Applying Data Envelopment Analysis Methodology to Site-specific Precision Agriculture Data

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Abstract
Data envelopment analysis (DEA) has been applied to agricultural decision making units (DMU) such as individual farmers, groups of farmers, or other firms. Rather than firms as the DMU, each sub-field region within a farmer's field can be evaluated as the DMU such that the efficiency of different management practices are evaluated. A hypothetical grid superimposed upon a field creates the DMU's so that scale efficiency can be visually assessed in a map. Input variables include as-applied maps of inputs, geospatial data on soil characteristics, and remotely sensed imagery. Output variables are based upon yield monitor sensors from harvest equipment from one or more years and therefore one or more crops grown in rotation. Both bio-physical agronomic relationships and economic characteristics are evaluated. Based on our novel technique for evaluating geo-referenced technical efficiency scores, tests for global and local spatial autocorrelation indicate presence of spatial effects; thereby providing insights into natural versus man-made variability.

Keywords: data envelopment analysis, technical efficiency, precision agriculture, variable rate
JEL Codes: Q10, Q15

Introduction

The inspiration of this project stems from many a farmer's desire to be able to evaluate as-applied field data to make true economic decisions. There are a number of underlying issues which exist that make an analysis such as this difficult to standardize for analyses across multiple years. The nature of the industry, and the pricing structures with constant ebbs and flows make some years stand out from a profitability standpoint, while others do not. Upon considering this constant instability, it became clear that an economic analysis of a farm's true performance could not be fairly measured by the cash flow of the operation, but must also be able to stand alone in the event multiple years of data do not exist.

The interest in being able to evaluate the success and failure of an operation reaches far beyond profitability and production. As the industry continues to place an increasing emphasis on the efficiencies of inputs to produce output, as well as to provide transparency in their production, the concept has become more defined as to what the industry is seeking as a mechanism of determining performance. The interest of growers to be able to utilize on-farm data collected by implements, yield monitors, and sensors to make decisions has driven this research to reach beyond the whole-farm level, down to one which is much more spatial and intra-field based. In the past, growers would evaluate the economics of a field by using basic accounting methods. When a grower would make a seed purchase, for example, typically the entire purchase would be divided by the number of acres which that product covered and then compared to the ending yield of the field in which it was planted. While considered a much more specific answer to the question of profitability than evaluating the entire operation, the question still exists as to where the product performed the best spatially within the area.

Today, harvesters are capable of collecting data which growers can use to truly determine where their crops statistically performed their best. There are, of course, limitations to the analysis which can be conducted, and without multiple years of data, the quantity and quality of the analysis becomes increasingly correlated to the number of observations. Up until a few years ago, the analysis of the operation was contained to output only, but in that time, inputs began being applied at varying rates. The success/failure of the year's decisions was tied to the uniformity of the field as read by the yield map, but there has become an increasing demand to determine whether this uniformity truly equals profitability.

A few companies have released products defined as "profit maps." Conceptually, these maps utilize the yield data to determine the location of output, and then use accounting to break out the purchases and sales of the crop to define where the grower is making or losing money. These maps provide a terrific value when it comes to visually defining areas which are costing the grower the most money, but they do little in terms of making economic decisions and truly defining profitability. For this type of analysis to take place, the variability and the bias held by the prices of the inputs and commodities make it difficult to pin down whether the farm's profitability was truly tied to the performance of the field or to the pricing structure of the farm manager.

To get away from using accounting as a measure of performance, there came the need to determine a new means of breaking down the field so that it could be analysed using economics. First, there was a need to define exactly what is trying to be determined. Was it profitability?

The initial thought was yes, but was determined to be heavily tied to the accounting practices of the farm. In the end, the true analysis desired to be conducted was that of efficiency. There are a number of means to measure this - cost efficiency, technical efficiency, allocative efficiency, economic efficiency (the list goes on and on), but the limitation of data available, and the result anticipated reflects the type of efficiency measured here.

Technical efficiency was the chosen economic theory for this project because of its lack of being affected by pricing decisions, was not dependent upon variables which the machinery could not automatically collect data for, and could be visually presented in a spatial form similar to a yield map. The concept of collecting all input data (planting, spraying, fertilizing) and then comparing those results to the output (yield) to determine the technical efficiency fit all of the limitations which growers are held to, but enables them the capability to make performance determinations based upon price versus output.

Background

Data and Methods

Rather than apply DEA techniques to farm firms as DMs, similar techniques treat DMUs as sub-field areas within a field. A grid was superimposed upon a field in a manner similar to Figure 5.11 with the results of the scale efficiency study and DEA generating a visual analysis of technical efficiency on a by-acre basis. This will be conducted using as-applied maps of products not applied at a base uniform rate as a means of determining input and yield maps as a means of determining output. The thought being that multiple agronomic layers could be laid upon this diagram to determine the economic results of applying products or making decisions for future applications of inputs. Given the geo-referenced technical efficiency scores, tests for spatial autocorrelation can determine whether productivity remains spatially clustered thereby providing insights into natural or man-made variability. Spatial autocorrelation indicates how similar the values of a variable are with respect to distance.

A 100 by 100 foot grid was superimposed over the field. The 100 foot grid cell was chosen based on the layer of interest, fertilizer application, having a 100 foot swath width. Using the filtered yield data layer, a dissolved buffer was applied to define an area of influence. Given the 31 foot harvester swath, the buffer was set to an arbitrary 10% greater than the harvester swath width to be 17 feet (31*0.5 * 1.1). The dissolved buffer removes buffer overlaps such that the final layer is a single polygon rather than a layer of independent buffered regions. Using the buffered area around yield data layer prevents regions outside the area of interest from being considered during the analysis; areas such as end rows, waterways, and terraces are not desirable since no crop production occurred.

Results

Summary

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [month/day/year].