Estimating Technical Efficiency of the Mid-Atlantic Scallop Dredge Fleet Using a Bootstrapped DEA Model

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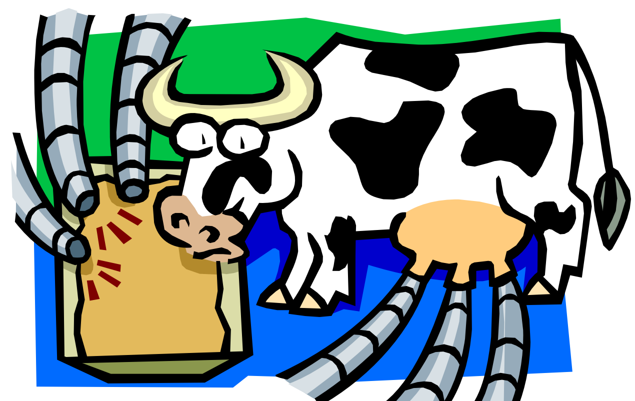
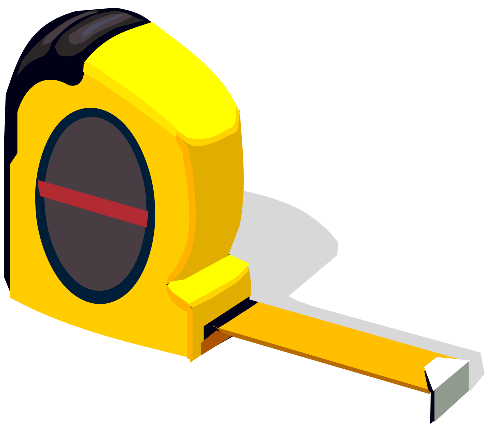
What is Technical Efficiency and Why Should we Estimate TE?

- Technical Efficiency is relative concept which compares actual output with a benchmark output.
- Ideally, we would like to measure efficiency from a profit maximization standpoint.
- Lack of cost data often prevents this. Fishing vessels may have other objectives, such as revenue maximization, or fishing to fill ‘market orders’
- Technical Efficiency (TE) is a necessary condition for economic efficiency.



Methods for Estimating Technical Efficiency

- **Data Envelopment Analysis (DEA)**
- **Stochastic Production Frontier (SPF)**
- **Past studies include Kirkley, Squires and Strand (1995, 1998), Weninger (2001) and Kirkley, Squires,Alam and Ishak (2003)**



- Present DEA Model
- Talk a little about the statistical properties of DEA models.
- Present the Bootstrap Routine
- Apply the Model to the Mid-Atlantic Scallop Dredge Fleet.
- Compare the technically efficient output to the TAC for a given year.

Review

Production Set of Physically Attainable Points

Output Correspondence

P ≡ {(x , y) | x can produce y}

Farrell Output Efficiency Boundary:

$$y^{\partial}(x) = \{y \mid y \in y(x), \lambda y \notin y(x) \ \forall \ \lambda > 1\}$$

Shephard Output Distance Function

$$D_O(x, y) \equiv \inf\{\theta > 0 \mid (x, \theta^{-1} y) \in \mathrm{P}\}.$$

$$\underset{\theta,z}{Max}\,\theta$$

$$s.t.$$

$$\theta u_{jm} \le \sum_{j=1}^{J} z_j u_{jm}, m = 1,2,\ldots, M,$$

$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn},$$

$$z_j \ge 0, j = 1,2,\ldots, J,$$

Statistical Properties of Frontier Models

- **Banker et. al (1988) <u>Applications of Modern Production Theory.</u>**
- **Simar, 1995. *Journal of Productivity Analysis.***
- **Korostelev et. al, (1995) *Annals of Statistics*.**
- **Banker et. al, (1993, 1996) *European Journal of Operational Research.***
- **Park, et. al, 1999 *Econometric Theory***
- **Reinhard et. al (2000). *European Journal of Operational Research.***
- **Holland and Lee (2002). *European Journal of Operational Research***
- **Felthoven and Paul (2004). American Journal of Agricultural Economics.**

What are Some Properties of DEA Estimators??

- **Measurement of inputs and outputs in a DEA model are the result of an underlying Data Generating Process (DGP).**
- **DEA estimators are defined as minimal sets containing the observed data.**
- **Efficiency is measured relative to an estimate of the true frontier, with inputs and outputs that are subject to uncertainty.**
- **Due to the complexity and multidimensional nature of the DEA estimators, their sampling distributions are not easily obtainable.**

Bootstrap Basics

- **Ψ, $\partial X(y)$ and $\theta(x,y)$ are all unknown.**
- **The bootstrap is based on the idea that the known bootstrap distribution will mimic the unknown sampling distribution of the estimator of interest**
- **Through the bootstrap, the bias of the original estimator can be calculated, and the original estimator corrected for the bias.**
- **Naïve bootstrap consists of sampling the pairs (x^*,y^*) with replacement. With boundary problems, this yields inconsistent estimates.**

Key Literature

- **Three articles by Simar and Wilson:**
  - **"Sensitivity Analysis of Efficiency Scores: How to Bootstrap in Nonparametric Frontier Models" Management Science Vol. 44, No.1, 1998, 49-61**
  - **Journal of Applied Statistics, Vol. 27, No. 6, 2000, 779-802.**
  - **Journal of Productivity Analysis, Vol. 13, No. 1, 2000, 49-78**

Correcting for Bias and calculating Confidence Intervals

- In an output oriented model, the DEA scores are a lower bound of the true efficiency scores.
- A bias corrected estimator of the true value of the DEA score can be computed.
- Confidence Intervals can also be constructed from the bootstrapped values

Case Study: Mid-Atlantic Scallop Dredge Fleet.

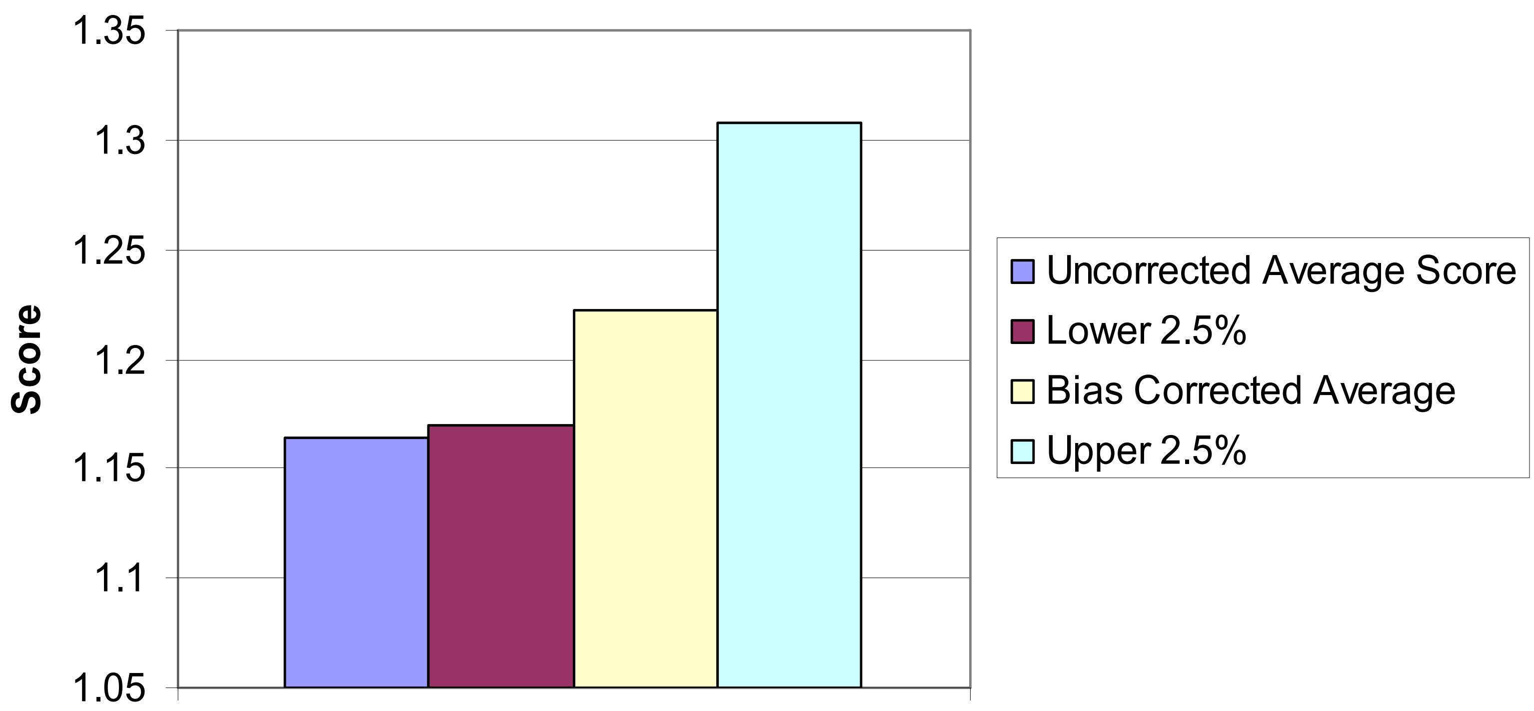
Vessel Characteristics

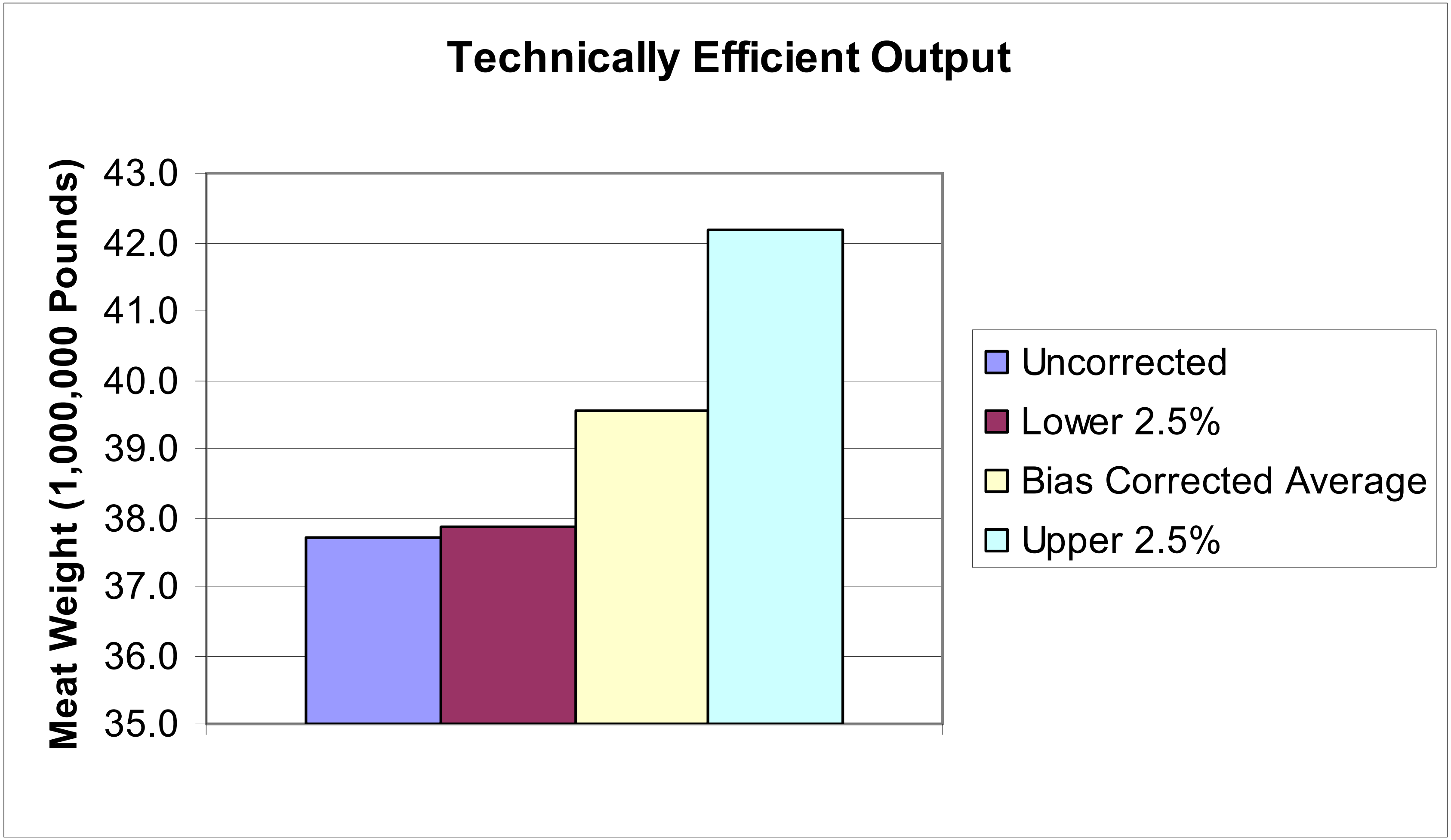
- **Vessels – 201**
- **Inputs**
  - **Dredge Width – 326 (inches)**
  - **Tonnage – 160**
  - **Horsepower – 844**
  - **Length – 83**
  - **Days at Sea – 94**
  - **Crew – 7**
- **Outputs**
  - **Scallops – 166,000 Pounds (meat weights)**
  - **Monkfish – 4,035 pounds (live weight)**
  - **Summer Flounder – 377 pounds (live weight)**

Method

- **First, solve the original linear program to obtain estimates of θ_k for the k observations.**
- **Select k samples of θ^*, and "Smooth" them using the approach of Silverman (1986).**
- **Adjust the output values of the original sample using the ratio θ_k / θ_k^* .**
- **Compute the bootstrap estimate of θ` using the original LP model.**
- **Repeat B times to provide for N=1,..,n set of samples.**

Figure 1. Mean Uncorrected and Bias Corrected Scores from the DEA Bootstrapping Routine




Technically Efficient Output
Meat Weight (1,000,000 Pounds)
43.0
42.0
41.0
40.0
39.0
38.0
37.0
36.0
35.0
Uncorrected
Lower 2.5%
Bias Corrected Average
Upper 2.5%

Management Implications

- **The MSY level for the Mid-Atlantic Resource is roughly 30.4 million pounds.**
- **Results show that the fleet has the ability to harvest between 7.5 and 11.8 million more pounds than the MSY level (24.7 and 38.8 percent greater than MSY).**
- **These results are for the dredge component with individual days at sea allocations. Other fleet sectors also harvest scallops.**
- **Results are conditional on regulations in place which restrict dredge width and crew size.**

Summary and Conclusions

- **NOT for the Faint of Heart. Involves Three GAMS routines and Two PERL programs.**
- **Currently, only have used for standard DEA model where all outputs are expanded radially.**
- **Further Research is needed to extend the techniques to models which examine efficiency from a profit, or revenue maximization standpoint, or using a Pareto-Koopman's approach.**