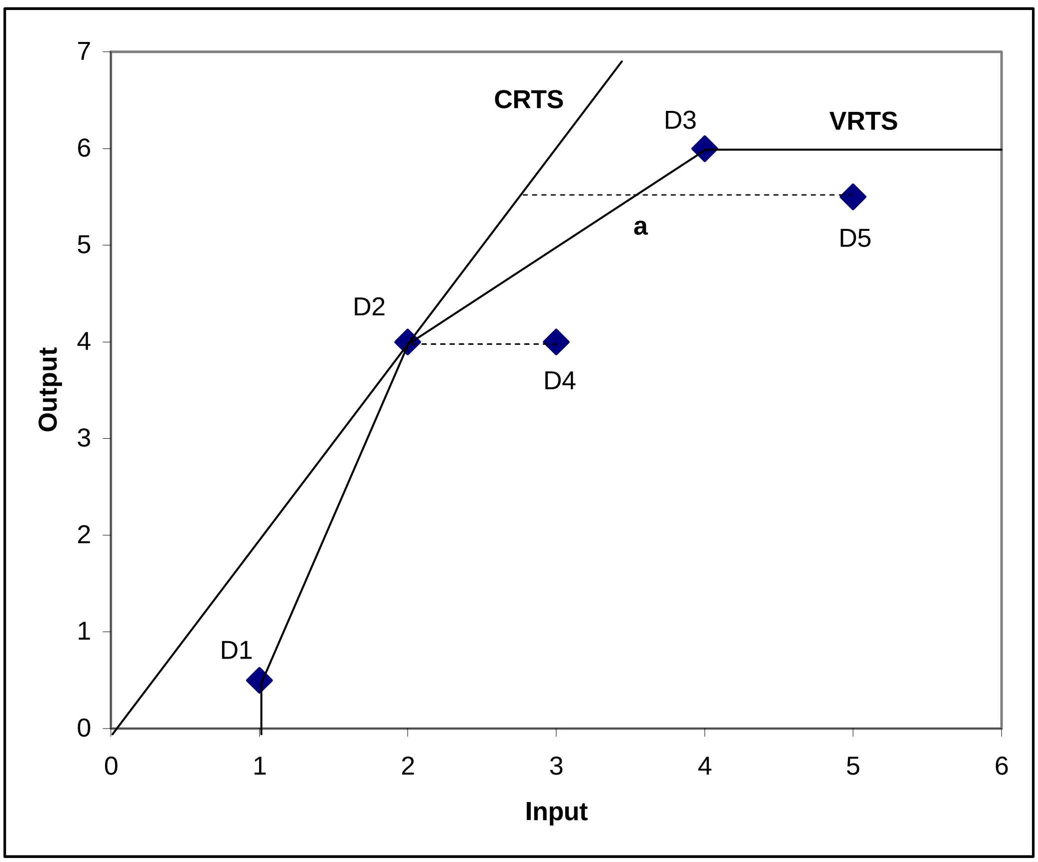
The objective of this paper is to compare the efficiencies of departments within the College of Agriculture, Food Systems, and Natural Resources (CAFSNR) at North Dakota State University in converting teaching inputs into measurable outputs of student credit hours, undergraduate majors, and graduate students. Rather than comparing departments based on a single measure of efficiency, such as cost per student credit hour generated, DEA permits consideration of multiple inputs and outputs. This advantage of DEA recognizes the importance of undergraduate majors, graduate students, and student credit hours generated in the teaching mission of the university.

---

* The author is Department Head and Professor, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo. The author appreciates useful review comments from Drs. Eric DeVuyst, Simeon Kaitibie, and Robert Harrold that improved the theoretical, empirical, and editorial quality of the paper. The editorial assistance of Carol Jensen in preparing the manuscript for publication is also gratefully acknowledged.

Figure 1 illustrates the concept of efficiency analysis and DEA. Observed inputs and outputs of five decision making units are included in the figure, D1-D5. Two production frontiers, representing the maximal amount of output that can be produced given the observed input levels, are graphed. The linear surface marked “VRTS” represents efficient production under variable returns to scale. Thus, D1, D2, and D3 are equally efficient in converting inputs to outputs under a technology characterized by variable returns to scale. Units D4 and D5 are inefficient. From an input orientation, both D4 and D5 can reduce input levels and maintain the same levels of output if they were as efficient as D1, D2, and D3. The Farrell efficiency measure, derived using DEA, measures the proportional reduction in inputs that will move D4 and D5 to the production frontier. In the case of D4, inputs could be reduced from 3 units to 2 units, while still producing four units of output, yielding an efficiency score of 2/3, or 0.67. Inputs for D5 could be reduced from 5 to about 3.5 with no decrease in output produced, giving D5 an efficiency score relative to the VRTS frontier of 0.7.

Figure 1. Data Envelopment Analysis and Efficiency



A constant returns to scale technology is represented by the line marked "CRTS." Constant returns to scale mean that, if all inputs were doubled, for example, outputs would also double. An alternative definition of efficiency relative to a constant returns to scale technology is that decision making units lying on the CRTS frontier are attaining the maximum average productivity of inputs in producing outputs. In Figure 1, only D2 lies on the CRTS frontier. The average product of the input, defined as the output produced per unit of input, equals 2.0 for D2, or 2 units of output are produced for each unit of input. All decision making units lying to the right of the CRTS frontier have average products (y/x) less than 2.0. For example, D3, produces 6 units of output for 4 units of input, resulting in an average product of 1.5.

The horizontal distance of the decision making units from the CRTS frontier measures scale efficiency. For example, the distance from D5 to **a** measures the technical inefficiency of D5 under variable returns to scale. The additional distance from **a** to the CRTS line measures the extent to which D5 diverges from achieving maximal average productivity from its use of inputs. The scale efficiency score for D5 would be approximately 0.79, representing the added reduction from 3.5 to 2.75 units of input to achieve the CRTS frontier. The product of technical and scale efficiency scores, or 0.53, measures the overall efficiency of D5's performance of converting inputs to outputs relative to the most efficient decision making unit in the sample, D2.

Figure 1 is a simple representation of the DEA efficiency measurement using a single input and a single output. DEA allows efficiency measures to be derived when firms use multiple inputs and produce multiple outputs. The next section describes the data used in defining the teaching inputs and outputs characterizing departments in CAFSNR.

Data and Procedures

Historical data on faculty FTEs, teaching budgets (excluding faculty salaries), and student credit hours (SCH) generated by departments within the CAFSNR were attained from the NDSU Office of Analysis and Institutional Research (OAIR). Annual undergraduate and graduate majors were attained from College administration. Data covered academic years from AY2000 (Fall 1999-Spring 2000) to 2004 (Fall 2003-Spring 2004).

Standard linear programming procedures (Charnes, Cooper, Lewin, and Seiford) were programmed in GAMS to derive Farrell efficiency measures under both variable and constant returns to scale for each department for each year in the study.

Specific inputs included department teaching faculty FTEs and teaching operating budgets. Recognizing the mix of outputs consistent with each department's mission, outputs included total student credit hours generated, the number of undergraduate majors, and the number of graduate students pursuing degrees within each department. Several departments offer multiple degrees:

- Agribusiness and Applied Economics (AGEC) – Agricultural Economics, Agribusiness (since 2001), Economics (since 2001)
- Agricultural and Biosystems Engineering (ABE) – Agricultural and Biosystems Engineering, Agricultural Systems Management

- Animal and Range Science (ARS) – Animal and Range Science, Veterinary Technology and Equine Studies (since 2003)
- Plant Science (PLSC) – Horticulture, Crop and Weed Science, Plant Sciences, Sports and Urban Turfgrass Management
- Cereal and Food Sciences (CFS) – Food Science (Undergraduate), Cereal Science (Graduate)
- Veterinary Medicine (VETM) – Pre-veterinary Medicine,[1] Microbiology, Molecular Pathogenesis

Majors in these programs were included in each department's totals.

Majors in interdisciplinary graduate programs (e.g., Natural Resource Management, Food Safety, Cellular and Molecular Technology) were allocated to specific departments based on the home department of the students' major professors. Undergraduate students in multidisciplinary majors were not allocated due to the multidisciplinary range of courses taken and difficulty to assign majors to specific departments. However, student credit hours generated by undergraduate students in these interdisciplinary majors did appear under each department's generated SCHs. For example, students in Natural Resource Management must take core courses in several departments within the College. Credits generated by these students are included in the total SCHs for that department.

Department abbreviations are shown in Table 1. Data used in the DEA analysis are in Table 2.

Table 1. Department Abbreviations

Abbreviation	Department Name
AGEC	Agribusiness and Applied Economics
ABE	Agricultural and Biosystems Engineering
ARS	Animal and Range Sciences
CFS	Cereal and Food Sciences
ENT	Entomology
PPTH	Plant Pathology
PLSC	Plant Sciences
SOILS	Soil Science
VETM	Veterinary and Microbiological Sciences

[1] Although not an undergraduate major, the pre-vet medicine program enrolls approximately 50-60 students who start their programs at NDSU, then transfer to Schools of Veterinary Medicine after two to three years to complete their veterinary studies.

Table 2. Teaching Data Used in the DEA Analyses

Dept	Year	Faculty FTEs	Budget	Student Credit Hours	Undergrad Majors	Grad Majors
AGEC	AY2000	6.46	62566	4849	177	23
AGEC	AY2001	6.93	49095	7333	178	14
AGEC	AY2002	6.85	63623	10001	147	23
AGEC	AY2003	8.28	50975	9903	164	25
AGEC	AY2004	8.26	60598	10746	155	24
ABE	AY2000	2.51	52454	1736	144	11
ABE	AY2001	2.51	48804	1780	145	13
ABE	AY2002	2.65	55809	1950	138	9
ABE	AY2003	2.93	52983	1656	132	11
ABE	AY2004	2.66	55679	1684	134	10
ARS	AY2000	5.60	152433	2819	230	34
ARS	AY2001	5.84	152030	2543	221	39
ARS	AY2002	6.98	296628	5255	220	46
ARS	AY2003	9.90	276806	4879	221	48
ARS	AY2004	10.34	290164	4997	255	46
ENT	AY2000	1.44	27240	506	0	7
ENT	AY2001	1.36	20018	434	0	6
ENT	AY2002	1.24	19076	512	0	14
ENT	AY2003	1.36	20544	556	0	18
ENT	AY2004	1.35	18485	615	0	20
PLSC	AY2000	7.37	69450	4649	154	27
PLSC	AY2001	7.44	59962	4398	140	44
PLSC	AY2002	6.54	82178	4243	128	50
PLSC	AY2003	6.96	71985	4636	115	42
PLSC	AY2004	8.15	58346	5444	126	66
CFS	AY2000	1.68	16921	292	17	14
CFS	AY2001	1.17	8488	726	11	16
CFS	AY2002	2.26	21892	356	8	18
CFS	AY2003	1.86	20294	426	8	17
CFS	AY2004	1.26	21503	445	8	16
PPTH	AY2000	0.99	13773	412	0	16
PPTH	AY2001	1.00	12296	505	0	15
PPTH	AY2002	1.10	21439	407	0	9
PPTH	AY2003	1.35	12427	354	0	12
PPTH	AY2004	1.71	13315	451	0	15
SOILS	AY2000	1.73	21460	991	6	10
SOILS	AY2001	1.72	16089	891	4	8
SOILS	AY2002	1.71	19806	890	2	7
SOILS	AY2003	1.94	17390	820	2	6
SOILS	AY2004	1.57	18637	1093	3	11
VETM	AY2000	6.12	141653	5748	97	14
VETM	AY2001	5.26	155170	4985	116	14
VETM	AY2002	3.33	92377	3162	112	15
VETM	AY2003	3.92	67735	4192	107	19
VETM	AY2004	4.91	73009	5270	117	26

Results

Table 3 and Figure 2 report results from the procedures. Agribusiness and Applied Economics and Agricultural and Biosystems Engineering are efficient in all years both in the technical conversion of inputs to outputs under variable returns to scale. Both departments also are scale efficient, lying on the constant returns to scale efficiency frontier. Four other departments were technically efficient in all years (ARS, PLSC, CFS, and Plant Pathology (PPTH)). However, these four departments were not scale efficient in at least one of the five years analyzed. In terms of Figure 1, these departments are similar to D1 and D3. Although technically efficient relative to the VRTS frontier, they have not achieved maximal average productivity of inputs (scale efficiency) in generating SCHs and undergraduate and graduate majors. The numbers in parentheses in the last column of Table 3 indicate whether the department was scale inefficient due to operating in the region of increasing returns to scale (RTS values less than one, similar to D1 in Figure 1) or decreasing returns to scale (RTS values greater than one, similar to D3 in Figure 1). As expected, the larger units (ARS and PLSC) exhibit decreasing returns to scale (i.e., allocating additional resources would generate less than proportional increases in output without improvements in teaching efficiency). Smaller scale inefficient units [Soil Science (SOILS), Entomology (ENT) prior to AY02] operate under increasing returns to scale. Were they to maintain their technical efficiency, these departments should be able to increase outputs more than proportionally for a given level of increase in faculty and teaching budgets. The implications for both decreasing and increasing returns to scale are, of course, conditional upon sufficient student demand existing to increase SCHs and departmental undergraduate and graduate majors. A few departments (VETM in AY02, PLSC and CFS in AY03) are close to the CRTS frontier.[2]

Note that scale efficiency is not correlated to departmental size in CAFSNR. For example, PPTH is scale efficient in all but one of the five years, ENT is scale efficient in three of the five years, and CFS is either scale efficient or almost scale efficient over the entire period. All three units have, for most years, fewer than two teaching faculty FTEs, small operating budgets, and generate fewer than 1000 student credit hours. However, all three departments have large numbers of graduate students relative to teaching inputs. Since DEA procedures allow consideration of multiple outputs, the units are scale efficient when graduate student numbers are included as teaching outputs.

---

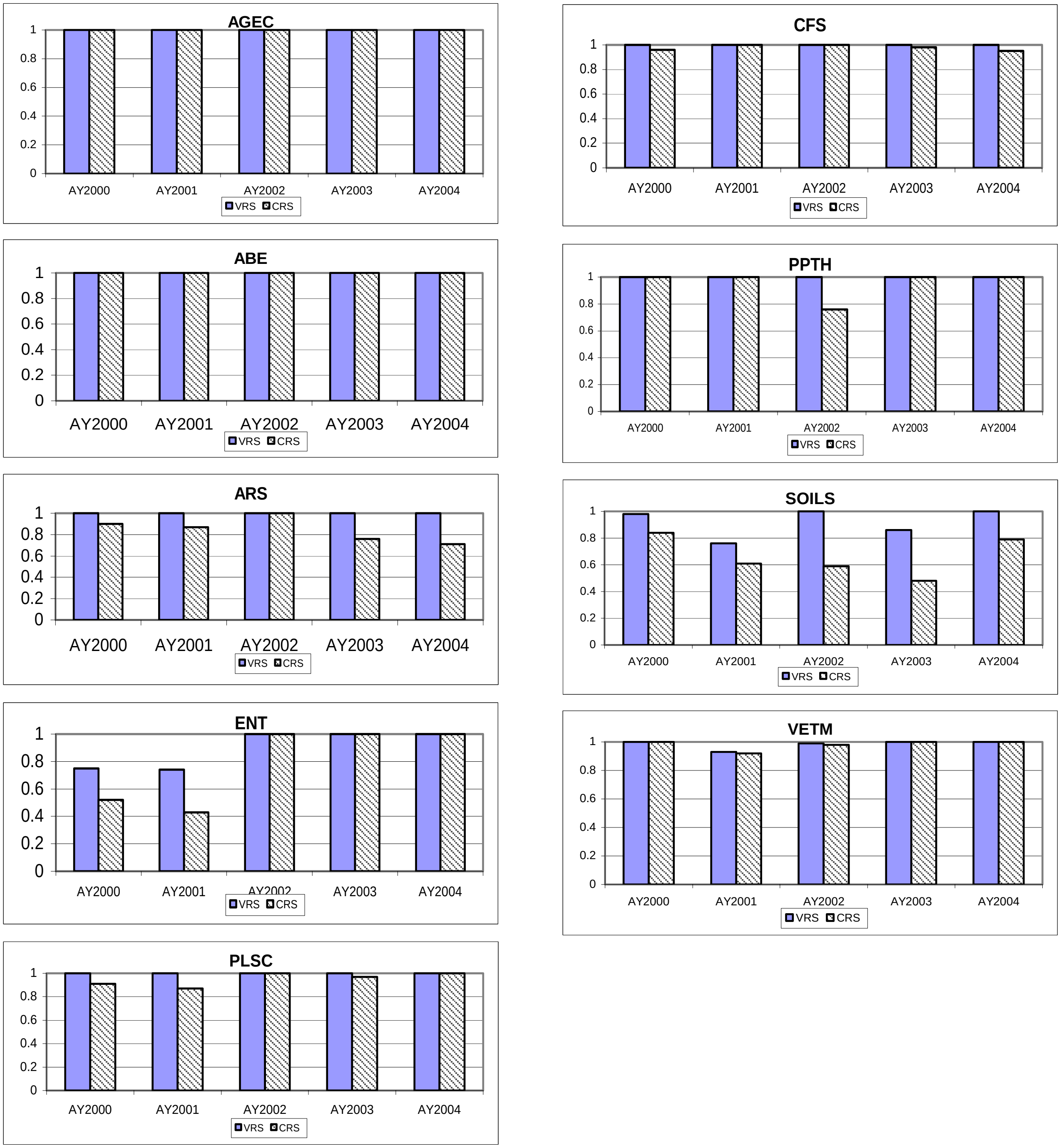
[2] At the suggestion of one reviewer, SCH was replaced by student FTEs generated in each department. The latter term accounts for differences in course class level (e.g., lower or upper division and graduate courses). Using AY04, the modified output measure had no effect on VRTS efficiency scores. CRTS efficiency scores were also unaffected, with the exception of ARS falling from 0.71 to 0.68 using the modified measure. The reviewer also suggested using faculty salaries rather than FTEs. Unfortunately, data supplied by the OAIR assume a uniform faculty salary in determining departmental "total faculty salaries." Therefore, faculty FTEs and salaries are perfectly correlated and results are unaffected by the suggested modification.

Table 3. Technical and Scale Efficiency Results for Departments in CAFSNR, AY00-AY04

	Departmental Efficiency (Variable Returns to Scale)		Departmental Efficiency (Constant Returns to Scale)		Scale Efficiency
AY	Efficient	Inefficient[1]	Efficient	Inefficient[1]	Scale Inefficient[2]
2000	AGEC ABE ARS PLSC CFS PPTH VETM	ENT (0.75) SOILS (0.98)	AGEC ABE PPTH VETM	ARS (0.90) ENT (0.52) PLSC (0.91) CFS (0.96) SOILS (0.84)	ARS 0.90 (2.62) ENT 0.69 (0.45) PLSC 0.91 (1.28) CFS 0.96 (0.83) SOILS 0.84 (0.57)
2001	AGEC ABE ARS PLSC CFS PPTH	ENT (0.74) SOILS (0.76) VETM (0.93)	AGEC ABE CFS PPTH	ARS (0.87) ENT (0.43) PLSC (0.87) SOILS (0.61) VETM (0.92)	ARS 0.87 (2.71) ENT 0.58 (0.38) PLSC 0.87 (2.85) SOILS 0.80 (0.51) VETM 0.99 (0.96)
2002	AGEC ABE ENT PLSC CFS PPTH SOILS	VETM (0.99)	AGEC ABE ARS ENT PLSC CFS VETM	PPTH (0.76) SOILS (0.59) VETM (0.98)	PPTH 0.76 (0.64) SOILS 0.59 (0.44) VETM 0.99 (0.70)
2003	AGEC ABE ARS ENT PLSC CFS PPTH VETM	SOILS (0.86)	AGEC ABE ENT PPTH VETM	ARS (0.76) PLSC (0.97) CFS (0.98) SOILS (0.48)	ARS 0.76 (3.14) PLSC 0.97 (2.26) CFS 0.98 (1.09) SOILS 0.55 (0.33)
2004	AGEC ABE ARS ENT PLSC CFS PPTH SOILS VETM		AGEC ABE ENT PLSC PPTH VETM	ARS (0.71) CFS (0.95) SOILS (0.79)	ARS 0.71 (3.03) CFS 0.95 (0.83) SOILS 0.79 (0.53)

[1]Numbers in parenthesis are Farrell efficiency scores under VRTS and CRTS.
[2]The first numbers are scale efficiency scores. Numbers in parentheses indicate departments exhibit increasing returns to scale (if < 1) or decreasing returns to scale (if > 1).

Figure 2. Department Efficiency Measures under VRTS and CRTS



Output Increases to Attain Efficiency with Current Resources

Table 4 illustrates changes in inputs and outputs needed for the three departments operating below the CRTS efficiency frontier in AY2004 to attain scale efficiency. The first row of Table 4 repeats departmental information from Table 3. The second row indicates proportional decreases in inputs needed to attain the CRTS efficient frontier. These numbers result from the proportional reduction in inputs indicated by the respective efficiency score under CRTS of 0.71 for ARS, 0.95 for CFS, and 0.79 for SOILS.

Table 4. Changes in Outputs Necessary to Achieve CRTS Efficiency in AY2004

Department	Teaching Faculty	Operating Budget	SCHs	Undergrad Majors	Grad Students	CRTS Efficiency
ARS - Current	10.34	$290,164	4997	255	46	0.71
Reduced Inputs	**7.34**	**$206,016**	4997	255	46	1.00
Increase SCH	10.34	$290,164	**11,397**	255	46	1.00
Increase UGM	10.34	$290,164	4997	**489**	46	1.00
Increase GM	10.34	$290,164	4997	255	**98**	1.00
CFS - Current	1.26	$21,503	445	8	16	0.95
Reduced Inputs	**1.20**	**$20,428**	445	8	16	1.00
Increase SCH	1.26	$21,503	**716**	8	16	1.00
Increase UGM	1.26	$21,503	445	**13**	16	1.00
Increase GM	1.26	$21,503	445	8	**17**	1.00
SOILS-Current	1.57	$18,637	1093	3	11	0.79
Reduced Inputs	**1.24**	**$14,723**	1093	3	11	1.00
Increase SCH	1.57	$18,637	**1586**	3	11	1.00
Increase UGM	1.57	$18,637	1093	**39**	11	1.00
Increase GM	1.57	$18,637	1093	3	**18**	1.00

The next three rows indicate increases in individual outputs necessary for the departments to attain CRTS efficiency. In the case of SOILS, for example, for current levels of faculty, operating budget, and undergraduate and graduate student majors, AY04 student credit hours would have to increase from 1,093 to 1,586 for SOILS to be comparable in teaching efficiency to the six departments on the CRTS frontier in AY2004. Alternatively, undergraduate majors would have to increase from 3 to 39, or graduate student numbers (11 in AY04) would have to increase to 18. A comparable interpretation applies to necessary changes in ARS to achieve the CRTS efficiency frontier defined over the six efficient departments in AY2004. Given AY04 levels of faculty and operating budgets, student credit hours would have to increase 128%, or undergraduate majors by 89%, or graduate student numbers by 113% for ARS to lie on the CRTS efficiency frontier. Since CFS is fairly close to the CRTS frontier, increases necessary to attain the frontier are smaller for CFS. Student credit hours would have to increase 61%, undergraduate majors by 63%, or graduate student numbers by 6% for CFS to lie on the CRTS efficiency frontier.

Efficiency Scores Pursuant to Teaching Input Increases

Two final analyses are reported. First, department teaching inputs (faculty FTEs and operating budgets) are increased for each department individually, holding inputs and outputs for other departments constant. Faculty teaching FTEs are increased by one, two, and three FTEs. Operating budgets are increased proportional to the operating budget per faculty FTE reported in the NDSU OAIR data. The second analysis increases all departments simultaneously by one and by two faculty FTEs, with operating budgets increased, again proportional to AY04 ratios of teaching budgets to teaching FTEs.

Table 5 reports the effects of impacts on efficiency for individual department increases. Only AGEC, ABE, and PLSC retain efficiency under VRTS and CRTS for the department-specific increases. Smaller departments are affected most severely by individual increases since the proportional change in inputs is greater due to their smaller AY04 base. Without corresponding increases in outputs, the negative efficiency impacts for smaller departments are greater relative to the larger units for individual department faculty and budget increases.

Table 6 reports college-wide increases in FTEs and teaching budgets. Efficiency impacts from these uniform increases are less severe. Although dealing with five inputs and outputs instead of the two illustrated in Figure 1, the effect of the uniform increase would be similar to shifting the entire frontier in Figure 1 to the right. Technical efficiency under VRTS is unaffected, as seen in Table 6. Scale efficiency, or distance from the CRTS frontier corresponding to maximal average productivity of inputs, does change, however. Compared to the departments defining the CRTS frontier (i.e., are scale efficient), average productivity falls for ARS, ENT, CFS, PPTH, and SOILS as faculty resources are evenly spread across the College and operating budgets are increased proportional to AY04 levels per faculty FTE.

Table 5. Technical Efficiency Scores Adding *n* New Teaching FTE, Plus Operating Budget Proportional to Departmental AY04 Teaching Budget Per FTE Ratio and Holding Other Departments Constant at AY04 Levels

	AY04 Base Efficiency		1 FTE Efficiency		2 FTEs Efficiency		3 FTEs Efficiency	
Department	VRTS	CRTS	VRTS	CRTS	VRTS	CRTS	VRTS	CRTS
AGEC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ABE	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98
ARS	1.00	0.71	1.00	0.64	1.00	0.59	1.00	0.55
ENT	1.00	1.00	0.77	0.76	0.54	0.53	0.42	0.41
PLSC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CFS	1.00	0.95	0.63	0.53	0.44	0.37	0.34	0.28
PPTH	1.00	1.00	0.88	0.63	0.64	0.46	0.50	0.36
SOILS	1.00	0.79	0.66	0.48	0.48	0.35	0.37	0.27
VETM	1.00	1.00	0.90	0.88	0.77	0.75	0.67	0.65

Table 6. Technical Efficiency Scores Adding *n* New Teaching FTE Plus Operating Budget Proportional to Departmental AY04 Teaching Budget Per FTE Ratio to All Departments Uniformly

	AY04 Base Efficiency		1 FTE to all Departments Efficiency		2 FTEs to all Departments Efficiency	
Department	VRTS	CRTS	VRTS	CRTS	VRTS	CRTS
AGEC	1.00	1.00	1.00	1.00	1.00	1.00
ABE	1.00	0.71	1.00	1.00	1.00	1.00
ARS	1.00	1.00	1.00	0.85	1.00	0.94
ENT	1.00	1.00	1.00	1.00	1.00	0.92
PLSC	1.00	1.00	1.00	1.00	1.00	1.00
CFS	1.00	0.95	1.00	0.87	1.00	0.76
PPTH	1.00	1.00	1.00	0.75	1.00	0.62
SOILS	1.00	0.79	1.00	0.64	1.00	0.51
VETM	1.00	1.00	1.00	1.00	1.00	1.00

Conclusions

Data Envelopment Analysis is a proven procedure for comparing efficiency among similar decision making units. The advantage of DEA is the procedure's capability to identify efficiency for units using multiple inputs and producing multiple outputs. The latter consideration is of special relevance when the mix of outputs might change over time in response to changing market conditions or internal objectives of the decision making units.

Annual teaching efficiencies of departments within CAFSNR indicate that, with few exceptions, most units achieve technical efficiency under VRTS. Part of the high VRTS efficiency scores result from the large number of inputs and outputs (five) considered relative to the number of units being analyzed (nine). However, efficiency under VRTS indicates departments within the College are generally efficient. In addition, efficiency has been improving over the last five years.

Various strategies have been adopted by the departments to achieve efficiency (Table 3). AGEC has greatly increased student credit hours, with less than proportional increases in teaching faculty and no change in teaching budgets. ARS has similarly increased SCHs and graduate students, though both faculty and budgets have roughly doubled since the beginning of the period. PLSC inputs and SCHs have been relatively stable over the five years, but the department has seen increases in graduate student numbers. Entomology has seen little change in faculty, budget, or SCHs, but has increased graduate student numbers three-fold since AY00. SOILS' efficiency under variable returns to scale in AY04 is due to a drop in faculty, a 20% increase in SCHs, and a nearly two-fold increase in graduate students housed in the department.

Scale efficiency results from achieving maximal average product from a department's teaching inputs. By this measure, several departments are scale inefficient over much of the period. Dual to the productivity argument is the cost of producing SCHs, majors, and graduate students. In terms of faculty and teaching budgets, the cost of providing these measurable outputs is higher for the scale inefficient departments. The scale efficiency results reported in Table 3 differ somewhat from the single index, budget per student FTE, reported by the OAIR since faculty numbers are considered as an input separate from budget and majors and graduate students are included as teaching outputs. However, there is some correspondence between the scale efficiency results and the OAIR index for the years surveyed.

Without output increases, additional teaching resources may either have no effect or worsen a department's efficiency relative to other units within the College. Increases to individual departments (Table 5) tend to have greater negative impacts on the efficiency of smaller departments. Increases in faculty and budgets uniformly distributed among the College's nine departments (Table 6) do not affect the VRTS efficiency frontier for the College but does have negative impacts on scale efficiency for some units.

Finally, improvements in input productivity (i.e., scale efficiency) can be achieved by reducing other inputs proportional to the scale efficiency measure or by holding inputs fixed and increasing student credit hours, majors, and/or graduate students. The analysis reported in Table 4 focused on increasing outputs one at a time, consistent with a department identifying specific goals to, for example, increase graduate student numbers. For the most part, increases in a single dimension necessary to achieve scale efficiency, or the CRTS frontier, are substantial. The procedures can be used, however, to differentially increase outputs consistent with specific goals identified by a department and subsequently measuring the impacts on the department's scale efficiency.

References

Charnes, A., W.W. Cooper, and E. Rhodes. "Measuring the Efficiency of Decision Making Units." *European Journal of Operations Research* 2(1978): 429-44.

Charnes, A., W.W. Cooper, A. Lewin, and L.M. Sieford. *Data Envelopment Analysis: Theory, Methodology, and Applications.* Boston: Kluwer Academic Publishers. 1997.

Coates, Dennis C., and Douglas J. Lamdin. "School Performance Evaluation Using Data Envelopment Analysis." *Public Finance and Management* 2(2002): 566-91.

Day, Diana, Arie Lewin, Hongyu Li, and Ronald Salazar. "Strategic Leaders in the U.S. Brewing Industry: A Longitudinal Analysis of Outliers." In *Data Envelopment Analysis: Theory, Methodology, and Applications.* A. Charnes, W.W. Cooper, A. Lewin, and L.M. Sieford, eds. Boston: Kluwer Academic Publishers. 1997.

Drake, Leigh, and Maximilian J.B. Hall. "Efficiency in Japanese Banking: An Empirical Analysis." *Journal of Banking and Finance* 27(May 2003): 891-917.

Farrell, M.J. "The Measurement of Production Efficiency." *Journal of the Royal Statistical Society, Series A.* 120(1957): 253-90.

Haas, Dieter J. "Technical Efficiency in the Major League Soccer." *Journal of Sports Economics* 4(August 2003): 203-15.

Jacobs, Rowena. "Alternative Methods to Examine Hospital Efficiency: Data Envelopment Analysis and Stochastic Frontier Analysis." *Health Care Management Science* 4(June 2001): 103-15.

Johnes, Geraint, and Jill Johnes. "Measuring the Research Performance of UK Economics Departments: An Application of Data Envelopment Analysis." *Oxford Economic Papers* 45(1993): 332-47.

Lambert, David K., and Elliott Parker. "Productivity in Chinese Provincial Agriculture." *Journal of Agricultural Economics* 49(September 1998):378-392.

Lambert, David K., and Volodymir Bayda. "The Impacts of Farm Financial Structure on Production Efficiency." *Journal of Agricultural and Applied Economics* (forthcoming).

Managi, Shunsuke, and David Karemera. "Biased Technological Change in U.S. Agriculture." *Applied Economics Letters* 11(April 2004): 283-86.

Mazur, Mark J. "Evaluating the Relative Efficiency of Baseball Players." In *Data Envelopment Analysis: Theory, Methodology, and Applications.* A. Charnes, W.W. Cooper, A. Lewin, and L.M. Sieford, eds. Boston: Kluwer Academic Publishers. 1997.