Estimating Technical Efficiency of Wetland Measures to Reduce the Run-Off of Nutrients: Applying a Nonparametric Frontier Model

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1. Introduction

Constructed wetlands are used as one measure among others to reduce the run-off of nutrients (nitrogen and phosphorous) at low costs (Gren 1993; D'Angelo and Reddy, 1994; Gren, 1995). However, nutrient reduction varies substantially among different types of wetlands and climate conditions (Jansson et al., 1994; Leornardson 1994). Furthermore, the cost of creating a wetland depends on the constructing strategy.

The objective of this paper is to evaluate the cost efficiency of implemented wetland projects. An important contribution of our study compared to previous studies is that we focus on the heterogeneity in our sample instead of average cost and average reduction possibility. Hence, while previous studies have attributed deviations from the average cost as noise in the econometric estimation, we use a linear programming approach where the difference is interpreted in terms of (in)efficiency. This approach is ideal for evaluating performance, as it uses the best performing projects as a benchmark in comparison to the others in order to seek for future improvements.

In this paper, we evaluate past efforts utilizing data from the Swedish Local Investment Program *(LIP)*. Utilizing the LIP data, we evaluate the creation of wetlands to reduce the run-off of nitrogen and phosphorous using the non-parametric frontier technique known as Data Envelopment Analysis *(DEA)*. The idea of looking at production efficiency was originally suggested by Farrell (1957). The method facilitates a comparison between the most efficient projects with those that are less efficient. More specifically, considering reduction of nitrogen and phosphorus as two outputs, we estimate the production frontier and the corresponding distance between the efficient and the inefficient projects. We then test if some of the efficiency can be explained by differences between wetlands in connection to; agricultural land, waste water pipes or rainwater pipes. Finally, using the results from the linear programming model, we test if there is a relationship between the level of financial support that the different project perceived and cost efficiency, applying a nonparametric regression method (Lowess).

As far as the authors know, there are no other studies that have treated nitrogen and phosphorus reduction as two separate outputs in a multiple output framework using DEA to estimate the production frontier of wetland measures. Point estimates of wetland costs to reduce nutrients are frequently used as basic input in cost-efficiency models. By estimating the production frontier and the corresponding distance function this study focus on how the utilized wetland projects differ in efficiency.

2. Method

The idea of estimating production efficiency scores in a nonparametric framework using linear programming was developed by Charnes, Cooper and Rhodes (1978). By comparing the use of output and input among the decision making units (DMUs) in the sample at hand, the best practice among DMUs are set to define the efficient frontier as a piecewise linear function.

The efficiency of each DMU is then calculated by comparing output and input uses with DMUs on the efficient frontier. That is, relative efficiency of each DMU is determined as its relative position to the efficient frontier. Units on the frontier are assigned an efficiency score of one, and units inside the frontier score smaller than one[1].

From the observed inputs and outputs, DEA calculate relative efficiency for each DMU by taking the ratio of total weighted input to the total weighted output (reverse if input oriented perspective). The weights are chosen from a mathematical programming model to show each DMU in its most favorable light (relative to the efficient frontier).

One of the limitations in Charnes, Cooper and Rhodes (1978) was an assumption of constant return to scale. Allowing variable return to scale opens the possibility that scale of production could affect efficiency. In this analysis, the less restrictive assumption of variable return to scale is made.

3. Data Description

In Sweden, different initiatives have been taken in order to stimulate wetland construction that aims to reduce the detrimental effects of eutrophication. One of them is The Swedish Local Investment Program (LIP) initiated in 1997. Its overall goal is to "promote an environmental sustainable society". This is done, for example, by providing subsidies to municipalities for various measures aiming to reduce the load of nitrogen and phosphorus to the Baltic Sea. One of the measures that the LIP provides financial support for is the creation of wetlands. This study focuses on those projects that have been approved financial support by LIP, for the construction of wetlands[2].

The available data set contains information about type of project, expected reduction of nitrogen and phosphorus, total investment cost and amount of subsidy received. After cleaning for missing and inconsistent data, the total number of observations is 47. Three different types of wetlands are distinguished in the data set: i) wetlands in connection to agricultural land and other wetlands (28 observations); ii) wetlands in connection to rainwater pipes (11 observations) and iii) wetlands in connection to waste water pipes (8 observations).

Two outputs are considered when calculating the DEA efficiency scores. These are expected reduction in nitrogen and expected reduction in phosphorous. Total investment cost is used as a single input variable. Descriptive statistics for the whole sample as well as stratified for the three different groups of wetlands, shows large heterogeneity concerning annual investments costs per kg nitrogen and phosphorous both within and among the different groups of wetlands. The average annual investments costs per kg nitrogen reduction is lowest for the group "wetlands in connection to agricultural land and other wetlands" and highest for the group "wetlands in connection to waste water lines". Also in the case of phosphorus, average annual investments costs are lowest for the group "wetlands in connection to agricultural land and other wetlands", but in this case the group "wetlands in connection to rainwater pipes" displays the highest average annual investments costs.

The average investment cost per kg nitrogen reduction is for the whole sample SEK 401 kg^{-1} $year^{-1}$ (46 USD kg^{-1} $year^{-1}$). Compared to other studies (e.g. the results by Söderqvist 2002, USD 1.35-2.15 kg^{-1} $year^{-1}$), this is a substantially higher cost. The discrepancy may partly be explained by the fact that Söderqvist (2002) assumes a reduction of nitrogen per hectare wetland corresponding to 1000 kg-N ha^{-1} $year^{-1}$. Needless to say, using a rule of thumb ignores the fact that different wetlands can be more or less efficient in reducing the nutrients and thereby ignores heterogeneity among different wetland projects. The average reduction of nitrogen per hectare for the observations in our data set is 572[3] kg

[1] An alternative approach to DEA is Stochastic Frontier Analysis (SFA) developed by Aigner et. al (1977) and Meeusen & van den Broeck (1977). The advantage of SFA relative to DEA is that it accounts for stochastic noise in the data. Disadvantages are that a functional form of the production function has to be specified together with a distributional assumption for the inefficiency term.

[2] Unfortunately, there is no data available on the projects that did not get approved.

[3] Only 26 observations out of 47 in our data contain information about the size of wetlands. The calculations therefore is not for the whole sample but only based on these 26 observations. This is similar for all calculations depending upon hectare wetlands.

ha^{-1}. Hence, wetlands in our sample are in average only half as efficient as assumed by Söderqvist (2002). Byström (1998) also estimated the costs of reducing nitrogen by construction of wetlands. Here an abatement cost function for wetlands is defined by linking a function for construction cost of wetlands with a function that defines the nitrogen abatement capacity of wetlands. Although being more sophisticated, the study only considers two relevant aspects in explaining the cost of wetlands to reduce nitrogen. In accordance with the mentioned study by Söderqvist, it takes a one-sided focus on the average cost of wetlands with respect to size and nitrogen load, thus ignoring that different wetlands can be more or less efficient in reducing nutrients.

4. Results

Output related efficiency scores for each of the different wetland projects were calculated. Note that as input is aggregated as total costs, allocative efficiency and technical efficiency will be confounded in the overall efficiency measure. Using an output oriented perspective, we seek to increase the outputs for the DMU being evaluated while keeping the amount of input constant.

FEAR software package (Wilson, 2007) was used when computing the efficiency scores. Table 1 displays the average efficiency scores for different sub-samples. When interpreting these results, it should be kept in mind that the reference technology (frontier) is constructed from all of the observed input and output combinations in the sample. Also bias corrected efficiency scores as well as average lower and upper limits of a 95-% confidence interval (CI) are shown. The bootstrap method[4] suggested by Simar & Wilson (1998, 2000) is used to analyse the sensitivity of the measured efficiency scores relative to the sampling variations of the estimated frontier.

Table 1 Technical efficiency scores and 95 percent confidence intervals.

		VRS assumed	
Sample and subsamples	Average output efficiency score	Average bias-corrected output efficiency score	Average lower and upper 95% CI
Sample: All Wetlands	0.264	0.198	0.164 - 0.250
Sub sample 1: Wetlands in connection to waste water lines	0.212	0.169	0.138 - 0.206
Sub sample 2: Wetlands in connection to rainwater pipes	0.114	0.0891	0.0727 -0.110
Subsample 3: Wetlands in connection to agricultural land and other wetlands	0.338	0.250	0.208 - 0.318

The average output efficiency in the sample is 26.4 per cent. This means that an additional amount of 285[5] per cent of the total discharge could, on average, be reduced without increased cost if wetlands as efficient as those in the frontier would have been implemented. If we look at the different sub-samples, we find considerable differences in efficiency. Furthermore, the confidence intervals for the bias-corrected efficiency scores do not overlap between subsamples, indicating significant differences in

[4] The idea is to construct a new pseudo dataset for each DMU in the sample based on re-sampled efficiency scores (by repeatedly simulating the data generating process) and the original inputs, outputs and efficiency scores. The DEA equations are solved again to generate new efficiency scores based on the pseudo dataset and the procedure is repeated many times.

[5] Hence, $\theta^{-1} = 0.26 \Rightarrow \theta = 3.85$ (=1/0.26) = 385 percent. The 285 percent is when the efficiency of 100 is deducted.

terms of their average technical efficiency. Note that due to the dependence structure of the technical efficiency estimator, we do not calculate critical values or p-values. Moreover, there are reasons to be cautious when interpreting the bias corrected efficiency scores. Hence, it is likely that the data we have is selected, meaning that efficient projects could be included with a higher probability than inefficient projects, which violates the basic assumption of the bootstrap approach.

Highest efficiency is obtained for wetlands likely to be in connection to agricultural land. This was expected due to the clear dominance structure seen from the descriptive statistics. The dominance structure between the two remaining construction strategies is not as straightforward. Reducing nitrogen using wetlands in connection to rainwater pipes are much cheaper per unit nitrogen reduced than if the wetland was in connection to waste water pipes. On the other hand, wetlands in connection to waste water pipes are more than twice as effective in reducing phosphorous than wetlands in connection to rainwater pipes. The results show that wetlands in connection to waste water pipes are more efficient than wetlands in connection to rainwater pipes.

Finally, we look at the relationship between the level of financial support that the different projects perceived and their corresponding cost efficiency, using Lowess, a non-parametric locally weighted regression approach (Cleveland, 1974). Scatter plots of the Lowess regression curve and the obtained efficiency scores shows, that wetland efficiency regarding reduction of nutrients, have not been the criteria for distribution of subsidies or at least not the only one. Other criteria may include the extent of improved biodiversity or some political decision.

5. Conclusions

The purpose of this study has been to evaluate the efforts to reduce the run-off of total discharge (nitrogen and phosphorus) using Data Envelopment Analysis *(DEA)*. Treating reduction of nitrogen and phosphorus as two separate outputs in a multiple output framework, the production frontier and the corresponding distance between the efficient and the inefficient projects were estimated. As far as the authors know, there are no other studies that utilize nitrogen and phosphorus reduction in a multiple output framework.

The data used in the empirical application is obtained from the Swedish Local Investment Program *(LIP)*. The data contains, for example, information about type of project, expected reduction of nitrogen and phosphorus and total investment cost.

Our results suggest that an additional amount of 285 per cent of nitrogen and phosphorus could, on average, be reduced without absorbing further resources given that wetlands as efficient as those in the frontier would have been implemented. Hence, there seems to be a substantial difference in cost efficiency for the different projects in our sample. Furthermore, the results suggest that wetlands in connection to agricultural land are most efficient in reducing the run-off of nutrients compared to wetlands in connection to waste water pipes and rainwater pipes. Finally, our result shows no significant relationship between the level of financial support that the different project perceives and the level of cost efficiency. Hence, there seems to be potential for future improvement here.

There are important and difficult areas for future research. Our result indicates that there is a substantial heterogeneity in efficiency between different wetland projects implemented in Sweden. However, because of limited data we are only able to explain part of this heterogeneity with observable differences. Identifying additional determinants would be interesting as well as policy relevant for future implementation of wetland measures.

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