Data Envelopment Analysis (DEA): Benchmarking Efficiency of Colleges and Universities

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Format: Research in Action / Demonstration session

Abstract:

This session demonstrates an application of Data Envelopment Analysis (DEA) methodology, an increasingly popular (Emrouznejad et al., 2008) benchmarking approach for institutional planning, budgeting, and research. Using data for public, four-year Historically Black Colleges and Universities (HBCUs), the session facilitators will present two basic data envelopment models to illustrate how DEA can be used to answer such key institutional research questions as:

1. What are appropriate benchmarks for retention and graduation rates given current levels of financial resources?

2. What changes in budget allocations can be made without negatively affecting current retention and graduation rates?

3. What are the most efficient institutions in the peer group?

4. Does productivity of institutions improve over the years?
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Purpose

• Share experience in utilizing DEA methodology
  – Demonstration: Retention and Graduation Rates
    in the context of Financial Resources

• Informed by Archibald & Feldman (2008)
  – “[G]raduation rates should be compared to best
    practice measured by a production frontier, not
    average practice measured by a regression
    equation” (p. 81)

Agenda

I. Rationale
II. Data Envelopment Analysis (DEA): A (very)
   Brief Overview
III. Application of DEA: Graduation and Retention
    Rates in the Financial Resources Context
IV. Summary, Next Steps, and Conclusion
I. Rationale

Introduction

Higher Education Finance Law
"Pursuit of Excellence"
"Doing MORE with MORE"

Current Political / Economic Environment
"Doing MORE with LESS"
Strategies for Doing More with Less

• More outputs with Same inputs
  – Output Maximization

• Same outputs with Less inputs
  – Input Minimization
Largely “Unanswered” Questions

- Can institutions improve performance with the revenues they already have?
- Can institutions maintain or improve performance with even fewer revenues?

(Kelly & Jones, 2005/rev. 2007, p. 1)

Efficiency of HBCUs

“Since efficiency lies at the forefront of policy debates around the restructuring of HBCUs, it seems increasingly important that we investigate, empirically, the organizational efficiency of HBCUs…”

(Coupet & Barnum, 2010, p. 188)

Research Questions

1. What are appropriate benchmarks for retention and graduation rates given current levels of financial resources? = Output Maximization
2. What changes in budget allocations can be made without negatively affecting current retention and graduation rates? = Input Minimization
3. What are the most efficient institutions in the peer group? What are the role models for institutional improvement?
4. Does productivity of institutions improve over the years?
II. Data Envelopment Analysis (DEA):
A (very) Brief Overview

For an in-depth review, see Selected Bibliography, Section B

DEA: A Definition

• Nonparametric efficiency frontier estimation methodology utilized to compare peer or functionally similar complex institutions.
  – Captures the relationships between multiple inputs and outputs of a complex institution by creating a single composite/virtual ratio (efficiency ratio) between the institution’s aggregated inputs and aggregated outputs weighted based on the best practice performance in the peer group.

\[
\text{Weighted} \left( \frac{\text{Input}_1 + \text{Input}_2 + \ldots + \text{Input}_n}{\text{Output}_1 + \text{Output}_2 + \ldots + \text{Output}_n} \right) = 0-1 \ (0-100\%)
\]

What is “Envelopment”?

• Institutions are plotted in a multidimensional space created by the input/output ratios

• Frontier (Boundary)
  – A virtual line that represents maximum output that can be produced given available inputs, or, alternatively, minimum inputs required to produce given outputs
  • Best practice performance in the peer group
  – Frontier formed by best practice institutions envelops all other (inefficient) institutions in the group
Why Use DEA in IR?

1. DEA approach takes into consideration the complex nature of educational institutions and accommodates multiple inputs and multiple outputs in a single analysis.

2. DEA does not assume nor require a judgment on the relative importance or weights of inputs and outputs.

3. DEA application can be used to set specific input and output targets for inefficient institutions based on the observed performance of best practice institutions in the peer group.
   - Focuses on optimal, not average, performance
   - Sets input and output targets that are practical and attainable.

4. DEA helps identify the “efficient reference group” or specific best practice institutions for the focus institutions.

III. Application of DEA:
Graduation and Retention Rates in the Financial Resources Context

A Basic Model Example
Efficiency Model 1

Questions 1-3

Sample

- Data Source
  - NCES IPEDS
- Sample / Peer Group
  - 35 historically Black colleges and universities (HBCUs)
    - Public
    - 4-year
- Focus Institution
  - Comprehensive university
  - Urban setting
  - Approximately 7,000 students

Model 1 Variables: Selection

- Research Questions
  - Expenditures and student success
- Literature
  - “Full range of resources used” (Dyson et al., 2001) / “Web of interlocking initiatives” (Kuh, 2002)
  - Inconclusive research on the relationship between expenditures in different categories and student success (Selected Bibliography, Section A)
- Sample Size
  - Number of institutions per variable = 2M x S (where M is the number of inputs and S is the number of outputs) (Dyson et al., 2001)
Model 1 Variables

**Input Variables**
- Quality of Teaching
- Quality of Student PI
- Percentage of Students Receiving Federal Grants

**Output Variables**
- Retention Rate
- Graduation Rate

**Processes**

**Procedures**

- **Orientation**
  - Output Orientation (O/O) = Output Maximization
  - Input Orientation (I/O) = Input Minimization

- **Assumption**
  - Variable Returns to Scale (VRS)

  - Archibald & Feldman (2008) – unknown nature of higher education production function

Overall Findings:

**Output Orientation / Output Maximization**

- **Efficiency Scores**
  - 17 out of 35 institutions are efficient
  - Mean efficiency score = 91%
  - Focus Institution’s efficiency score = 90%

- **Efficiency Score Correlations**
  - Graduation rate = 0.62
  - Retention rate = 0.72
Overall Findings:

**Input Orientation / Input Minimization**

- Efficiency Scores
  - 17 out of 35 institutions are efficient (score of 100%)
  - Mean efficiency score for the sample = 90%
  - Focus Institution’s efficiency score = 82%

- Efficiency Score Correlations
  - Instruction Expenses = -0.24
  - Academic Support Expenses = -0.30
  - Student Services Expenses = -0.40
  - Institutional Support = -0.72

Summary: Overall Sample

- High efficiency scores in both solutions (O/O and I/O) indicate that most public, 4-year HBCUs are operating near the efficiency frontier
  - HBCUs’ traditional focus on student success
  - Learning to deal with chronic underfunding.

- Caveat: Although public HBCUs appear to be efficient as a group, the results of this DEA study do not show how HBCUs are performing in comparison with other types of institutions.

- Budget expenditures as well as retention and graduation rates are moderately to strongly associated with efficiency scores.

Findings for Focus Institution

*Potential Improvements in Efficiency*
Question 1 – Output Maximization

1.A Doing MORE with the Same
   – How much can Focus Institution increase its outputs given the current level of inputs?
   – What are appropriate benchmarks for retention and graduation rates for Focus Institution given the current levels of financial resources?
     • Focus Institution Retention Rate Target = from 69% to 76% (+7 points)
     • Focus Institution Graduation Rate Target = from 31% to 38% (+7 points)

1.B SLACK / “Doing MORE with LESS”
   • Can Focus Institution reach the target output benchmarks (see previous slide, 1.A) while decreasing current inputs?
     – Is there any true “fat” to cut? = YES
     • Decrease
       – Instruction expenses/FTE = -$202 (-3%)
       – Academic support expenses/FTE = -$187 (-6%)
       – Student services expenses/FTE = -$374 (-36%)

Question 2 – Input Minimization

2.A Doing the Same with LESS
   – What changes in budget allocations can Focus Institution make without negatively affecting current retention and graduation rates to achieve relative efficiency?
   – How much could the inputs be decreased while maintaining the current level of outputs?
   • Relative Efficiency Targets
     – Instruction expenses per FTE = from $6,502 to $5,330 (-18%, 1172)
     – Academic support per FTE = from $2,992 to $1,730 (-41%, 1192)
     – Student services per FTE = from $1,025 to $841 (-18%, 185)
     – Institutional support per FTE = from $2,541 to $2,003 (-21%, 538)
Question 2 – Input Minimization (cont’d)

2.B SLACK / “Doing MORE with LESS”

• Can the Focus Institution increase its outputs while decreasing the inputs to relative efficiency levels (see previous slide, 2.A)?
  – Is there any capacity to improve student success while cutting budget allocations? = NO
  • Slacks:
    – Retention rate = 0
    – Graduation rate = \textbf{+0.15 points}

Questions 1 and 2 Summary for Focus Institution

• Output increase ranges
  – Retention rate = 0 – 7 percentage points
  – Graduation rate = \textbf{0.15} – 7 percentage points

• Input decrease ranges
  – Instruction expenses per FTE = - \textbf{202} – 1,172
  – Academic support per FTE = -\textbf{187} – 1,192
  – Student services per FTE = -\textbf{185} – 374
  – Institutional support per FTE = -\textbf{50} – 538

\textbf{Bold} = Slacks // \textit{Italics} = Change to achieve efficiency targets

Focus Institution: Budget-Cutting Scenarios

1. If the institution is satisfied with the current level of outputs and the major goal is to cut expenditures, then the budget cutting targets will be in the upper part of the input decrease ranges.

2. If the institution is concerned primarily with increasing the outputs to the efficient levels (i.e., by 7 points), then the budget cutting targets will be in the lower part of the input decrease ranges.

3. If the institution plans to do both – increase outputs and decrease inputs, then the targets will be somewhere in the middle of output increase and input decrease ranges.
Question 3

**3A.** What are the best practice institutions in the sample? What are the “role models” for public HBCUs?

- Leader Institution
  - **Albany State University**
    - Combined 24 references in O/O and I/O solutions
  - Savannah State University
    - Combined 17 references in O/O and I/O solutions

**3B.** What are the reference institutions for Focus Institution? What institutions can serve as specific “role models” for Focus Institution?

- Reference Sets for Focus Institution
  - Input-Oriented (I/O) VRS
    - Bluefield State College
    - North Carolina A&T State University
    - Savannah State University
  - Output-Oriented (O/O) VRS
    - Florida A&M University
    - North Carolina A&T State University

Note: The values of Focus Institution are scaled to 100% in the graph.
Efficiency Model 2

Question 4: Does productivity of institutions improve over the years?

Model 2 Variables

Malmquist Productivity Change Index Components

- **Catch-Up** sub-score
  - Efficiency Dynamics in Individual Institutions // Change in the position of a given institution relative to the frontier
  - Change in the Input / Output Ratios (cost management)

- **Frontier Shift** sub-score
  - Technical or Technology Dynamics in the Sample // Change in the position of the frontier itself (contraction or expansion)
  - Change in the technology (i.e., educational practices) transforming inputs into outputs
Question 4

- Continuous Quality Enhancement – Does institutional productivity improve over time?

Dynamics in Institutional Productivity between 2005 and 2009

<table>
<thead>
<tr>
<th></th>
<th>Output-Oriented VRS</th>
<th>Input-Oriented VRS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Malmquist Index</td>
<td>Catch-Up</td>
</tr>
<tr>
<td>Average for 35 HBCUs</td>
<td>0.98</td>
<td>1</td>
</tr>
<tr>
<td>Focus Institution</td>
<td>1.07</td>
<td>1.11</td>
</tr>
</tbody>
</table>

Productivity Change

- Sample overall
  - Slight decrease in productivity ("Malmquist index" <1)
    - No change or very slight improvements in cost management practices ("Catch-up" score ~ 1)
    - Some decline in educational production technology ("Frontier shift" score < 1)

- Focus Institution
  - Slight increase in productivity ("Malmquist index" ~ 1)
    - Significant improvement in cost management practices ("Catch-up" score > 1)
    - Some decline in educational production technology ("Frontier shift" score < 1)

Summary: Productivity Change for Public HBCUs

- Efficiency (i.e., input/output ratio)
  - Virtually no change ("Catch-up" score ~ 1)
    - Under-performing institutions slightly increased efficiency
    - Best-practice institutions decreased efficiency
      - Implications for performance funding?

- Educational Practices
  - Negative dynamics ("Frontier shift" score <1)
    - Contraction of frontier
      - Implications for innovation adoption and diffusion?
Summary: Productivity Change for Focus Institution

- Inverse relationship between increase in efficiency and decline in educational production technology
  - Focus Institution was not able to transform improved cost management (budget allocation amounts and priorities) into advances in educational production technology
  - Technology change requires changes in administrative, faculty, (and student) behaviors
    - Short time period?

IV. Summary, Next Steps, and Conclusion

Interpretation of DEA Results

- DEA provides data to stimulate campus-wide reflection and discussion.
- Results of DEA analysis are not “information for action.” They are “food for thought and discussion” as we are streamlining, aligning, and improving our operations for student achievement and success.
**Interpretation of DEA Results**

- DEA provides objective, observed practice-based data not only to stimulate thinking, it is also designed to help administrators and institutional researchers focus and structure thinking about campus operations.
  - “It is the interpretations of events (or constructs) within a structured ‘meaning making’ environment whereby learning can occur” (Sutherland & Katz, 2005, p. 237, emphasis added).

**Some Limitations of DEA**

- Focus on “relative,” not “absolute,” efficiency
- Requirement for a homogenous peer group of institutions for analysis // Limitations of IPEDS expenditures data
- Because of the non-stochastic nature of DEA, the existence of omitted variables and errors of measurement of the inputs and outputs can potentially affect efficiency scores.
- Further, including numerous outputs and inputs might result in multi-collinearity.
- If the VRS model is applied to an environment where there are no returns to scale effects, the efficiencies are likely to be overestimated.

**Next Steps**

- **Model**
  - Apply a two-stage DEA model with retention and transfer-out rates as intermediate output variables
  - Calculate multi-year Malmquist change indices
    - Use constant dollars
- **Triangulation**
  - Conduct stochastic frontier analysis in addition to DEA
  - Conduct DEA analysis with a different peer group to review and compare improvement targets
Next Steps (Cont’d)

- Procedures
  - Utilize principal component analysis to facilitate selection of variables and strengthen model’s discriminatory power
  - Further explore the effects of returns to scale on efficiency
    - Optimal size for Focus Institution
  - Use bootstrapping to determine confidence intervals for efficiency scores and analyze the sensitivity of scores.

Conclusion

- “Researchers should make further attempts to distinguish efficient HBCUs from inefficient ones, through rigorous quantitative and qualitative analyses”
  (Coupet & Barnum, 2010, p. 194)

- “Just like other institutions of higher education, HBCUs cannot explain away big differences in graduation rates simply by reference to the usual suspects. The management practices of our colleges have to be part of the explanation—and part of the solution.”
  (Arne Duncan, U.S. Secretary of Education, 2009)
FIGURE 1.
A BASIC EXAMPLE OF AN OUTPUT-ORIENTED CRS model for 1 Output ("Retention Rate") and 2 Inputs ("Instruction Expenses per FTE" and "Student Services Expenses Per FTE")

- X and Y axes represent ratios. 2 inputs serve as numerators in the ratio and 1 output serves as the denominator in both ratios.
- The X-axis represents the ratio of "instruction expenses per student FTE" (input 1, numerator) to "retention rate" (output, denominator).
- The Y-axis represents the ratio of "student services expenses per FTE" (input 2, numerator) to "retention rate" (output, denominator).
- Institutions are plotted based on these two ratios.
- Four efficient institutions (red circles) form a concave efficiency frontier (yellow line) that envelopes other data points or inefficient institutions (grey circles) in the sample.
- Inefficient institutions (grey circles) are inefficient because their output per unit of inputs are below the observed best practice (institutions represented by red circles).
- Inefficient institutions can become efficient by a proportional increase of the output (retention rate, denominator in the ratios).
  - By increasing "retention rate" or the denominator in the X and Y ratios, both ratios are decreasing thus moving the target institution to the left on the graph – closer to the yellow line or efficiency frontier.
- The blue circle inside the envelope represents the focus institution, which is classified as inefficient.
- The point of intersection between the grey arrow from the focus institution (blue circle) and the frontier (yellow line) represents the performance target for the focus institution or maximization of the output (increase in the retention rate) needed to move the focus institution onto the efficiency frontier.

Legend:
- Efficient institutions in the peer group (score of 1 in technical efficiency)
- Efficiency frontier
- Inefficient institutions in the peer group (score of <1 in technical efficiency)
- Focus institution
FIGURE 2.
A BASIC EXAMPLE OF AN INPUT-ORIENTED CRS model for 2 Outputs ("Retention" and "Graduation") and 1 Input ("Instruction Expenses per FTE")

- X and Y axes represent ratios. 2 outputs serve as numerators in the ratios and 1 input serves as denominator in both ratios.
  - The X-axis represents the ratio of "retention rate" (output 1, numerator) to "instruction expenses per student FTE" (input, denominator).
  - The Y-axis represents the ratio of "graduation rate" (output 2, numerator) to "instruction expenses per student FTE" (input, denominator).

- Institutions are plotted based on these two ratios.
  - Three efficient institutions (red circles) form a convex efficiency frontier (yellow line) that envelopes other data points or inefficient institutions (grey circles) in the sample.
  - Inefficient institutions (grey circles) are inefficient because inputs per unit of output exceed the observed best practice (institutions represented by red circles).
  - Inefficient institutions can become efficient by a proportional reduction of input (denominator in the ratios)
    - By decreasing the denominator or "instruction expenses per FTE" (input), the X and Y ratios are increasing thus moving inefficient institutions to the right on the graph – closer to the yellow line or efficiency frontier.
  - The blue circle inside the envelope represents the focus institution, which is classified as inefficient.
  - The point of intersection between the grey arrow from the focus institution (blue circle) and the frontier (yellow line) represents the performance target for the focus institution or minimization of the input (decrease in the "instruction expenses per student FTE") needed to move the focus institution onto the efficiency frontier.

Legend:
- Efficient institutions in the peer group (score of 1 in technical efficiency)
- Efficiency frontier
- Inefficient institutions in the peer group (score of <1 in technical efficiency)
- Focus institution
Overview of Key DEA Points

**Basic Presupposition**

- If a given college or university is capable of producing outputs at a certain level with a certain level of inputs, then other similar institutions should also be able to do the same if they were to operate efficiently.
  - It is important to note that DEA efficiency scores are relative – institutions are considered to be efficient or inefficient only in the context of the set of the institutions in the given sample.

**Philosophy**

- *Systems Thinking*
  - Higher education institutions produce certain *outputs/outcomes* from certain *inputs* by utilizing certain production *processes*.
- *Complexity*
  - Universities have *multiple* inputs and outputs.
- *Uncertainty*
  - In higher education settings, it is difficult to specify direct relationships (functional forms or parameters) between inputs and outputs and to assign specific weights to specific inputs and outputs.
- *Observed Best (not average) Practice Orientation*
  - Efficiency is measured relative to the *actual* performance of the ‘best practice’ institutions.
- *Action Orientation*
  - Identification of inefficient institutions as well as identification of best practice-based specific performance *targets* (benchmarks) for those institutions.

**DEA vs. Regression-Type Analyses**

- No a priori assumptions / hypotheses about the parameters or the functional form of the relationship between inputs and outputs;
- Focus on the empirical best practice, not average behavior of institutions in the sample.

**Analytical Procedures**

- *DEA Assumptions*
  - Constant Return to Scale (CRS) – an increase in inputs produces a *proportionate* increase in the output;
  - Variable Return to Scale (VRS) – an increase in inputs produces a *disproportionate* increase in the output.
- *DEA Orientations*
  - Output Orientation (O/O) – *inputs are kept constant* while the possibility of *expansion of outputs* is explored.
    - Output Maximization // **MORE** Outputs with **SAME** Inputs
      - Feasible performance targets.
Input Orientation (I/O) – outputs are fixed and the possibility of reduction in inputs is explored.
  - Input Minimization // SAME Outputs with LESS Inputs
    - Data-informed cuts/reallocations in budget expenditures

Identified “Slacks” in DEA Analysis

Output Orientation (O/O)
  - How much can the inputs (expenditures) be cut while increasing the outputs (graduation and retention rates)?

Input Orientation
  - How much can the outputs (graduation and retention rates) be increased while cutting the inputs (expenditures)?

DEA Linear Programming Equation (VRS input-oriented model with uncontrollable inputs) (Avkiran, 2001, pp. 76-77)

\[
\begin{align*}
\text{max } h_0 &= \frac{\sum_{r=1}^{s} u_r y_{rq} - \sum_{j=1}^{p} w_j z_{jq} + c_0}{\sum_{i=1}^{m} v_i x_{iq}} \\
\text{subject to } & \quad \frac{\sum_{r=1}^{s} u_r y_{rq} - \sum_{j=1}^{p} w_j z_{jq} + c_0}{\sum_{i=1}^{m} v_i x_{iq}} \leq 1, \ q = 1, \ldots, n, \\
& \quad u_r \geq 0, \ r = 1, \ldots, s, \ v_i \geq 0, \ i = 1, \ldots, m, \ w_j \geq 0, \ j = 1, \ldots, p,
\end{align*}
\]

where \( s \) is the number of outputs; \( u_r \), the weight of output \( r \); \( y_{rq} \), the amount of output \( r \) produced by the institution under evaluation; \( m \) the number of controllable inputs; \( v_i \), the weight of controllable input \( i \); \( x_{iq} \), the amount of controllable input \( i \) used by the institution; \( p \) the number of uncontrollable inputs; \( w_j \) the weight of uncontrollable input \( j \); and \( z_{jq} \) the amount of uncontrollable input \( j \) used by the institution.
Figure 3. Model 1 Variables

**Inputs**
- Instruction Expenses per FTE (av. 2005-2009)
- Academic Support Expenses per FTE (av. 2005-2009)
- Student Services Expenses per FTE (av. 2005-2009)
- Institutional Support Expenses per FTE (av. 2005-2009)
- Percentage of Students Receiving Federal Grant Aid (av. 2005-2009)

**Controlled Inputs**
- Proxy: Quality of teaching
- Proxy: Quality of learning resources
- Proxy: Quality of student life
- Proxy: Quality of institutional management
- Proxy: Student SES

**Processes**

**Outputs**
- Retention Rate (av. 2005-2009)
- Graduation Rate (2009)
Figure 4. Model 2 Variables

- **Inputs**
  - **Proxy:** Quality of teaching
  - **Proxy:** Quality of learning resources
  - **Proxy:** Quality of student life
  - **Proxy:** Quality of institutional management
  - **Proxy:** Student SES

- **Controlled Inputs**
  - Instruction Expenses per FTE (2005, 2009)
  - Academic Support Expenses per FTE (2005, 2009)
  - Student Services Expenses per FTE (2005, 2009)
  - Institutional Support Expenses per FTE (2005, 2009)
  - Percentage of Students Receiving Federal Grant Aid (2005, 2009)

- **Processes**

- **Output**
  - Retention Rate (2005, 2009)

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Institutional Sample: Descriptive Statistics

Model 1.

Table 1: Sample: Descriptive Statistics

<table>
<thead>
<tr>
<th>35 Public, 4-Year HBCUs</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instruction expenses/ FTE*</td>
<td>Academic support expenses/ FTE*</td>
</tr>
<tr>
<td>Minimum</td>
<td>4,149</td>
<td>613</td>
</tr>
<tr>
<td>Maximum</td>
<td>10,015</td>
<td>3,340</td>
</tr>
<tr>
<td>Mean</td>
<td>6,137</td>
<td>1,779</td>
</tr>
<tr>
<td>SD</td>
<td>1,360</td>
<td>681</td>
</tr>
</tbody>
</table>

Table 2: Focus Institution: Descriptive Statistics

<table>
<thead>
<tr>
<th>-Urban, comprehensive university -7,000 UG and GR students</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instruction expenses/ FTE*</td>
<td>Academic support expenses/ FTE*</td>
</tr>
<tr>
<td></td>
<td>6,502</td>
<td>2,922</td>
</tr>
</tbody>
</table>

NOTES:
*Average 2005-2009 data
**2009 data
1Uncontrolled (environmental) variable

Model 2.

Table 3: Sample: Descriptive Statistics

<table>
<thead>
<tr>
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<th>Outputs</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Instruction expenses/ FTE*</td>
<td>Academic support expenses/ FTE*</td>
</tr>
<tr>
<td>2005 av.</td>
<td>5,867</td>
<td>1,691</td>
</tr>
<tr>
<td>2009 av.</td>
<td>6,557</td>
<td>1,912</td>
</tr>
<tr>
<td>Change</td>
<td>+690</td>
<td>+221</td>
</tr>
<tr>
<td>%Change</td>
<td>+12%</td>
<td>+13%</td>
</tr>
</tbody>
</table>

Table 4: Focus Institution: Descriptive Statistics

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<tbody>
<tr>
<td></td>
<td>Instruction expenses/ FTE*</td>
<td>Academic support expenses/ FTE*</td>
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<tr>
<td>2005</td>
<td>6,458</td>
<td>2,673</td>
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<tr>
<td>2009</td>
<td>6,288</td>
<td>2,415</td>
</tr>
<tr>
<td>Change</td>
<td>-170</td>
<td>-258</td>
</tr>
<tr>
<td>%Change</td>
<td>-3%</td>
<td>-10%</td>
</tr>
</tbody>
</table>
Findings for Focus Institution

**QUESTION 1** “Doing MORE with Same – How much can Focus Institution increase the outputs given the current level of inputs?” // **Output-Oriented (O/O) VRS Solution**

Table 5. *Output Targets/Benchmarks for the Focus Institution*

<table>
<thead>
<tr>
<th></th>
<th>Inputs</th>
<th>Outputs – MORE with Same</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instruction expenses/student FTE</td>
<td>Academic support expenses/student FTE</td>
</tr>
<tr>
<td>Focus Institution Av. 2005-2009</td>
<td>6,502</td>
<td>2,922</td>
</tr>
<tr>
<td></td>
<td>Slacks // MORE with LESS</td>
<td>-202</td>
</tr>
</tbody>
</table>

**QUESTION 2** “Doing same with LESS – How much could the inputs be decreased while maintaining the current level of outputs? // **Input-Oriented (I/O) VRS Solution**

Table 6. *Input Targets/Benchmarks for the Focus Institution*

<table>
<thead>
<tr>
<th></th>
<th>Inputs – Same with LESS</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instruction expenses/student FTE</td>
<td>Academic support expenses/student FTE</td>
</tr>
<tr>
<td>Average 05-09</td>
<td>Target 6,502</td>
<td>Target 5,330 (-18%)</td>
</tr>
<tr>
<td>Focus Institution</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slacks // MORE with LESS</td>
<td></td>
</tr>
</tbody>
</table>

**QUESTION 3** “What are the best practice public HBCUs?” // “What institutions can serve as ‘role models’ for Focus Institution?”

- **Efficiency Leaders for Public HBCUs**
  - **Albany State University**
    - Combined 24 references in O/O and I/O solutions
  - **Savannah State University**
    - Combined 17 references in O/O and I/O solutions.
Reference Sets for Focus Institution

Table 7. Reference Sets for Focus Institution

<table>
<thead>
<tr>
<th>Input-Oriented (I/O) VRS</th>
<th>Output-Oriented (O/O) VRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluefield State College</td>
<td>Florida A&amp;M University</td>
</tr>
<tr>
<td><strong>North Carolina A &amp; T State University</strong></td>
<td><strong>North Carolina A &amp; T State University</strong></td>
</tr>
<tr>
<td>Savannah State University</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Reference Comparison.

Note: The values of Focus Institution are scaled to 100% in the graph.

**QUESTION 4** “Does institutional efficiency improve over time?” – Principle of Continuous Quality Enhancement


<table>
<thead>
<tr>
<th></th>
<th>Output-Oriented VRS</th>
<th>Input-Oriented VRS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Malquist Index</td>
<td>Catch-Up Frontier Shift</td>
</tr>
<tr>
<td>Average for 35 HBCUs</td>
<td>0.98</td>
<td><strong>1</strong></td>
</tr>
<tr>
<td>Focus Institution</td>
<td>1.07</td>
<td><strong>1.11</strong></td>
</tr>
</tbody>
</table>

Note: A value of 1 shows no change over the observed period. A value greater than 1 indicates improvement in productivity, whereas a value less than 1 represents a decline in performance.

- If “Catch-Up” > “Frontier Shift”, then dynamics in productivity (Malquist Index) reflect changes in efficiency
- If “Catch-Up” < “Frontier Shift”, then dynamics in productivity (Malquist Index) reflect changes in the production technology in the field.
Model Variables: Definitions

OUTPUTS

- **Retention Rate** of first-time full-time bachelor's (or equivalent) degree-seeking undergraduates. The full-time retention rate is the percent of the (fall full-time cohort from the prior year minus exclusions from the fall full-time cohort) that re-enrolled at the institution as either full- or part-time in the current year.

- **Graduation Rate** of first-time, full-time degree or certificate-seeking students. Graduation rate of first-time, full-time degree or certificate-seeking students is calculated as the total number of completers within 150% of normal time divided by the revised cohort minus any allowable exclusions.

INPUTS

**Controlled Inputs**

- **Instruction Expenses per FTE.** Instruction is a functional expense category that includes expenses of the colleges, schools, departments, and other instructional divisions of the institution and expenses for departmental research and public service that are not separately budgeted. Includes general academic instruction, occupational and vocational instruction, community education, preparatory and adult basic education, and regular, special, and extension sessions. Also includes expenses for both credit and non-credit activities. Excludes expenses for academic administration where the primary function is administration (e.g., academic deans).

- **Academic Support Expenses per FTE.** Academic support is a functional expense category that includes expenses of activities and services that support the institution's primary missions of instruction, research, and public service. It includes the retention, preservation, and display of educational materials (for example, libraries, museums, and galleries); organized activities that provide support services to the academic functions of the institution (such as a demonstration school associated with a college of education or veterinary and dental clinics if their primary purpose is to support the instructional program); media such as audiovisual services; academic administration (including academic deans but not department chairpersons); and formally organized and separately budgeted academic personnel development and course and curriculum development expenses.

- **Student Services Expenses per FTE.** Student services is a functional expense category that includes expenses for admissions, registrar activities, and activities whose primary purpose is to contribute to students emotional and physical well-being and to their intellectual, cultural, and social development outside the context of the formal instructional program. Examples include student activities, cultural events, student newspapers, intramural athletics, student organizations, supplemental instruction outside the normal administration, and student records. Intercollegiate athletics and student health services may also be included except when operated as self-supporting auxiliary enterprises.

- **Institutional Support Expenses per FTE.** Institutional support is a functional expense category that includes expenses for the day-to-day operational support of the institution. Includes expenses for general administrative services, central executive-level activities concerned with management and long range planning, legal and fiscal operations, space management, employee personnel and records, logistical services such as purchasing and printing, and public relations and development. Also includes information technology expenses related to institutional support activities.

**Uncontrolled Input // Environmental Input Variable**

- **Percentage of full-time, first-time degree/certificate-seeking undergraduate students who received federal grants** (grants/educational assistance funds). Federal grants (grants/educational assistance funds) - Grants provided by federal agencies such as the U.S. Department of Education, including Title IV Pell Grants and Supplemental Educational Opportunity Grants (SEOG). Also includes need-based and merit-based educational assistance funds and training vouchers provided from other federal agencies and/or federally-sponsored educational benefits programs, including the Veteran's Administration, Department of Labor, and other federal agencies.
Glossary of Key Terms

(Also see: http://www.banxia.com/frontier/resources/glossary/)

- **Constant Return to Scale (CRS)** = a DEA analytical approach assuming that an increase (decrease) in inputs produces a *proportionate* increase (decrease) in the output. The CRS approach assumes a linear relationship between the inputs and outputs.

- **Data Envelopment Analysis (DEA)** = a nonparametric efficiency frontier estimation methodology utilized to compare peer or functionally similar complex institutions with multiple inputs and outputs. Essentially, it is based on an optimization algorithm solved through a mathematical linear programming method.

- **Efficiency Ratio** = a single composite/virtual ratio between the institution’s aggregated weighted inputs and aggregated weighted outputs weighted in the context of the observed best practice performance in the peer group.

- **Efficiency Score** = a measure of the technical efficiency of the institution in the context of performance of peer institutions. It is expressed as a number between 0 (0%) and 1 (100%).
  - An institution is rated as fully efficient (score of 1 or 100%) “on the basis of available evidence if and only if the performance of other [institutions] does not show that some of its inputs or outputs can be improved without worsening some of its other inputs or outputs.” (Cooper et al., 2004, p. 3)
  - Specific score represents the distance of how far the given institution is from the efficiency frontier.

- **Envelope** = a frontier that represents “best performance” in the group and is formed by 100% efficient institutions.

- **Frontier (efficiency/best practice frontier)** = production function that expresses the relationship between the inputs utilized and the outputs produced.
  - *Efficiency / Best Practice frontier*
    - Indicates the maximum quantity of outputs that can be obtained from a given combination of inputs *and*
    - Expresses the minimum quantity of inputs that must be used to achieve a given output level. (Vercellis, 2009, pp. 386-387)

- **Inputs** = various resources used by the institutions to produce outputs.
  - *Controlled Inputs* = Inputs over which institutional administration has control and can alter the amount used.
  - *Environmental Inputs* = Inputs representing some important aspects of the environment in which the institutions operate.
  - *Uncontrolled Inputs* = Inputs over which institutional administration does not have control and cannot alter the amount used.

- **Input Orientation (I/O) / Input Minimization** = A DEA analytical procedure under which outputs are fixed and the possibility of reduction in inputs is explored
  - Input minimization procedure determines the amounts that each institution can reduce in at least one of the input categories without reducing current retention and graduation rates.

- **Leader** = a best practice institution for the peer group as a whole. It is an efficient institution that appears most frequently in the reference sets for inefficient institutions.

- **Linear Programming** = a mathematical method for establishing a production function to achieve the best desired results in a given model in the context of certain conditions in the form of linear equations. “Linear
programming is concerned with the general problem of allocating limited resources among competing activities in the best possible way.” (Zheng & Stewart, 2002, p. 5)

- **Malmquist Productivity Change Index** = a measure of the growth in productivity between the two points in time.
  - Efficiency Catch Up = change in input/output ratio or the reduction of distance between the focus institution and the efficiency frontier // change in the institution’s location relative to the frontier
  - Change in budget allocation amounts and priorities
  - Frontier Shift = change in the location of the frontier itself // dynamics in production technology or changes in processes of transforming inputs into outputs (technology of delivering education) in the peer group.
    - “Technological change is a mixture of new technology, mainly associated to new equipment and capital…, improved management skills and learning-by-doing” (Ouellette & Vierstraete, 2010, p. 69).
    - Change in behaviors of administrators, instructors, (and students).

- **Outputs** = measures of products, services, and other outcomes which result from processing and expending inputs.

- **Output Orientation (O/O) / Output Maximization** = A DEA analytical procedure under which inputs are kept constant while the possibility of expansion of outputs is explored
  - Output maximization procedure determines the extent to which each inefficient institution can increase its graduation and/or retention rates in order to become efficient without increasing the current level of inputs.

- **Production Function** = a process of transformation of inputs into outputs.

- **Productivity** = “the net effect of changes in efficiency (or movements relative to the existing frontier) and shifts in the production frontier (or technical change).” (Worthington & Lee, 2008).

- **Reference Set** = A group of “role-models” for a given inefficient institution. It is group of efficient institutions that have the most similar input/output combination to a given inefficient institution.

- **Slacks** = measures of the under production of output in input-oriented (input minimization) models or measures of the over use of input or input excess in output-oriented (output maximization) models.

- **Targets** = the values of the inputs and outputs which would result is an inefficient unit becoming efficient.

- **Variable Return to Scale (VRS)** = A DEA analytical approach assuming that an increase (decrease) in inputs produces a *disproportionate* increase (decrease) in the output. The VRS approach assumes a non-linear relationship between the inputs and outputs.
Selected Bibliography

A. Institutional Expenditures and Student Success


B. Overview of DEA Methodology

Books


Chapters and Journal Articles


Manuals


C. DEA Applications Using Retention and/or Graduation Rates as Model Variables


D. DEA Applications in Exploring Efficiency Change Over Time in Higher Education (Malmquist Index applications)


E. Other DEA Applications in Higher Education


F. Web Resource

Popular DEA Software Packages

- DEA Solver
  - [http://www.saitech-inc.com/Products/Prod-DSP.asp](http://www.saitech-inc.com/Products/Prod-DSP.asp)

- DEA Frontier
  - [http://www.deafrontier.net/software.html](http://www.deafrontier.net/software.html)

- D.E.A.O.S. DEA Online Software
  - [http://www.deaos.com](http://www.deaos.com)

- DEAP

- Frontier Analyst *(utilized for this project)*

- KonSi Data Envelopment Analysis for Benchmarking

- Open Source DEA

- PIM DEASoft
  - [http://www.deasoftware.co.uk/](http://www.deasoftware.co.uk/)