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A METHOD TO BENCHMARK FARMED SEA BREAM BATCHES EFFICIENCY

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ABSTRACT

Sea bream fish farming is a well-established industry in Mediterranean basin with Greece, Turkey and Spain being the main production countries. The competition between producers has increased through the years and the vast majority of production firms compete in the same market with unbranded commodity products. The main competitive advantage of the producers acting in the market remains the price and as such the efficient production seems to be the ultimate goal in order to survive under hard price competition. In order to achieve the highest economic performance, high technical efficiency of batches of fish stocked every single year needs to be achieved. To date, a number of traditional biological indicators such as feed conversion ratio (FCR), specific growth rate (SGR), and survival are used to compare various batches. A method of benchmarking batch efficiency is proposed. Data Envelopment Analysis employed to estimate Technical Efficiency using several batches of Gilthead sea bream (Sparus auratus) stocked during 2012 in representative production areas of Greece and in farms operating under the same overall management. DEA efficiency scores and ranking using traditional indicators is presented. The findings provide support to production managers in focusing on improvement of specific factors of interest for batch efficiency and to evaluate their decisions, such as month of stocking, area of stocking and juveniles’ weight at stocking. Furthermore, findings may assist administrators in providing best practice guidelines for Mediterranean fish farming operations.

Key words: DEA, Benchmarking, Technical efficiency at batch level, Gilthead sea bream

Jel Codes

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1 Introduction

Gilthead sea bream (*Sparus auratus*) fish farming is a well-established industry in Mediterranean basin with Greece, Turkey and Spain being the main producing countries. The competition between companies increases over the years and the vast majority of the producers compete in the same markets offering unbranded commodity products. The main competitive advantage of the companies acting in the market remains the price and, as such, economic efficient production seems to be the ultimate goal in order to survive under hard price competition.

In order to be economic efficient, initially the industry needs to be technical efficient. Coelli et al. (2005) are dealing with efficiency and productivity and they explain that the reason why efficiency and productivity should be estimated is the need for improvement of economic performance. Both, efficiency and productivity are performance indicators for any economic activity. Even the fact that the majority of the producers seem to be focused on the “bottom line” of the balance sheets, financial results are significantly improved when productivity and efficiency are improved. In order to improve economic performance of any production activity the sources affecting inefficiency and productivity have to be identified. In a capital intensive industry like the Mediterranean fish farming, decisions of stocking, growing and harvesting of each individual batch of fish constitutes medium term investments (Asche & Bjorndal 2011). These financial investments are, in most cases, based on a specific biotechnology (reproduction, growing, feeding) and on the use of raw material like juveniles, fish feeds and infrastructure like, cages, nets, boats, barges etc. So far, the vast majority of the industry evaluates the performance of batches based on key performance indicators (KPI’s) such as food conversion ratio (FCR), growth rate, and survival. These “biologic” indicators are often a ratio of an output to an input, for example feed quantity provided divided by the achieved growth rate is the FCR, growth compared to time spent in the farm in the case of growth rate and finally number of juveniles harvested compared to juveniles stocked in the case of survival. While KPI’s can be indicative of the performance of a batch, they face scale limitations as they inherently assumed that input and output can scale up in a linear fashion thus assuming constant returns to scale. On top, each KPI only presents partial evaluation and contradictions between KPI's may often present unclear results on the best performing batch (Bogetoft and Otto, 2011). The need for a new method for benchmarking and at the same time estimation of technical efficiency clearly arises in the case of the fish farming industry.

In the current paper, the use of Data Envelopment Analysis (DEA) for batch ranking and at the same time estimation of Technical Efficiency is proposed. While the use of DEA is widely
used in various industries (Bogetoft & Otto, 2011), including fisheries (Tingley et al., 2005) and aquaculture (Cinemre A.H. et al, 2006; Yin et al, 2014) to date, the use of DEA is mostly limited to the overall estimation of technical efficiency between firms in the same industry. DEA approach is preferred to the stochastic frontier approach as in DEA there is no need to explicitly specify a production function. What's more, there is available open software such as R and DEAP, while in simple cases, a simple spreadsheet software may be used.

For the current application of DEA, several batches of Gilthead sea bream stocked in 2012 in representative production areas of Greece are used. Intra-organizational comparisons are performed in order to evaluate the performance of various production centers based on DEA benchmarking method. Impacts on inefficiency of key production parameters and tactics are evaluated. Data is based on production centers under the management of a unique aquaculture company.

A more reliable ranking method which allows at the same time for the estimation technical efficiency of individual batches of fish and a method to benchmark them, is expected to allow producing organizations to compare between production entities in order to coordinate better, to motivate local management and to learn by identifying sources of inefficiency. This method is expected to assist producers to evaluate their strategic choices for stocking dates, juveniles sourcing, fish health prevention practices, personnel appraisal and at the very end to increase profitability by gaining more from each euro invested in their fish farms. At the very end the improvement of the overall productivity will be the ultimate goal.

2 Methodology

In the current application, DEA is used to rank batches and at the same time estimate technical efficiency (TE) for various batches of sea bream farmed in various locations in Greece. DEA is a non parametric technique based on linear programming model. The principal idea of Data Envelopment Analysis is the creation of an Envelopment Technology (frontier) using the batches formulating the sample population. Envelopment Technology creation is based in minimal extrapolation principal, which is the minimum convexity, and surrounds all batches under consideration. Each batch of fish constitutes a Management Unit, in which various inputs are allocated; one technology is used to grow them up and to harvest them, the same for all batches of the sampled population. Where DEA method used, the

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3 Group of farms under the same local management
efficiency of each batch is measured comparing output obtained and inputs used, with points on the production frontier. If the batch lies on the frontier it is assumed to be perfectly efficient with efficiency score “h” equal to 1. Batches assigned below the frontier are assumed to be inefficient with efficiency scores is smaller than 1 (h<1). The mathematical equation for the estimation of technical efficiency score using DEA method is the following:

\[
h_j = \frac{\sum_{r=1}^{s} u_{rj} y_{rj}}{\sum_{i,j} v_{ij} x_{ij}} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}}
\]  

(1)

where \( x_{ij} \) are observed positive values of the i-th input of Batch j

\( y_{rj} \) are observed values of the r-th output of Batch j (r=1,2,…,s)

In this case technical efficiency is estimated by aggregating inputs and outputs by a weighted sum. So efficiency could be defined as the ratio of the weighted sum of outputs over the weighted sum of inputs in case of output orientation or as the inverse of this ratio in the case of input orientation. In the current application the input oriented model is used.

As output in the current application, we use the growth of the batch of fish in terms of biomass (Kg), which equals the harvesting biomass minus the initially stocked biomass of each batch.

\[
\text{Growth} = \text{Harvesting biomass} - \text{Initially stocked biomass}
\]

Harvesting biomass = No of fish harvested * Average Harvest weight

Initially stocked biomass = No of fish stocked * Average stocked weight.

The same growth period is examined for all batches in the current application. The growth period starts from the transfer of the juveniles from the nursery to the marine cages and ends few days prior of harvesting at the targeted weight of 400gr based on the sales policy of the company at that time.

In addition two inputs are used in the model that incorporate the vast majority of production costs. The first one is feed consumed by each batch during the production period in kilograms (Kg) and the second one is time spend from stocking to harvesting defined as day degrees (dd), the product of days and the average sea temperature.
Feed costs represent the major cost of Mediterranean fish farming (Hellenic Competition Commission, 2010). Feed consumed depends on the fish age, the sea temperature and the feed quality. In the current case feed quality is the same for all batches as the various farms sourced feed from the same manufacturer under one specification. Energy provided by the feed addressed to two pathways, the maintenance pathway in which energy is used just to maintain the achieved weight of the fish and the growth pathway. In the latter case the energy provided used to increase in daily basis the weight of the fish. Both pathways vary between different fish ages’ and environmental conditions. In any case feed consumption is related to time spend in the farm. Finally in the current application, feed consumed by the dead fish of the batch is also introduced in the equation.

Fish are poikilothermic organisms and as such they don’t waste energy to maintain body temperature. On the other hand their metabolism is heavily dependent on environmental temperature, sea temperature in the current case. As such, time spend in the sea is a critical factor and the vast majority of production costs, other than feed costs, of fish farming are time related. These are depreciation of capital, labor costs and other costs.

### 2.1 Scale impact on efficiency estimation

Using DEA it is possible to account for the scale when one estimates efficiency (Coelli 1996). Bogetoft & Otto (2011) describe six classical DEA models that can be used to estimate efficiency, the constant returns to scale (CRS) model, the decreasing returns to scale (DRS), the increasing returns to scale (IRS), the variable returns to scale (VRS) model and finally the free disposability hull (FDH) and the free replicability hull models (FRH). As DEA method estimates efficiency comparing a group of batches, scale effects might alter the final result. In selecting scale model, the biology of the species and the farm capacity need to be accounted for. In the current case, farm capacity is restricted, thus inputs in terms of day degrees are also restricted. On top, given the current production technology, restrictions also apply on the inputs in terms of feed consumed and day degrees. It is not efficient to depart from an optimal food ratio as energy provided would be either insufficient or wasted. It is also not efficient, given the target market, to depart from an optimal fish size as growth rate decreases by the time. For those reasons in the current application the VRS model is employed. DEA accounts for variable returns to scale in the model using the following formulation:

$$
\min_{\theta, \lambda} \theta \\
- y_i + Y\lambda \geq 0, \quad \text{(DEA Variable Returns to Scale model Equation)} \\
\theta_{si} - x\lambda \geq 0, \\
N\lambda = 1, \\
\lambda \geq 0
$$
2.2 Second stage DEA

There are good arguments (Pascoe and Coglan 2002, Tingley et al. 2005) about the use of DEA efficiency scores as descriptive measure (depended variable) in a second stage analysis. Factors related to management decisions and peculiarities of the farms, definitely affect efficiency. While for example, the management may prepare a plan for batch stocking every single year, such planning is affected by the availability of the juveniles in the market, the availability of transportation means and availability of space on the farms. In the case of vertically integrated companies that operate owned hatcheries, management can easier overcome these constraints.

Given the fact that TE results are fractional data that can have values belonging to a bounded area between zero and one, the use of tobit regression is proposed by many researchers (Tingley et al. 2005, Singh et al. 2009). On the other hand, McDonald (2009) argues that as the efficiency scores in DEA are fractional data not generated by a censoring process, Ordinary Least Square (OLS) can be used to estimate parameters of variables that affect efficiency scores.

In the current application both OLS regression and tobit regression are used to estimate parameters for variables that are expected to affect efficiency.

2.3 Data

Data used in the current application originate from batches farmed in various locations in Greece. All batches were stocked in various months of the same year (2012), coming from different hatcheries, although hatcheries and farms were under the same overall central management. Minor changes in local management techniques between areas are due to different environmental characteristics, availability of equipment and personnel experience. Thirty six (36) batches, of approximately 30 millions of juvenile sea bream, stocked from January 2012 to July 2012 in 7 different areas in Greece, are considered in the current application. The batch average harvested weight of 400gr which was the targeted commercial weight of the species at the time is considered as the end period. In order to avoid the effects of repeated starvation periods during harvesting, data collection was concluded on the last month before harvesting. Descriptive statistics on outputs and inputs used are provided in the following table.

| Table 1. Descriptive Statistics of inputs and output |
|---------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                           | Mean            | Range           | Min             | Max             | Std Dev         | Variance        |
| Juveniles                 | 829,083         | 2,052,000       | 98,000          | 2,150,000       | 478,206         | 2,287,000,      |
| Weight at stocking (g)    | 4.9             | 10.20           | 1.90            | 12.10           | 2.75            | 7.56            |
| Weight at harvesting (g)  | 454.4           | 205.90          | 372.10          | 578.00          | 56.9            | 3,339           |
| Growth (Kg)               | 283,541         | 766,258         | 24,265          | 790,524         | 175,208         | 307,000         |
| Feed (Kg)                 | 577,230         | 1,525,828       | 54,889          | 1,580,717       | 358,034         | 1,282,000       |
| Time (dd)                 | 9,575           | 3,002           | 8,242           | 11,244          | 883,4           | 780,384         |
| Time (days)               | 507             | 137             | 425             | 562             | 47.7            | 2,276           |
In the current application batches with various initial number of fish are included. Stocked number of fish varied from 98,000 juveniles to 2,150,000 juveniles depending on the farm site, the availability and size of the cages. On top, initial juvenile size varies as both ordinary (1.90g – 2.4g) and preffatened (5.0g – 12.1g) juveniles are used in the batches under consideration. A significant variation of days spend in the sea is obvious in the data, mainly affected by the initial stocking month. Batches were transferred in the sea at approximately equal proportions in the cold period (January to April) and in the warm period (May to July).

2.4 Software used

In the current application DEAP 2.1. software was used, to estimate batch technical efficiency. DEAP 2.1. is a computer program special designed to conduct Data Envelopment Analysis. Instructions about use of DEAP 2.1. are provided by Coelli 1996. Data analysis for descriptive statistics and data transformation were implemented with the use of Microsoft Excel (2010). R language and environment were used for tobit regression and SPSS v22 were used for OLS and data descriptives.

3 Results

The results of VRS DEA model are presented in table 2. It is clear that even the fact that mean technical efficiency is quite high (91.14%) there is enough space for improvement given the high percentage (38.1% of juveniles stocked) of batches with TE scores below 90%. Potentially the produced biomass could be increased by 8.86% using the same level of inputs if all batches of fish were produced efficiently, given technology and quality of raw material used.

Table 2.: Efficiency rate scores under the VRS DEA Model

<table>
<thead>
<tr>
<th>Efficiency rate</th>
<th>No of batches</th>
<th>%</th>
<th>Juveniles %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95&lt;TE&lt;1</td>
<td>11</td>
<td>30.6</td>
<td>31.7</td>
</tr>
<tr>
<td>0.90&lt;TE&lt;0.95</td>
<td>9</td>
<td>25</td>
<td>30.2</td>
</tr>
<tr>
<td>0.80&lt;TE&lt;0.90</td>
<td>16</td>
<td>44.4</td>
<td>38.1</td>
</tr>
<tr>
<td>TE VRS : 0.9114</td>
<td>36</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Production KPI’s and TE scores

<table>
<thead>
<tr>
<th>Efficiency rate</th>
<th>Juveniles %</th>
<th>Degree days</th>
<th>Days</th>
<th>FR%</th>
<th>FCR</th>
<th>TGC</th>
<th>Survival %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95&lt;TE&lt;1</td>
<td>31.7</td>
<td>8,926</td>
<td>443</td>
<td>0.80</td>
<td>1.98</td>
<td>0.61</td>
<td>77.3</td>
</tr>
<tr>
<td>0.90&lt;TE&lt;0.95</td>
<td>30.2</td>
<td>9,521</td>
<td>472</td>
<td>0.77</td>
<td>2.02</td>
<td>0.54</td>
<td>75.6</td>
</tr>
<tr>
<td>0.80&lt;TE&lt;0.90</td>
<td>38.1</td>
<td>10,191</td>
<td>507</td>
<td>0.77</td>
<td>2.05</td>
<td>0.56</td>
<td>80.9</td>
</tr>
</tbody>
</table>
In table 3 the batches are sorted in arbitrary classes of TE scores. In addition the average values of KPI’s frequently used in aquaculture firms are presented. It is quite clear that the best performing classes tend to present better KPI’s. In average the most efficient classes achieved the targeted harvest weight a month earlier than the average efficient and two months earlier compared to the less efficient classes. Furthermore, growth rate expressed as Thermal Growth Coefficient (TGC) and feed utilization expressed as Feed Conversion Ratio (FCR) present better results in more efficient classes. The feeding rates (FR%) which present the quantity of feed provided in daily basis as percentage of fish body weight, are almost identical between the various technical efficiency classes.

Table 4. Monthly distribution of TE and related KPI’s

<table>
<thead>
<tr>
<th>Month</th>
<th>% Juveniles</th>
<th>TE</th>
<th>Degree Days</th>
<th>Days</th>
<th>FR%</th>
<th>FCR</th>
<th>TGC</th>
<th>Survival %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan-Feb</td>
<td>9.1</td>
<td>0.84</td>
<td>10,497</td>
<td>525</td>
<td>0.68</td>
<td>2.01</td>
<td>0.55</td>
<td>78.7</td>
</tr>
<tr>
<td>Mar</td>
<td>20.6</td>
<td>0.90</td>
<td>9,805</td>
<td>490</td>
<td>0.75</td>
<td>2.04</td>
<td>0.59</td>
<td>79.5</td>
</tr>
<tr>
<td>Apr</td>
<td>29.7</td>
<td>0.93</td>
<td>9,323</td>
<td>465</td>
<td>0.77</td>
<td>2.07</td>
<td>0.60</td>
<td>83.0</td>
</tr>
<tr>
<td>May</td>
<td>14.3</td>
<td>0.91</td>
<td>9,628</td>
<td>480</td>
<td>0.80</td>
<td>2.07</td>
<td>0.57</td>
<td>73.6</td>
</tr>
<tr>
<td>Jun</td>
<td>18.2</td>
<td>0.91</td>
<td>9,398</td>
<td>470</td>
<td>0.83</td>
<td>2.00</td>
<td>0.51</td>
<td>77.5</td>
</tr>
<tr>
<td>Jul</td>
<td>8.1</td>
<td>0.94</td>
<td>9,272</td>
<td>464</td>
<td>0.83</td>
<td>1.90</td>
<td>0.59</td>
<td>77.1</td>
</tr>
</tbody>
</table>

Based on the month that each batch was transferred on the sea, the mean values of batch TE scores and of relevant KPI’s are presented on Table 4. Batches introduced in the sea in the beginning of the season (January – February) tend to under perform in terms of TE score. The same results also hold for some of the KPI's, that is for Day Degrees, Days, FCR and TGC. Survival is inherently introduced in the DEA estimation as we account for survival in the output variable. Nevertheless, we expect that an explicit inclusion of survival in the outputs might better account for the costs of the juveniles. This hypothesis is not tested in the current application.

3.1 Parameters affecting efficiency

Parameters like mean weight at stocking, the month that the batches were stocked and the area that the fish grew up were examined as possible parameters that could affect batches technical efficiency. Due to the low number of batches examined, batches were grouped in three areas. The first one incorporates all farms located at or close to the Ionian sea, the second incorporates all the farms located at the Evia Island and the third, the reference level, incorporates all the farms located at Eastern Aegean Sea. Based on the stocking period batches were divided in two stocking periods the “cold” period from January to April and the “warm” period starting from May and ending at July. In the two stage procedure followed to determine factors influencing TE both Ordinary Least Square (OLS) and tobit estimators were presented. Table 5 presents the estimates of the coefficients of factors expected to influence technical efficiency. Both tools are in agreement about the parameters that influence technical efficiency. Mean weight at stocking and the area that the fish are growing up affects significantly technical efficiency. In contrast, the period that the fish are transferred to the sea, does not seem to impact the technical efficiency.
Table 5. Second stage DEA for parameters affecting TE

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Ordinary Least Square</th>
<th>Tobit regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Marginal effect (st. error)</td>
<td>Sig.</td>
</tr>
<tr>
<td>Constant</td>
<td>0.879 (0.043)</td>
<td>***</td>
</tr>
<tr>
<td>Mean stocking weight</td>
<td>0.008 (0.003)</td>
<td>**</td>
</tr>
<tr>
<td>Hot Season</td>
<td>-0.010 (0.022)</td>
<td>n/s</td>
</tr>
<tr>
<td>Farm location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionian Sea</td>
<td>0.001 (0.025)</td>
<td>***</td>
</tr>
<tr>
<td>Evia Island</td>
<td>-0.066 (0.025)</td>
<td>**</td>
</tr>
</tbody>
</table>

***Significant at 1%; **Significant at 5%; *Significant at 10%; n/s non significant

4 Discussion

In this paper, we employ VRS DEA to benchmark sea bream batches using technical efficiency scores based on two inputs, namely feed consumed in kilogrammes and degree days. The overall growth of each batch is considered as output. TE scores are presented along with traditional KPI's where it is evident that VRS DEA performs as expected, and efficiently accounts for the traditional KPI's. The fact fish farms examined are operating under the same overall management explain the high average Technical Efficiency value. Even in this case there is a variation in the performance of different batches and different areas. These variations expected to be bigger if batches under different management will be examined.

Factors affecting efficiency may be also identified using second stage DEA. Nevertheless, in the current application, sample size restrictions did not allow the identification of all factors expected to affect efficiency. Average weight at stocking and the areas that the farms are located, affect technical efficiency. In contrary, there are not enough evidence that batches stocked in the warm or the cold period of the year present different efficiency. Based on our results we conclude that DEA is a useful method in order to benchmark batches thus aiding managerial decisions.

5 References


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