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Decision Support

A hybrid genetic algorithm for multiobjective problems with activity analysis-based local search ☆

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Abstract

The objective of this research was the development of a method that integrated an activity analysis model of profits from production with a biophysical model, and included the capacity for optimization over multiple objectives. We specified a hybrid genetic algorithm using activity analysis as a local search method, and NSGA-II for calculation of the multiple objective Pareto optimal set. We describe a parallel computing approach to computation of the genetic algorithm, and apply the algorithm to evaluation of an input tax to regulate pollution from agricultural production.
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Keywords: Activity analysis; Data envelopment analysis; Genetic algorithms; Multiple criteria analysis; Parallel computing

1. Introduction

The Conservation Effects Assessment Project (CEAP) at the Agriculture Research Service, United States Department of Agriculture, has the objective of producing a national assessment of environmental benefits of conservation programs to support policy decision and program implementation[1]. As part of the CEAP economics team, we were charged with the development of a method that integrated an economic model of agricultural production with a biophysical model. Further, the method had requirements to optimize over multiple objectives to show the trade-offs among alternative conservation practices. We chose a model derived from an activity analysis model proposed by Shephard (1970). In this study, we differentiate activity analysis and data envelopment analysis (DEA). Data envelopment analysis (Charnes et al., 1978; Cooper et al., 2004) is generally considered to be an approach to for evaluation of the performance of a set of decision-making units (DMU) by the calculation of efficiency and related measures. Färe and Grosskopf (2002) point out that the DEA approach of Charnes et al. (1978) coincides with Shephard's (1970) activity analysis output price model. Much of literature that we reference concerns DEA, but is identically applicable to activity analysis. We note that where an activity analysis model is used to specify an objective in this study, a DEA model could be used in exactly the same way if the objective concerned the classic DEA results, such as efficiency. Our interest here is to calculate the maximum profit possible for each DMU. We use an activity analysis model that establishes the production possibility frontier by constraining input/output combinations to lie within a production possibility set defined by

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[1] http://www.nrcs.usda.gov/technical/nri/ceap/index.html, http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=407655.

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experimental observation. Variations of the activity analysis model have been usefully applied to agricultural production in several studies, and have also been integrated with the biophysical model, soil and water assessment tool (SWAT) (Whittaker et al., 2003).

Fig. 1 illustrates the requirements of the CEAP project. First, consider the calculation of the trade-offs between two objectives, maximization of farm profit and minimization of surface water pollution resulting from farm production, where a "green" tax is imposed on fertilizer (Fig. 1a). The first objective is specified by an activity analysis model that calculates maximum farm profit, constrained by fertilizer taxation. The second objective is specified by using the optimal inputs and outputs chosen by the profit maximizing activity analysis model to drive a physical model that calculates the chemical pollution from farm production.

The CEAP objectives also require the use of multiple activity analysis models to calculate the trade-offs among objectives. In Fig. 1b, two different activity analysis models are used to specify the objectives of profit maximization

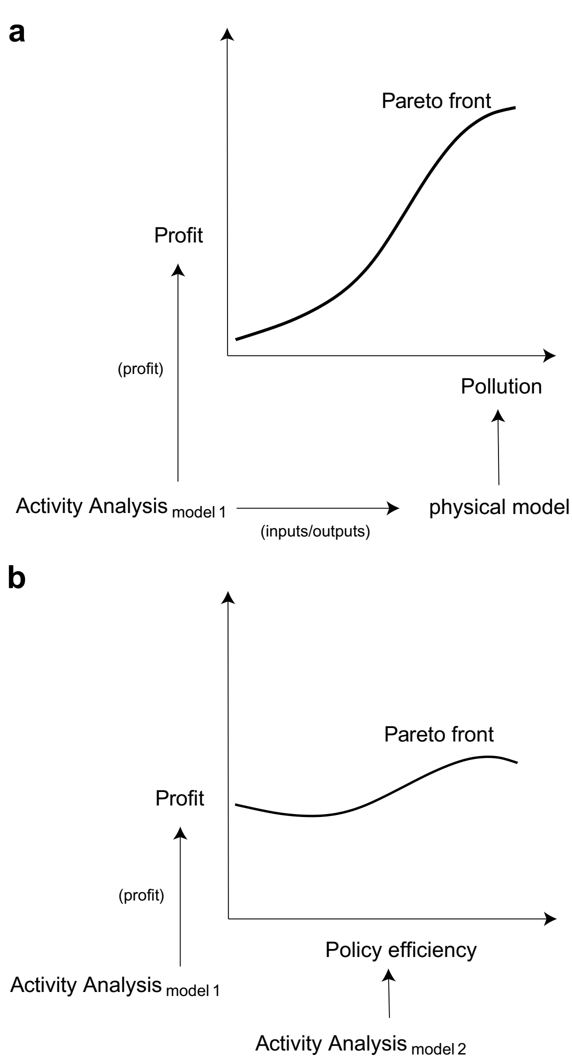

Fig. 1. Requirements for the CEAP project.

and policy efficiency, where policy efficiency is defined in the context of CEAP as the expenditure on conservation programs per unit increase in environmental quality. Activity Analysis$_{\text{model 1}}$ calculates inputs and outputs to maximize farm level profit and Activity Analysis$_{\text{model 2}}$ optimizes industry wide (see for example, Brännlund et al. (1998). The Pareto frontiers represented in Fig. 1 can be easily calculated a single point at a time by applying a series of weights to the objectives. However, the CEAP program requires the calculation of the Pareto frontier for all objectives at once; a surface in four dimensional space (farm level profit, environmental quality, program efficiency, and location within the watershed). Calculation of a Pareto optimal surface in four dimensional space, one point at time, is not practical without an algorithm to direct the search. A more formal statement of the problem described above follows.

A multi-objective optimization problem (MOOP) is generally understood to contain a number of objective functions that are to be minimized. Following Deb (2001), the general form of a MOOP is

$$\begin{array}{lll} \text{Minimize/Maximize} & f_m(x), & m = 1,2,\dots,M, \\ \text{subject to} & g_j(x) \geqslant 0, & j = 1,2,\dots,J, \\ & h_k(x) = 0, & k = 1,2,\dots,K, \\ & x_i^L \leqslant x_i \leqslant x_j^U & i = 1,2,\dots,n. \end{array} \tag{1}$$

The MOOP consists of M objective functions, with J inequality constraints and K equality constraints. A solution x is a vector of n decision variables that are constrained by lower x_i^L and upper x_i^U boundaries. This formulation of a MOOP strongly resembles both activity analysis and data envelopment model specifications. Some researchers have pointed out that DEA itself is a multiple criteria decision analysis (MCDA) method, where multiple inputs and outputs function as multiple criteria (Jahanshahloo and Foroughi, 2005; Korhonen and Syrjänen, 2004; Li and Reeves, 1999). Others have noted common elements in DEA and multiple criteria analysis methods, and have combined the two approaches in identifying the most efficient firms (Belton, 1992; Belton and Stewart, 1999; Belton and Vickers, 1993; Joro et al., 1998).The application that motivates the research presented here requires a more general interpretation of (1). The CEAP project plan requires that several objective functions $f_m(x)$ can be specified by a separate activity analysis model for each m, e.g. profit maximization at the firm level for $m = 1$ and permit trading at the watershed level for $m = 2$. It is additionally required that other objective functions $f_m(x)$ are defined by an altogether different specification that can include hydrologic and agronomic models.

The simplest way to calculate a MOOP with activity analysis specification of multiple objectives is to convert the problem into a single objective by using a weighting