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A decision support methodology for increasing public investment efficiency in Brazilian agrarian reform

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Abstract

The Brazilian Agrarian Reform Program has subsidized the settlement of over 425,000 destitute families on previously unproductive land in what has become a very effective vehicle for social inclusion and productivity growth for those settlers who reach the final stage of the process and receive definitive title to the land. Unfortunately, there is a large difference in efficiency and productivity between more and less successful settlements – fewer than 10% of relocated families have received title and over 25% of them have abandoned the property to which they were assigned. This paper presents a decision support methodology for increasing the efficiency of public investments in agrarian reform that includes a data envelopment analysis model and a mechanism for building consensus among the various constituencies of the agrarian reform process, who not infrequently have conflicting objectives. The OR model described herein uses principal component analysis and data envelopment analysis to identify the most important success factors for relocated families leading to an increase in the chance of both autonomous integration with the market economy and definitive entitlement by these displaced families as well as an increase in the predictability of future settlement success. The model was implemented successfully in Rio Grande do Sul, the southernmost state of Brazil, and was partially used in a pilot project for the countrywide agrarian reform accelerated consolidation program.

Keywords: agrarian reform; agriculture efficiency; DEA; decision support systems

1. Introduction

Agrarian reform, here defined as the purchase of unproductive land by the government and the subsequent distribution of that land through subsidized resale to eligible low-income families, is a policy instrument that has been used in developing countries with varying degrees of success. Not

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only is agrarian reform meant to be an effective tool for wealth redistribution and social inclusion, but also, at its best, it provides a mechanism for increasing land productivity and for stimulating economic development when executed on previously underutilized land. The success rates of various agrarian reform programs in developing countries around the world, however, have been varied.

In Brazil results have been mixed. On the one hand, there has been a marked improvement not only in productivity, but also in quality of life and social inclusion of resettled families that have reached the last milestone in the agrarian reform process, known as definitive entitlement. As described in Section 3 below, definitive entitlement occurs when the property deed (title to the land) is issued to the resettled family after it has reached a target level of independent, self-sustained economic activity and integration into the market economy. On the other hand, the Brazilian agrarian reform program historically has not achieved the initially expected results when measured by the number of newly settled families that have reached definitive entitlement (a metric that is sometimes not accepted by all stakeholders as a measure of agrarian reform success).

Subsidized public investments in the Brazilian agrarian reform program, including funding for land purchases for subsequent distribution, agricultural credit lines, and investments in infrastructure, totaled almost US\$5 billion between 1979 and 1997, or an average of over US\$250 million per year (Gasques et al., 1998). During the same period over 425 thousand families were relocated to new settlements for an average public investment of slightly over US\$11 thousand per relocated family, with large regional variation (INCRA, 2000). Unfortunately, less than 10% of these relocated families had obtained definitive entitlement by 2004, and a great percentage of those who had reached that milestone did so with significant delay. Furthermore it is estimated that over 25% of all relocated families had abandoned their new settlements (INCRA, 2001). On the other hand, the success of the families that concluded the consolidation phase fulfilling conditions for definitive entitlement has been well publicized and thus has given considerable hope to those destitute families who are candidates for future participation. In 2002 over 800 thousand families were formally waitlisted in the Brazilian agrarian reform program (INCRA, 2002), 200 thousand of which had spent the previous several years literally camping near various tracts of land that were candidates for reform. Members of settlements reaching entitlement report significant social and economic benefits, with improved levels of productivity, a substantially higher standard of living, and better social inclusion than before relocation. Moreover, because amortization of the reform-related subsidized government loans begins once relocated families obtain definitive entitlement, reaching that milestone in a timely manner also helps establish a self-sustaining virtuous cycle whereby subsequent rounds of relocation are more easily subsidized. Consequently, the challenge currently facing the Brazilian agrarian reform program is that of raising the number of families who obtain definitive entitlement within the desired 5-year timeframe.

This paper describes a methodology that was partially used by the Brazilian Agrarian Reform Agency to identify the most important success factors in the agrarian reform settlement process in a given region. The objective of this methodology's application was to increase the predictability of success of future settlements and to increase the incidence of consolidation, integration with the market economy, and definitive entitlement of settler families. The methodology was implemented successfully in the southern state of Rio Grande do Sul (Melgarejo, 2000) and was partially used in a pilot project for the accelerated consolidation program (Programa de Consolidação e

Emancipação de Assentamentos Resultantes da Reforma Agrária – PAC) of the Brazilian Department of Agrarian Development. The methodology applies data envelopment analysis (DEA) techniques to measure settlement efficiency and to modify each settlement's *modus operandi* in an effort to shorten the length of time to achieve self-sufficiency.

The rest of the paper is organized as follows. Section 2 briefly describes the Brazilian agricultural sector and provides the context within which agrarian reform has been used as a policy instrument for wealth and income distribution as well as sustainable economic development. Section 3 describes the Brazilian agrarian reform program in detail and suggests some reasons for the proliferation of inefficient settlements. Section 4 offers a brief literature review of the DEA methodology including its use in rural applications and a description of different techniques for identifying the appropriate input and output variables. Section 5 describes the above mentioned decision-support methodology. Section 6 describes the application of this methodology in southern Brazil, including a description of the region, the characteristics of the settlements, and the various input and output variables used. Section 6 also presents results of this Rio Grande do Sul case study. The last section offers concluding remarks and comments on the methodology's possible role as an agrarian reform decision-support tool for the Brazilian government.

2. The context

Brazil is a developing country with over 180 million inhabitants and a 2003 GDP of US$500 billion. The average annual economic growth rate between 1991 and 2003 was 1.6%, with the agricultural output far surpassing that rate – agribusiness exports grew at an annual rate of almost 8% during the period. In 2003, 42% of all Brazilian exports were either agricultural or industrialized agricultural products and the country was the world's largest exporter of sugar, coffee, soy products, orange juice concentrate, and poultry. The sector's productive efficiency is based on state-of-the-art managerial capabilities as well as advanced technology. Embrapa (the Brazilian federal agribusiness research center) has played a major role in the sector's productivity growth – two high-profile examples of Embrapa's contribution are the doubling of the Brazilian grain production over the past 15 years (planted area grew by only 20% during this same period) and the successful development of agribusiness alternatives for the 200 million hectares of the relatively acidic soil of the "cerrado" region in the Brazilian Center-West.

At the same time, Brazil has very unequal income and wealth distribution. An estimate for Brazil's Gini index for distribution of family income is 0.607, the third highest inequality rate in a list of 110 countries (US Government World Fact Book, 2003). In rural areas of the country such inequality is even more pronounced – Brazil's Gini index for distribution of agricultural land assets is over 0.8 – for example, 0.8% of all registered rural properties have area above 2000 hectares and correspond to 31.6% of the total area of these properties (INCRA, 2002). Furthermore, according to the 2000 census, over five million rural families have total family income under US$180 per month, whereas there were over 16 million hectares of productive agricultural land that were not being utilized. The existence of large numbers of destitute rural individuals helps explain the widespread migration to large cities in recent decades. Partly as a result of this massive influx, over 80% of the Brazilian population now lives in cities of more than 20,000 people and Brazilian cities have been increasingly crippled. For example, largely due to this "rural exodus", the population of the metropolitan area of the city of São Paulo, which was under two million people in 1940, mushroomed to over 18 million in 2000 (it is now the third largest city in the world and has a long list of overpopulation-related problems).

For these reasons, income- and wealth-balancing policies that help diminish inequalities while at the same time raising productivity are very desirable. One type of such policy is agrarian reform, herein defined as a set of policies that permit the purchase of unproductive arable land by the government, its distribution to eligible very-low-income families who are committed to settling on this land, and the government support of these relocated families through various mechanisms (e.g., credit, infrastructure, health, and education programs) until they are able to refund the government for the investment made. An efficient agrarian reform program is expected to contribute to higher degree of social justice by creating opportunities for relocated families. It is also expected to contribute to the greater social good by decreasing the likelihood that these families will abandon their land and move to already over-crowded cities currently riddled with widespread unemployment and other social problems. Furthermore, Shiki et al. (1998) examined 78 rural settlements created between 1986 and 1994, and found that the cost of creating a job through agrarian reform in Brazil was at least six times lower during that period than the cost of creating a job in the manufacturing sector. Lastly, an important component of this politically controversial undertaking is the long-term level of efficiency and productivity of the resulting land settlements – the majority of settlements concluding the consolidation phase have outperformed traditional agricultural properties in the same municipalities (Leite et al., 2004).

3. Agrarian reform in Brazil

3.1. The process

The agrarian reform process in Brazil is coordinated by the Federal Government's Department of Agrarian Development (Ministério do Desenvolvimento Agrário) through the Brazilian Agrarian Reform Agency (Instituto Nacional de Colonização e Reforma Agrária – INCRA). This is the institution that manages the agrarian reform process in Brazil and is responsible for the vast majority of settlements (state government agencies are responsible for the remainder). INCRA manages registries of productive and unproductive arable properties that are potential candidates for government purchase and subsequent land distribution as well as lists of families and individuals that are willing to relocate to new agrarian reform settlements. There are four distinct phases in the agrarian reform process in Brazil.

First phase: settlement creation. The federal government purchases tracts of land that have been selected for future redistribution and settlement. Occasionally state governments also make the purchases and there have been many instances in which land already owned by the government – public land – has been redistributed. Simultaneously a primarily need-based selection process identifies the families that will settle on each such tract of land – once this matching process has been completed a settlement is formally created. In this first phase of the agrarian reform process there generally is substantial federal investment primarily through land purchases.

Second phase: settlement installation. The installation of a settlement involves relocation and installation of the families that will comprise the settlement project, forming a rural community.

The number of families in a settlement can vary from 10 to 1500 depending primarily on the size of the property. These families relocate to live on previously undeveloped land.

During this phase – which, like the first, is expected to last 6 months to 1 year – the government plays a pivotal part. It is INCRA's role to provide startup financial support to the families through specific credit lines for relocation, house construction, and agricultural development and also offer various forms of technical support to help the community in its inception. These include infrastructure investments, social programs such as support for education and health care, and the definition of initial production targets as well as a medium-term settlement development plan.

Third phase: settlement consolidation. During the consolidation phase, which usually lasts several years, the community is expected to approach economic self-sufficiency. Government support through infrastructure investments, special agriculture credit lines, and continuous technical support, is expected to decrease steadily over time. This phase is known to be the bottleneck in the process in that most settlements that have reached the fourth phase have taken much longer than the envisioned period of 5 years to do so. The federal government is now spearheading the accelerated consolidation program (PAC) with the objective of reducing the standard length of the consolidation phase to 3 years. It is expected that this acceleration will be achieved by replicating practices observed in various highly efficient settlements where consolidation occurred more quickly. Settlements remain under government tutelage during the first three phases until the community becomes self-sustaining and can be completely integrated into the market economy.

Fourth phase: definitive entitlement. The fourth and final phase of the agrarian reform process occurs when definitive entitlement takes place. At this point individual families receive definitive title to the land and ownership of tractors and other agricultural equipment. From here on the settlement does not receive any further preferential treatment or support from the government. From the relocated families' perspective, this milestone is filled with symbolic and practical meaning. Once it achieves definitive entitlement, each family takes full possession of the plot of land and assumes responsibility for partially repaying the government for the various subsidized loans that made the relocation possible.

3.2. The main constituencies involved in agrarian reform in Brazil

There are three main constituencies that are deeply involved in and also affected by the outcome of agrarian reform in Brazil once settlements have been created.

INCRA. The aforementioned Brazilian agrarian reform agency, INCRA, is responsible for suggesting and implementing policies, executing land purchases, establishing new settlements, and following each settlement through to definitive entitlement. Once a settlement is in its consolidation phase, INCRA's efforts are directed toward the final phase of the process so the families in the settlement can begin to refund the federal government for investments made.

State agricultural agencies. Most states also have a local agricultural agency that gives technical support to new settlements and provides regional-specific knowledge. These state agencies help families use available technology more efficiently in an effort to raise the productivity of their crops.

MST. Finally, the Movimento dos Trabalhadores Rurais Sem-Terra (MST – loosely translatable as "Movement of the Landless Rural Workers") has established itself as the most prominent grass-roots institutional representative of the families that currently have been shortlisted for relocation. The MST movement has evolved into a very structured nationwide organization with a distinctly leftist agenda. The movement is mostly funded by donations and by the waitlisted families themselves and has obtained substantial media visibility through several acts of civil disobedience, including property occupations and land-related conflict that in some instances have resulted in the loss of lives. Although the MST has social objectives beyond obtaining new land for the relocation of waitlisted families such as improving settlement infrastructure, health, and education, the movement has mostly succeeded in compelling the federal government to respond to their requests by stressing the need for more land reform. It is important to note that several other organizations represent waitlisted families. This paper focuses on MST's role because it is the largest and most visible of such organizations.

Each of these three constituencies is important to a settlement's success because each performs a different role in the process towards definitive entitlement. Moreover, each has a different and occasionally conflicting set of objectives. As a result of these conflicting and often very diverse strategies, INCRA, the state entities, and the MST sometimes have different views of what defines success for a particular settlement. Consequently, during the stages of the process leading up to definitive entitlement, there frequently is not full cooperation among these three constituencies. Not surprisingly, one of the findings of the decision support methodology described below is that settlement efficiencies were substantially higher in sub-regions where the three constituencies had similar objectives and cooperated with one another.

4. DEA

4.1. Literature review

In economic theory the most traditional measures of performance are productivity and efficiency. Productivity relates outputs to inputs while efficiency compares performance observed with the best performance possible. Debreu (1951) established the first modern technical efficiency measure – a radial measure which determines the smallest quantity of inputs for a given output level. In his seminal work, Farrell (1957) defined technical efficiency as the ability to produce the largest possible output from a given set of inputs and allocative efficiency (which he referred to as price efficiency) as the ability to combine those inputs in the cost-minimizing proportion given their prices. DEA is a non-parametric method for calculating a best-practice efficiency frontier and evaluating relative efficiencies of similar productive/decision making units (DMUs). Charnes et al. (1978) introduced DEA with a constant-returns-to-scale model, while Banker et al. (1984) presented a variable returns to scale (VRS) model and developed the concept of scale efficiency. There are several measures of efficiency, all defined in a relative sense, i.e., comparing the input–output combination of a specific production unit with the best practice observed production frontier. Cooper et al. (1999) provide a comprehensive introduction to DEA.

Farrell (1957) was the first to use efficiency measures to evaluate agricultural performance. Since its inception, DEA has been used extensively for agriculture sector applications both in developed as well as in developing countries. Recently, Lansik and Reinhard (2004) used DEA to investigate the possibilities for performance improvement in Dutch pig farms and Reig-Martinez and Picazo-Tadeo (2004) used DEA to identify opportunities for efficiency improvement in Spanish citrus farms. Helfand and Levine (2004) use DEA to find a nonlinear relationship between farm size and efficiency in the central region of Brazil, with efficiency first falling and then rising with size of farms, thus supporting the use of VRS models.

DEA appears to be the best technique for identifying the frontier for comparing efficiencies of different agrarian reform settlements because it is non-parametric and can accommodate different types of inputs and outputs, i.e., social parameters can also be included in the analysis both as inputs as well as outputs. The use of DEA techniques in agrarian reform is different from the use of DEA in other agricultural applications because, in agrarian reform, public funds are invested with an important objective beyond productivity improvement: that of social inclusion through the placement of destitute individuals who lack any other opportunity for self-improvement. In other words, agrarian reform can also be viewed as an instrument for providing individuals with job opportunities and for enhancing a region's development. This paper presents an innovation over the aforementioned applications of DEA to agriculture in that it uses DEA to measure the relative efficiencies of rural settlements established through agrarian reform by also incorporating social output variables in the analysis.

4.2. The DEA model

The basic DEA model considers efficiency as the weighted sum of outputs divided by the weighted sum of inputs, without knowledge of the tradeoffs among these factors, which means that, *a priori,* those weights are not known. Each DMU establishes its production plan, i.e., the appropriate output/input weights which should maximize its productivity. For a given DMU o in a set of n production units using similar technologies with r inputs X and s outputs Y, the objective is to determine the set of weights u_i $(i = 1, \ldots, r)$ and v_j $(j = 1, \ldots, s)$ that will maximize the relationship between its weighted outputs and its weighted inputs, subject to the restrictions that for every DMU in the set being analyzed, the weighted sum of its outputs be limited by the weighted sum of its inputs, i.e.,

$$\max_{u,v} e_o = \frac{\sum_{j=1}^{s} u_j Y_{jo}}{\sum_{i=1}^{r} v_i X_{io}} \quad \text{subject to} \quad \frac{\sum_{j=1}^{s} u_j Y_{jm}}{\sum_{i=1}^{r} v_i X_{im}} 1; \; m = 1, \ldots, n. \tag{1}$$

with the usual additional non-negativity constraints for the variables u and v. Without loss of generality, the denominator of the objective function of the fractional program above can be constrained to 1, so that model (1) can be transformed into a linear programming model. This model, referred to in the literature as a constant returns to scale (CRS) input-oriented model, will then be solved for each unit m of the DMU set, where $e_m \leqslant 1$. The DMUs with $e_m = 1$ are operating with production plans on the efficiency frontier, while those DMUs with $e_m < 1$ are operating within the frontier and are therefore inefficient when compared to the former.

Model (1) is called input-oriented because it measures the distance from DMU o's observed production plan to the efficiency frontier calculated by considering the smallest possible consumption of inputs for a given observed output production level. The problem described herein requires an alternative formulation of the basic DEA model described above because the objective is to determine the highest possible production of outputs for a given observed input consumption level. This latter model minimizes the relationship between weighted inputs and weighted outputs in the objective function (it is output-oriented) and therefore provides efficiency measures, which are the inverse of those of model (1). The output-oriented model is presented below in its already linearized form

$$\begin{aligned} &\min_{u,v} \mathrm{e}'_o = \sum_{i=1}^{r} v_i X_{io} \\ \text{subject to: } &\sum_{i=1}^{r} v_i X_{im} - \sum_{j=1}^{s} u_j Y_{jm} \geqslant 0;\ m = 1, \ldots, n, \\ &\sum_{j=1}^{s} u_j Y_{jo} = 1, \quad \text{with}\ u_j \geqslant 0;\ j = 1, \ldots, s \quad \text{and} \quad v_i \geqslant 0;\ i = 1, \ldots, r. \end{aligned} \tag{2}$$

Because in DEA applications the combined number of input resources and output products is smaller than the number of DMU observations, it is computationally preferable to solve the dual of model (2) which is presented below:

$$\begin{aligned} &\max f'_o \\ \text{subject to: } &\sum_{m=1}^{n} \lambda_m X_{im} \leqslant X_{io};\ i = 1, \ldots, r, \\ &\sum_{m=1}^{n} \lambda_m Y_{jm} \geqslant f'_o Y_{jo};\ j = 1, \ldots, s, \quad \text{with}\ \lambda_m \geqslant 0, \end{aligned} \tag{3}$$

in which $f_o{}'$ is unit o's maximum multiplier, which allows for the weighted combination of each unit's performance such that for each input the weighted combination of input quantities does not exceed unit o's input level and for each output the weighted combination of output quantities is at least $f_o{}'$ times unit o's output.

Because (3) is (2)'s dual, we have $\Theta = \max\ f_o{}' = \min\ e_o{}'$, herein defined as productive inefficiency. We therefore obtain DMU o's productive efficiency, e_o, which is $1/\Theta$.

The addition of a convexity restriction to the mathematical programming model (3),

$$\sum_{m=1}^{n} \lambda_m = 1, \quad \text{with}\ \lambda_m \geqslant 0, \tag{4}$$

shrinks the region of feasible solutions of the CRS model and introduces scale efficiency, resulting in the model referred to in the literature as a VRS output-oriented model. The solution of model (3) with the addition of (4) renders $\varphi = \max f_o{}''$. DMU o's technical efficiency, e^t_o, is the inverse of φ, i.e., $e^t_o = 1\varphi$.

Färe et al. (1994) propose an extension of the VRS model obtained through the combination of (3) and (4) incorporating the concept of weak disposal of outputs. Their formulation (FGL) identifies inefficiencies deriving from congestion in the productive process and permits the calculation of managerial and congestion components of technical inefficiency whenever $e^t_o < 1$.

The strong disposal of output restrictions in the original VRS model are relaxed (with the consequent elimination of possible slack), resulting in the following LP model:

$$\begin{aligned} & \max f_o^* \\ \text{subject to:} \quad & \sum_{m=1}^{n} \lambda_m X_{im} \leqslant X_{io};\ i = 1, \ldots, r, \\ & \sum_{m=1}^{n} \lambda_m Y_{jm} = f_o^* Y_{jo};\ j = 1, \ldots, s \quad \text{and} \quad \sum_{m=1}^{n} \lambda_m = 1, \quad \text{with } \lambda_m \geqslant 0. \end{aligned} \tag{5}$$

Whenever $\psi = \max f_o^* > 1$, the DMU o has managerial inefficiency given by $1/\psi$. The productive inefficiency component deriving from production congestion (congestion inefficiency, Θ_C) is given by the ratio between the maximum feasible expansion obtained in (5) and the maximum feasible expansion obtained through the VRS model: $\Theta_C = \psi/\varphi$. Although modified approaches to determine congestion inefficiency have been presented in the literature, such as, for example, Cooper et al. (2000), we have opted to use the original formulation in this paper. When congestion is detected, it is possible to identify its reasons by partially relaxing restrictions of products assumed to cause the congestion, and, therefore, it is possible to identify bottlenecks in the production process, leading to corrective action to increase efficiency.

4.3. Input and output variable selection

An ever-present challenge in the DEA process is the selection of the input and output variables to most accurately represent the production technology subject to analysis. Golany and Roll (1989) suggest a three-stage approach for the selection of the appropriate input and output variables. The first stage is qualitative and uses variable selection criteria such that selected variables do not contain redundant or conflicting information but contribute to performance evaluation. The second stage is a quantitative statistical analysis stage, using correlation analysis, principal component analysis (PCA), and/or other multivariate statistical methods to identify relationships between candidates for representative input and output variables. The third and last stage includes DEA-based analyses to further refine the input and output variable set.

The first stage is heavily dependent on the knowledge and judgment of the analyst, and therefore, the availability of a group of experts to help with the selection is advantageous, while there are many statistical techniques that are useful in the second stage. The methodology described herein relies primarily on correlation analysis and PCA for the quantitative statistical analysis of the data to reduce the number of variables in the second stage. For the further reduction in the number of variables that comprises the third stage, this methodology uses the stepwise method of Norman and Stoker (1991).

Conceptual overview of PCA. PCA is a powerful tool for analyzing large quantities of descriptive data because it is a method that permits the reduction of the dimension of a database with the loss of the smallest possible amount of information. The principal components (PCs) of a set X of original variables are non-correlated linear combinations of X that retain the highest quantity of information contained in the original variables. Those original variables are represented as the product of score and loading vectors, respectively t_h and p_h. These scores and loadings can be calculated iteratively through the following relationship: $X = t_1 p_1' + t_2 p_2' + \ldots + t_h p_h'$. As an

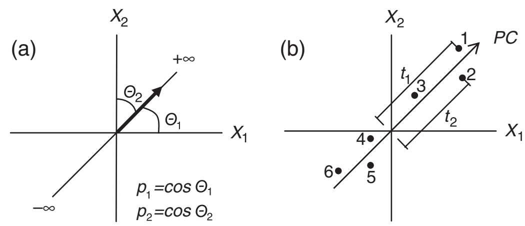

Fig. 1. The two-variable case principal component: (a) loadings are the cosines of the angles of the direction vector; (b) scores are the projections of the samples (1–6) in the principal component direction.

example, consider Fig. 1 that illustrates two variables X_1 and X_2. Figure 1a shows one principal component that is the vector pointing in the direction of highest change in the samples in Fig. 1b. The scores t_h are the projections of the samples in the direction of the principal component and the loadings p_h are the cosines of the angles between each component and each variable.

The principal components are extracted in order of importance, from highest to lowest explanatory power. The number of components is always the same as the number of variables, but some of the components (the "principal" ones) are responsible for a large portion of the explanatory power and they can be selected as representative of the original database. A comprehensive introduction to PCA can be found in Johnson and Wichern (1982).

Conceptual overview of the stepwise method of Norman and Stoker. These authors presented a stepwise approach to fine-tune the set of input and output variables that examines not only the correlation between efficiency measures and individual input and output variables but also the existence of causality between each variable and the efficiency measure. In summary, the approach combines statistical analysis through examination of correlations with socioeconomic cause-and-effect judgment-based analysis. The first step of the method proposed by Norman and Stoker is to suggest the most representative input variable and output variable, then to find the relative efficiencies through a DEA model and to determine the correlations between each variable and the current step efficiency measures. At each step one (or very few) variable(s) are included (or excluded) from the input/output set – variables with high correlations and strong cause-and-effect relationships with efficiency measures are candidates for inclusion into the model while variables with low correlations and weak cause-and-effect relationships with efficiency measures are candidates for removal at each step. The process continues until all significant correlations have been considered and all significant cause-and-effect relationships have been accounted for. At this point the addition of new variables to the input or output list does not alter substantially the resulting calculated efficiencies.

5. The decision support methodology

Although, as described in Section 3 above, different constituencies have different incentives and objectives regarding agrarian reform, an unbiased approach accepted by all parties is that a reliable measure of agrarian reform success is the percentage of settlements that conclude the consolidation phase fulfilling conditions for definitive entitlement, i.e., that reach self-sufficiency and achieve integration with the market economy, within an expected timeframe. Because less than 10% of the settlements in Brazil have reached this definitive entitlement phase (and because those that did so rarely achieved this goal in timely fashion), it is apparent that, according to this metric, there is ample margin for improvement in the Brazilian agrarian reform program. The methodology presented here uses DEA to identify the most efficient settlements and the reasons and characteristics for their success in order to be able to implement these same characteristics in other settlements to the extent possible.

An additional challenge of this undertaking was to develop a methodology that could serve as a basis of comparison among different settlements (decision-making units) that would be acceptable to all three constituencies involved in the process. In other words, there was a need for consensus in terms of the main variables to be used in such a methodology so that all three constituencies would accept the findings as legitimate. Furthermore, in order to reflect agrarian reform's dual objectives of productivity growth and social inclusion, the methodology would have to combine productivity and efficiency measures with indicators of social development in the process of identifying the most successful settlements. Table 1 shows a description of each step of the suggested methodology.

After going through the various steps in the methodology presented above, some level of convergence between at least one of the constituencies and the DEA-calculated efficiencies would be expected.

Table 1
The decision support methodology

1. Identify important settlement descriptive variables through input from several representatives from each of the three main constituencies and through analysis of main settlement agricultural products. The Delphi method is used to reach closure on the opinions of the representatives of the three constituencies.
2. Rank each representative's descriptive variables in order of importance (relative prioritization): use cluster analysis to verify (a) the consistency of responses by representatives of the same constituency, and (b) the existence of occasional differences in objectives among the three constituencies.
3. Have each representative rank order the settlements in terms of perceived degree of success.
4. Perform cross-correlation analysis on the descriptive variables, followed by principal component analysis. A subset of candidate representative input/output variables results from this step.
5. Compare this subset with the set of ranked variables obtained in step 2. If it is substantially similar, continue to step 6, otherwise return to step 1 (Delphi process) incorporating the additional information obtained from statistical analysis.
6. Execute the Norman and Stoker procedure to identify the few input and output variables (of those identified above) which best represent the production technology for use in the DEA model.
7. Use DEA to calculate efficiencies for each settlement.
8. Compare the ranked list of DEA-calculated efficiencies with constituency representatives' success lists. If they are substantially similar, continue to step 9, otherwise return to step 1 (the Delphi process) incorporating the additional information obtained from the DEA analysis.
9. Generate consensual categories of settlement performance.
10. Generate corrections due to environmental (uncontrollable) factors.
11. Use DEA and regression analysis to identify the main explanatory variables (environmental and organizational factors) for individual settlement success. Use these as potential inputs for improving other settlements' performance.
12. Analyze a new set of potential settlements (future settlements) to increase the chance of success of these new settlements given different combinations of environmental and organizational factors.

6. Application of the methodology – the case of Rio Grande do Sul

6.1. Description of the Rio Grande do Sul case

This methodology was applied to data obtained from settlements in the State of Rio Grande do Sul, the southernmost state in Brazil, to evaluate settlement efficiency, to verify the level of consistency among the constituencies' perceptions of outcomes, and to identify actions that could help increase the probability of settlement success in this and other regions of the country.

With an area of 282 thousand square kilometers (110 thousand square miles) and with a population of over 9.5 million people (24% of which are rural), Rio Grande do Sul is the fourth largest state in the country both in terms of GDP and in per capita income (over US$3300). Before 2005, the Brazilian agrarian reform program had created, installed, and consolidated 294 settlements in the state, with a total of 11,400 families relocated, of which only 627 had obtained definitive titles of property. Socioeconomic indicators for the state of Rio Grande do Sul are significantly better than the national average (Fig. 2).

The case examined 90 different agrarian reform settlements, each of which comprised a productive unit, with a total of 3600 families. These 90 settlements were arbitrarily grouped by the authors into three distinct regions. The first was the relatively populated Pioneira region in the northern part of the state with 37 settlements, the second was the sparsely populated Expansão region in the southern part of the state with 34 settlements, and the third was the Contraste region, located between the other two regions and sharing some characteristics with each of them, with 19 settlements.

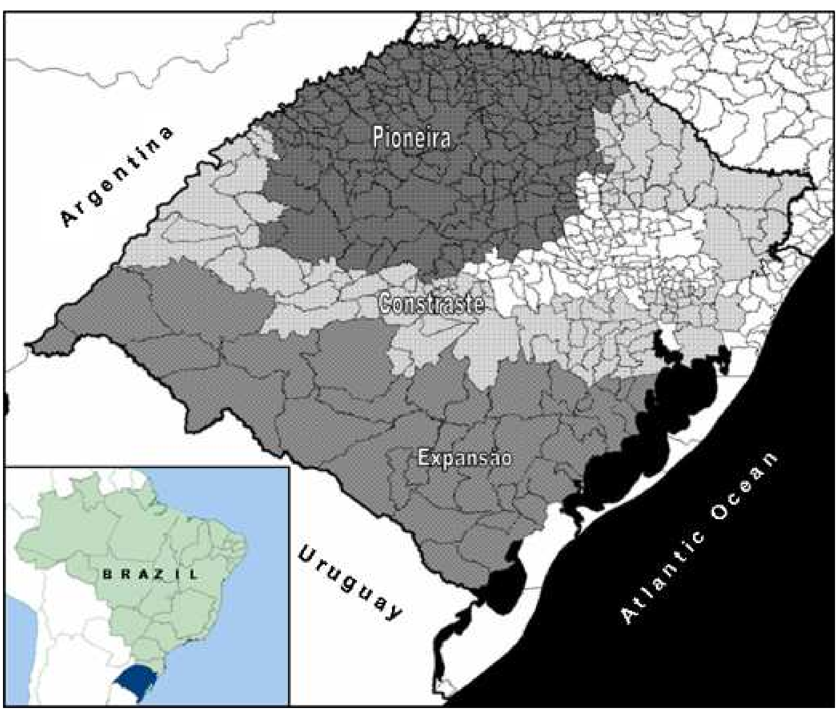

Fig. 2. Map of Brazil and the state of Rio Grande do Sul showing the three sub-regions with settlements

The data for each of the settlements was meticulously gathered from several sources: INCRA, EMATER (the main agricultural agency in the state of Rio Grande do Sul), the local MST organization, as well as the settlements themselves. A group of senior local (state) representatives from each of the three main constituencies was formed: 13 representatives from MST, 9 from INCRA, and 12 from EMATER. Through the iterative Delphi process, the constituency representatives collectively agreed upon a list of important variables covering several categories (quantitative indicators including output, investments, factors of production, infrastructure, and use of technology, as well as qualitative factors including history of the settlers, citizenship, relationship with institutions and community at large, and quality of life). Consensus was obtained on the variables to be included in the analysis, although, at first, there was disagreement about their relative importance.

6.2. Settlement descriptive variables

With input from the constituency representatives, over 100 variables were identified to describe the settlements. The Delphi process, which is a procedure used to identify parameters and variables of importance based on the opinion of a group of experts (Milkovich et al., 1972), was used to help create and then pare this long list down. Through the elimination of variables showing significant degree of redundancy and also through the combination of variables whenever appropriate and possible, the initial list of descriptors was reduced to 54. These remaining variables were grouped into several categories: production data, variables related to labor supply, descriptive variables for the land, for technology, and for infrastructure, financial data, data on settlement experience, and finally social indicators for each settlement. These variables are listed in Table 2.

Seven of the descriptive variables listed in Table 2 were numerical grades from 0 to 10 reflecting the level of the measured item and were arrived at by averaging grades given by the various social workers working in each settlement and by representatives of each constituency who knew the settlements well. In the representatives' opinion there still was some level of overlap in the variable list. Correlation analysis and further input from the Delphi process were used to reduce this list of variables one more time. The variables marked with an asterisk in Table 2 were removed in this last round, resulting in a list with 37 remaining variables.

6.3. Relative importance of variables – the constituency representatives' opinion

Cluster analysis (Ward's method) was used to examine the representatives' opinions. Three different patterns of perceptions of the relative importance of descriptive variables emerged: one for each constituency, demonstrating consistency among views of representatives of the same group – the group with the highest consistency was the MST (representing the settlers). Curiously, the opinions of INCRA representatives were clustered farther than the other two, suggesting some level of convergence between the agency EMATER and the MST. There was strong convergence as to perceptions of input and output variables by these constituencies, and although there were differences in weighting their relative importance, there was little difference in ranking them. The

Table 2
Descriptive variables for the data set of 90 settlements

(a) Production/sales data
LAV$VE – revenues from settlement agricultural product sales
STOT$V – revenues from settlement seed sales
PEC$VE – revenues from settlement livestock sales
CT$LP – settlement agriculture and livestock production for internal consumption
LAV$TOT – total agricultural production (sold and consumed) (*)
PEC$TOT – total livestock production (sold and consumed) (*)
(b) Data on families/people in settlement, i.e., variables related to labor supply
FAMILIAS – number of families in the settlement
PESSOAS – number of individuals in the settlement (*)
ADULTOS – number of adults in the settlement
FCSAOKrel – percentage of families with adequate housing
FKPROP – number of families arriving at the settlement with significant start-up resources
(c) Data on land supply per settlement including area and quality of soil
HATOTAL – total area of the settlement in hectares
HAAGRIC – area usable for agriculture in the settlement in hectares (*)
LOTES – number of separate tracts of land in the settlement (usually the same as FAMILIAS) (*)
HACULT – number of hectares with agricultural productive activity in the settlement
LMENOR – number of tracts in the settlement smaller than INCRA standard fiscal size for county (*)
INAPHA – area in hectares that is not usable for productive activities (*)
CSOLOpond – qualitative variable indicating quality of soil in settlement
(d) Data on technology, i.e., degree of use of mechanization and fertilizers
CAMINHAO – number of trucks in the settlement
TRATOR – number of tractors in the settlement
JTBOI – number of pairs of animals (e.g., oxen) used for traction in the settlement
AUTO – number of automobiles in the settlement
HP(trator) – tractor horsepower in the settlement
ADBRGHA – number of hectares using organic fertilizer
ADQUIHA – number of hectares using chemical fertilizer
PCHA – number of hectares planted with conservationist practices
CALHA – number of hectares treated with lime
(e) Data on infrastructure, including logistics and access to markets
FCALUZ – number of houses with electricity in the settlement (*)
FHRTDOM – number of families with vegetable garden for own consumption
FPMARD – number of families with orchard for own consumption
FAGFONT – number of families with spring well (*)
FAPÇART – number of families with artesian well (*)
FAPÇRS – number of houses with shallow well (*)
I$TINC – total settlement INCRA individual infrastructure financing (investments)
STRADpond – qualitative variable indicating settlement road conditions
PMERCpond – qualitative variable – level of year-round access to market
(f) Financial data
C$TINC – total settlement INCRA working capital financing
C%EMAOK – percentage of families receiving subsidized working capital credit in timely fashion
I%EMAOK – percentage of families receiving subsidized infrastructure investment credit in timely fashion
IC%EMAOK – percentage of families receiving working capital and investment credit in timely fashion
PDIVDA – debt level of settlement (*)
(g) Data on collective knowledge, experience, and level of organization in the settlement
IDADE – age of the settlement in years

Table 2. (Contd.)

PORGpond – qualitative variable describing the level of organization in the settlement
FGRLFAM – number of families participating in groups but exploring their own tract individually (*)
FINDIVL – number of families working individually and independently (not part of groups)
FEPAJ – number of families having prior experience in the region of the settlement
FGRORG – percentage of families participating in organized groups (*)
(h) Data on socio-economic variables
CRIANÇS – number of children in the settlement (*)
ALUNOS – number of children in the settlement who were going to school (*)
ANALF – number of illiterate adults in the settlement (*)
FALMTOK – number of families with adequate nourishment in the settlement
ALIMpond – qualitative variable indicating quality of nourishment in the settlement
PRELACIOpond – qualitative variable – quality of relationship with city hall, local trade, and other farmers
PCIDpond – qualitative variable – collective level of citizenship and social responsibility in the settlement

representatives considered the pared-down list of 37 variables resulting from the last round of interaction and correlation analysis to be very good descriptors of the settlements.

6.4. Selection of input and output variables for DEA

As mentioned in Section 4 above, DEA can measure the relative efficiency of settlements (here considered decision-making units) with multiple inputs and outputs in the absence of a known production function. The first step is the selection of the input and output variables to be considered. In this case, the basic premise for DEA input and output variable selection was the desirability for at least one variable representing each of the major factors of production: land, labor, capital, technology/knowledge; as well as at least two output variables: at least one economic variable representing production output and at least one social variable representing the degree of social evolution of the settlement.

The first step in the process was to use PCA techniques to identify the subset of variables that were the most relevant descriptors of the data in order to provide guidance for the Norman and Stoker stepwise process. The objective was to determine whether a smaller number of variables could represent the data set accurately. The XLSTAT software package was used for the PCA on the data set of 90 observations for 37 variables and Bartlett's sphericity test indicated significance of correlation among these variables. From the PCA output presented in Table 3, it can be observed that 13 components are sufficient to retain about 90% of the information contained in the data set. It is desirable to identify these 13 components. From Table 3, it is easy to surmise that the first component, with 39% explanatory power, is strongly associated to size because the size-related settlement variables of number of hectares and families have the strongest relationship with it. The second component, with 12% explanatory power, seems strongly associated with socioeconomic variables related to quality of nourishment and quality of relationships with local institutions and trade. Continuing the analysis, the next three components can be considered strongly associated respectively with citizenship (a social variable), technology (tractors, etc.), and level of organization. This offers some guidance but it is still difficult to select the variables that most influence each principal component with precision because each variable is the linear

Table 3
Principal component analysis summary

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	Relevance
Eigenvalue	14.521	4.427	3.172	2.447	1.601	1.367	1.238	0.957	0.875	0.775	0.732	0.605	0.544	
% variance	39.2	12.0	8.6	6.6	4.3	3.7	3.3	2.6	2.4	2.1	2.0	1.6	1.5	
Cumulative %	39.25	51.21	59.79	66.40	70.73	74.42	77.76	80.35	82.71	84.81	86.78	88.42	89.89	
FAMILIAS	5.948	0.625	1.777	0.447	0.093	0.029	0.003	0.505	0.071	0.389	0.053	0.196	0.647	2.63
ADULTOS	4.217	0.260	2.603	3.893	0.899	2.131	0.111	0.081	6.102	4.616	0.016	0.021	0.053	2.53
FHRTDOM	5.493	0.040	0.007	0.027	0.372	2.306	0.082	2.513	1.663	0.528	0.089	0.898	0.345	2.40
FPMARD	4.080	0.079	1.388	0.003	6.857	2.597	0.009	1.882	3.133	0.252	2.654	2.101	0.280	2.35
FINDIVL	3.627	0.308	0.023	2.555	1.016	5.405	0.088	6.503	0.033	6.393	3.709	0.748	0.544	2.27
FALMTOK	4.903	0.430	2.584	0.327	0.027	0.309	0.038	0.573	2.767	0.339	2.723	1.497	5.329	2.48
FEPAJ	3.835	0.500	0.320	0.290	5.008	7.100	3.151	1.410	1.990	0.229	2.555	0.004	3.865	2.39
FKPROP	2.410	2.250	7.479	0.257	2.405	0.195	5.722	3.438	0.614	2.160	0.001	0.354	8.730	2.46
IDADE	0.117	3.696	11.238	0.564	0.109	0.312	2.313	0.468	2.296	2.706	13.647	25.852	0.354	2.40
HATOTAL	2.379	0.979	2.004	0.000	0.594	0.529	0.469	0.152	1.621	1.320	0.430	0.123	0.617	2.55
HACULT	6.342	0.002	0.082	0.010	0.056	0.125	0.325	0.142	0.069	0.599	0.883	0.113	0.466	2.56
ADBRGHA	2.893	0.279	0.212	1.989	8.439	13.807	4.505	0.002	1.097	2.144	0.116	0.379	1.384	2.44
ADQUIHA	5.566	0.088	0.196	0.720	0.790	1.110	0.290	0.227	3.878	2.298	0.139	0.039	0.900	2.51
CALHA	5.389	0.374	0.264	0.865	0.223	0.020	4.028	0.532	2.624	5.482	0.182	0.961	0.048	2.60
PCHA	2.311	0.041	0.244	2.580	0.767	0.184	1.205	1.168	1.338	0.991	0.580	0.332	0.905	2.47
LAV$VE	3.599	0.000	2.824	6.047	0.026	0.264	0.165	2.372	0.762	3.659	0.327	1.599	2.467	2.30
PEC$VE	2.836	0.572	0.001	0.055	0.029	6.243	0.672	21.476	0.103	1.030	11.792	3.961	8.015	2.43
STOT$VE	0.014	0.604	4.798	10.790	1.890	16.900	2.955	2.710	7.396	0.005	0.566	0.420	4.080	2.33
CT$LP	3.395	1.506	3.070	0.135	1.788	4.497	0.103	3.629	6.803	7.418	1.007	0.222	0.010	2.47
I$TINC	5.214	0.684	2.663	0.001	1.327	0.360	0.994	1.973	0.041	0.392	0.353	0.273	0.501	2.54
C$TINC	4.028	0.423	5.855	0.118	0.170	0.286	2.164	2.489	7.725	0.481	0.013	0.003	0.002	2.49
CAMINHAO	2.667	0.040	1.351	7.267	1.298	1.002	3.283	0.175	0.132	2.404	6.537	2.904	12.985	2.28
TRATOR	3.242	0.333	5.867	7.484	0.003	0.042	4.774	1.623	0.406	0.283	0.330	0.289	3.189	2.59
HP (trator)	2.330	0.980	3.827	10.240	0.005	0.034	8.913	3.820	1.275	0.002	0.933	0.029	5.607	2.57
JTABOI	3.047	0.003	2.304	0.175	8.927	2.245	0.005	5.390	6.088	2.035	7.588	2.345	3.267	2.44
AUTO	2.611	1.660	6.900	0.733	0.163	0.971	0.789	10.809	0.012	0.730	0.708	2.226	0.809	2.29
FCSAOKrel	0.006	5.193	1.161	0.655	7.722	18.772	4.728	4.382	6.167	7.504	0.013	0.004	3.422	2.42
PORGpond	0.702	0.002	6.122	2.856	25.327	2.739	0.078	5.892	0.010	0.597	0.667	0.007	0.005	2.37
PCIDpond	0.043	0.036	11.793	4.185	19.030	1.417	0.101	0.001	5.830	1.762	0.928	0.051	0.222	2.39
CSOLOpond	0.187	10.405	0.000	2.384	0.275	2.588	0.625	0.071	9.916	8.692	1.586	9.025	9.247	2.32
STRADpond	0.062	3.544	0.012	1.423	0.090	0.140	9.611	0.583	0.027	4.021	19.580	20.729	0.815	2.43
PMERCpond	0.122	6.581	0.043	9.179	0.439	0.164	2.446	0.358	3.434	16.174	5.042	1.140	5.301	2.18
ALIMpond	0.073	14.105	0.115	0.501	0.065	0.090	1.453	0.047	3.923	3.650	5.655	1.938	0.294	2.13
PRELACIOpond	0.000	12.739	2.405	0.998	0.392	0.041	5.290	0.649	0.319	1.476	1.070	15.745	1.967	2.35
IC%EMAOK	0.156	9.884	2.372	7.821	0.971	0.219	11.794	5.209	3.547	0.061	0.035	0.683	0.023	2.64
C%EMAOK	0.078	5.631	4.911	5.884	0.001	4.016	0.138	0.312	6.056	6.227	6.838	1.869	13.252	2.31
I%EMAOK	0.075	9.122	1.184	6.543	2.406	0.812	16.245	6.435	1.451	0.352	0.654	0.923	0.051	2.58

combination of all the components and in most cases there is more than one which is important. Because 13 components retain 90% of the data set's information there should be at least 13 variables in a list of those with most influence in order to attempt to retain the same level of explanatory power. At this point, a procedure to rank-order the variables in order of explanatory power is suggested: the sum of the contributions of each variable weighted by the explanatory power of each of the first 13 components provides a measure of the relative information retention importance of each variable in the data set. Therefore it also provides yet another indicator as to relative priority in subsequent selection steps such as the Norman and Stoker stepwise method described below.

The output-oriented DEA model was chosen because the settlements (or DMUs) do not have decision power to significantly alter their own size and consequently cannot substantially increase input factor quantities, but can alter their production mix by deciding what to produce with available resources. Settlements also are unable to increase significantly their size to reach a scale that would permit higher productivity, favoring the use of the VRS DEA formulation (model 4 of Section 4.2). The General Algebraic Modeling System (GAMS), as per Olensen and Petersen (1996), with expanded treatment to accommodate the FGL formulation, was the main software package used to run the DEA models.

The stepwise method of Norman and Stoker was used to identify the most appropriate input and output variables to run the DEA model from this set of 37 variables. The initial input and output variables used were, respectively, a land-related input variable, total hectares with agricultural productive activity in the settlement (HACULT), and a socioeconomic variable, the number of families with adequate nourishment in the settlement (FALMTOK). These were chosen because they were respectively the input and output variable with the highest contributions to the first principal component PC1 in the analysis described above.

One variable (either input or output) was added to the DEA model in each of the 11 iterations – the final DEA model had eight input and four output variables. In each iteration, the correlations between the efficiencies obtained through the DEA model and the values of each variable were calculated. Table 4 shows the input and output variable entry sequence into the DEA model with the correlations between the variables and the calculated efficiencies at each stage. The variable added in the second iteration was ALIMpond, also a socioeconomic output variable, which had the highest correlation with the first round efficiencies and furthermore was the variable with largest contribution to the second principal component PC2 in the PCA analysis. In the third iteration, a pecuniary output variable (LAV$VE) had the largest correlation with the step efficiencies and was added. Next a series of five different input variables were selected because each had the highest correlation with the respective step efficiency and each had at least reasonable contribution to one of the first five components, provided that it could not serve as proxy for any variable already chosen. It is interesting to note that these five input variables represent various categories of factors of production – ADULTOS for labor, JTBOI for technology (mostly labor-related), C$TINC for working capital financing, PCHA for technology (mostly land-related), I$TINC for infrastructure investments. The five remaining input and output variables were identified in the same way. Please refer to Table 4 for the complete list of correlation values in each sequential step.

6.5. DEA results

The output-oriented CRS, VRS, and FGL models described in Section 4.2 above were used to evaluate the relative efficiencies of the 90 settlements in the three regions of the state of Rio Grande do Sul. Table 5 lists the input and output variables selected through the Norman and Stoker method and used in the evaluation of the settlements.

Table 4
Correlations for selection of input and output variables using the Norman and Stoker stepwise method

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10	Step 11
Outputs											
FALMTOK	x	x	x	x	x	x	x	x	x	x	x
ALIMpond		x	x	x	x	x	x	x	x	x	x
LAV$VE			x	x	x	x	x	x	x	x	x
PEC$VE									x	x	x
Inputs											
HACULT	x	x	x	x	x	x	x	x	x	x	x
ADULTOS				x	x	x	x	x	x	x	x
JTABOI					x	x	x	x	x	x	x
C$TINC						x	x	x	x	x	x
PCHA							x	x	x	x	x
I$TINC								x	x	x	x
FINDIVL										x	x
CALHA											x
FAMILIAS	−0.078	0.192	0.257	−0.124	−0.146	−0.188	−0.285	−0.314	−0.277	−0.295	−0.310
ADULTOS	−0.097	−0.218	−0.351	−0.344	−0.353	−0.389	−0.492	−0.512	−0.434	−0.443	−0.455
FHRTDOM	−0.136	−0.224	−0.237	−0.037	−0.026	−0.066	−0.170	−0.200	−0.182	−0.214	−0.235
FPMARD	−0.143	−0.222	−0.237	−0.064	−0.051	−0.085	−0.181	−0.210	−0.201	−0.217	−0.238
FINDIVL	−0.060	−0.143	−0.206	−0.139	−0.150	−0.162	−0.237	−0.249	−0.287	−0.461	−0.467
FALIVITOK	0.187	−0.058	−0.128	−0.025	−0.012	−0.033	−0.154	−0.187	−0.213	−0.176	−0.194
FEPAJ	−0.169	−0.228	−0.260	−0.173	−0.166	−0.188	−0.263	−0.257	−0.204	−0.171	−0.177
FKPROP	−0.094	−0.153	−0.161	−0.005	0.021	−0.005	−0.080	−0.097	−0.079	−0.098	−0.114
IDADE	−0.029	−0.033	−0.071	0.082	0.088	0.100	−0.001	0.007	−0.045	−0.029	−0.036
HATOTAL	−0.108	−0.215	−0.260	−0.125	−0.150	−0.190	−0.278	−0.306	−0.257	−0.276	−0.289
HACULT	−0.252	−0.360	−0.385	−0.212	−0.205	−0.251	−0.339	−0.381	−0.379	−0.378	−0.397
ADBRGHA	−0.096	−0.136	−0.180	−0.079	−0.089	−0.111	−0.160	−0.176	−0.179	−0.205	−0.215
ADQUIHA	−0.123	−0.216	−0.194	−0.006	0.002	−0.038	−0.138	−0.188	−0.156	−0.135	−0.153
CALHA	−0.165	−0.228	−0.282	−0.133	−0.115	−0.142	−0.217	−0.249	−0.220	−0.226	−0.243
PCHA	−0.188	−0.260	−0.334	−0.216	−0.185	−0.212	−0.302	−0.341	−0.339	−0.349	−0.365
LAV$VE	−0.262	−0.369	−0.021	0.072	0.082	0.032	−0.065	−0.114	−0.094	−0.116	−0.139
PEC$VE	−0.143	−0.229	−0.211	−0.078	−0.071	−0.117	−0.215	−0.263	0.010	0.019	−0.004
STOT$VE	0.049	−0.010	−0.140	0.128	0.100	0.072	0.093	0.060	0.025	0.136	0.124
CT$LP	−0.103	−0.171	−0.204	−0.030	−0.059	−0.093	−0.137	−0.166	−0.180	−0.132	−0.143
I$TINC	−0.056	−0.153	−0.242	−0.091	−0.123	−0.173	−0.273	−0.331	−0.297	−0.305	−0.321
C$TINC	−0.092	−0.202	−0.275	−0.189	−0.217	−0.283	−0.359	−0.401	0.327	−0.314	−0.329
CAMINHAO	−0.052	−0.129	−0.039	0.102	0.072	0.038	−0.033	−0.034	−0.032	−0.031	−0.043
TRATOR	−0.203	−0.282	−0.112	0.062	0.053	0.017	−0.066	−0.105	−0.118	−0.139	−0.154
HP(trator)	−0.207	−0.274	−0.082	0.095	0.083	0.047	−0.027	−0.067	−0.078	−0.105	−0.119
JTABOI	−0.116	−0.217	−0.322	−0.284	−0.353	−0.391	−0.497	−0.529	−0.438	−0.393	−0.399
AUTO	−0.082	−0.169	−0.117	−0.024	−0.038	−0.079	−0.172	−0.192	−0.163	−0.182	−0.191
FCSAOKrel	0.184	−0.166	−0.051	0.098	0.125	0.099	−0.006	0.017	0.022	−0.065	−0.068
PORGpond	0.073	−0.031	−0.067	0.219	0.201	0.154	0.146	0.052	0.080	0.076	0.058
PCIDpond	0.133	−0.109	−0.102	0.206	0.196	0.165	0.216	0.167	0.140	0.125	0.087
CSOLOpond	0.236	−0.190	−0.074	−0.088	−0.051	−0.063	−0.131	−0.118	−0.107	−0.097	−0.133
STRADpond	0.229	−0.265	−0.035	0.025	0.046	0.050	−0.011	−0.061	−0.120	−0.050	−0.027
PMERCpond	0.281	−0.300	−0.062	−0.009	−0.037	−0.037	−0.211	−0.217	−0.137	−0.082	−0.086
ALIMpond	0.490	−0.415	−0.172	0.232	0.258	−0.218	0.013	0.001	0.010	0.071	0.050
PRELACIOpond	0.334	−0.363	−0.066	0.090	0.093	0.073	−0.084	−0.089	−0.146	0.012	−0.002
IC%EMAOK	0.008	−0.003	−0.078	−0.070	−0.048	−0.036	−0.061	−0.071	−0.109	−0.038	−0.076
C%EMAOK	0.065	−0.076	−0.110	0.124	0.118	0.082	0.090	0.050	0.014	0.017	−0.015
I%EMAOK	−0.013	−0.016	−0.140	−0.126	−0.105	−0.082	−0.101	−0.079	−0.103	−0.035	−0.071

Table 5
Input and output variables in DEA model

Variable	Type	Category	Description
FALMTOK	Output	Socioeconomic	Number of families with adequate nourishment in the settlement
ALIMpond	Output	Socioeconomic	Qualitative variable indicating quality of nourishment in the settlement
LAV$VE	Output	Production/sales data	Revenues from settlement agricultural product sales
PEC$VE	Output	Production/sales data	Revenues from settlement livestock sales
HACULT	Input	Land	Number of hectares with agricultural productive activity
ADULTOS	Input	Labor supply	Number of adults in the settlement
JTBOI	Input	Technology (labor)	Number of animals (e.g., oxen) used for traction in the settlement
C$TINC	Input	Financial variable	Total settlement INCRA working capital financing
PCHA	Input	Technology (land)	Number of hectares planted with conservationist practices
I$TINC	Input	Infrastructure	Total settlement INCRA individual infrastructure financing
FINDIVL	Input	Knowledge/ organization	Number of families working individually and independently
CALHA	Input	Technology (land)	Number of hectares treated with lime

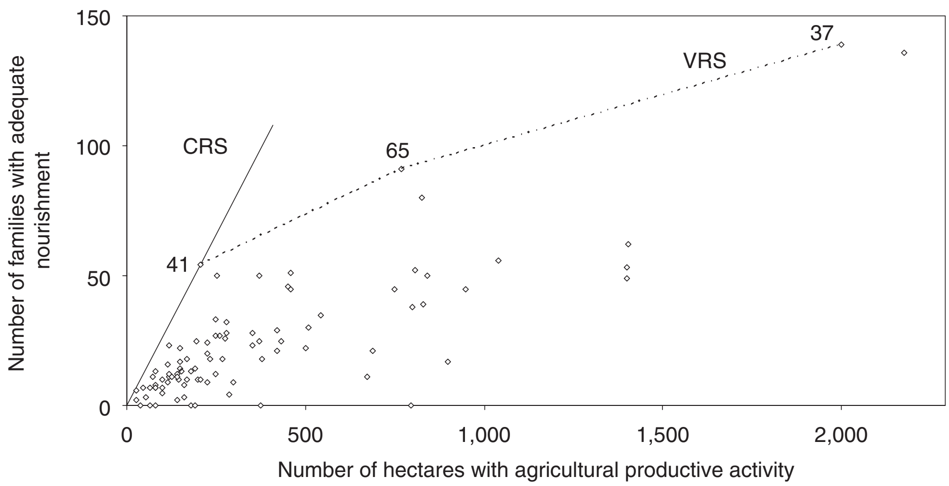

Fig. 3. CRS and VRS efficiency frontiers considering one input and one output

As an example, Fig. 3 shows the efficiency frontiers obtained with the CRS and the VRS models in the first step of the Norman and Stoker process, i.e., considering only one input, HACULT, and one output, FALMTOK.

It is apparent from Fig. 3 that two settlements or DMUs (65 and 37) that would be considered efficient in the VRS model operate under the CRS efficiency frontier. In this simplified case of one input and one output, DMU 41 operates with higher observed productivity while DMUs 65 and 37 operate with scale inefficiency.

Table 6 shows the values of each of the input and output variables as well as the results from the different DEA models for each of the 90 settlements with the inclusion in the analysis of all eight input variables and all four output variables. Because of the large number of settlements in the

Table 6
Input and output values and calculated inefficiencies for each settlement

Region	DMU	INPUTS								OUTPUTS				INEFFICIENCIES		
		HACULT	ADULTOS	JTABOI	C$TINC	PCHA	I$TINC	FINDIVL	CALHA	FALMTOK	ALIMpand	LAV$VE	PEC$VE	Productive	Technical	Managerial
Pioneira	1	900	337	70	185,856	650	562,124	51	150	17	0.40	164,373	38,443	0.26	0.58	0.66
	2	80	11	2	–	80	–	5	50	8	0.73	15,651	32,898	1	1	1
	3	113	33	8	8,000	70	53,819	4	70	9	0.60	32,042	34,262	0.84	0.86	0.86
	4	840	180	18	–	800	245,729	13	800	50	0.60	264,422	134,639	1	1	1
	5	140	69	18	6,548	5	64,926	2	40	2	0.37	10,761	10,389	0.66	0.68	0.81
	6	750	148	21	43,000	750	767,913	37	600	45	0.60	344,335	57,223	0.69	1	1
	7	543	80	9	33,000	543	590,091	6	543	35	0.67	149,653	193,017	1	1	1
	8	420	108	13	25,730	420	356,852	16	420	21	0.57	133,801	122,544	0.76	0.83	1
	9	674	183	30	34,200	600	262,546	39	120	11	0.41	159,964	27,237	0.34	0.59	0.87
	10	260	159	28	39,050	42	434,182	0	40	27	0.63	45,116	6,233	0.90	0.95	1
	11	500	174	28	43,000	150	568,223	35	100	22	0.50	77,422	13,841	0.30	0.57	0.73
	12	950	262	25	131,200	800	460,837	8	400	45	0.65	199,934	65,638	0.58	0.95	0.98
	13	200	81	12	22,000	80	281,544	25	60	10	0.47	29,154	5,835	0.34	0.59	0.69
	14	690	200	5	68,400	690	302,428	12	690	21	0.60	179,397	24,103	0.70	1	1
	15	800	280	28	111,200	700	426,393	0	700	38	0.53	122,045	95,236	0.60	0.94	0.97
	16	1400	342	48	153,900	400	804,916	64	600	49	0.83	287,166	74,684	0.32	1	1
	17	806	246	38	51,802	520	643,027	30	410	52	0.62	78,503	75,386	0.45	0.87	1
	18	510	234	28	67,533	200	258,530	4	150	30	0.67	27,920	35,659	0.50	0.88	1
	19	350	95	25	23,394	280	290,399	0	220	28	0.67	47,222	47,619	1	1	1
	20	120	80	23	30,070	0	173,093	0	20	23	0.67	43,340	–	1	1	1
	21	2175	379	95	230,151	1600	2,321,791	58	2175	136	0.53	175,775	167,334	0.68	1	1
	22	120	86	25	23,616	14	128,533	0	40	11	0.53	20,209	–	0.72	0.82	1
	23	378	41	0	–	120	49,126	18	120	18	1.00	74,201	72,253	1	1	1
	24	80	46	8	5,000	25	93,405	9	60	7	0.60	22,823	3,592	0.88	0.92	1
	25	1403	151	45	76,500	900	444,165	34	1430	62	0.75	364,044	151,456	0.79	1	1
	26	1400	163	50	68,400	900	507,684	36	1400	53	0.75	408,665	187,461	0.79	1	1
	27	190	66	0	18,362	150	–	0	65	14	0.57	28,656	29,202	1	1	1
	28	250	94	30	28,000	80	281,633	4	80	12	0.47	9,144	10,301	0.30	0.61	0.73
	29	350	122	17	96,286	340	508,533	0	340	23	0.83	101,304	306,854	1	1	1
	30	153	38	13	21,767	70	65,926	4	140	13	0.67	55,330	50,618	1	1	1
	31	299	85	10	55,482	70	255,604	0	180	9	0.45	37,501	11,609	0.40	0.66	0.70
	32	180	77	7	15,400	90	–	5	180	13	0.72	60,047	26,396	1	1	1
	33	370	205	20	90,000	80	355,604	0	120	50	0.67	72,870	6,681	1	1	1
	34	181	102	17	50,351	0	104,011	0	0	0	0.00	100,095	49,167	1	1	1
	35	432	71	31	37,860	280	405,656	0	120	25	0.53	–	43,780	1	1	1
	36	140	52	8	20,400	90	41,630	3	140	12	0.73	40,193	23,440	0.94	1	1
	37	2000	648	32	233,000	2000	1,562,178	118	2000	139	0.53	169,176	89,871	0.49	1	1
Contraste	38	150	48	2	7,139	0	135,807	2	10	22	0.67	49,595	31,740	1	1	1
	39	170	37	7	23,269	0	59,564	7	80	10	0.60	95,884	6,681	1	1	1
	40	795	85	9	86,000	170	1,054,591	22	142	0	0.00	379,614	16,819	1	1	1
	41	205	220	22	79,792	100	654,625	43	150	54	0.57	29,663	23,248	1	1	1
	42	80	41	14	16,430	18	90,501	0	8	7	0.57	5,760	–	1	1	1
	43	226	75	12	20,719	2	–	17	20	9	0.45	51,593	8,405	1	1	1
	44	54	28	5	5,226	3	101,428	6	14	3	0.43	3,748	13,060	0.89	1	1
	45	150	83	36	31,000	0	326,266	0	100	17	0.63	84,869	5,079	1	1	1
	46	40	27	3	–	7	49,505	0	7	0	0.38	1,241	4,694	1	1	1

Table 6. (Contd.)

Region	DMU	INPUTS								OUTPUTS				INEFFICIENCIES		
		HACULT	ADULTOS	JTABOI	C$TINC	PCHA	I$TINC	FINDIVL	CALHA	FALMTOK	ALIMpand	LAV$VE	PEC$VE	Productive	Technical	Managerial
	47	450	116	8	87,396	200	314,117	6	400	46	0.67	116,244	69,919	0.87	1	1
	48	66	41	4	11,700	10	146,193	0	25	7	0.50	17,494	4,177	1	1	1
	49	145	67	15	13,500	120	106,377	0	50	10	0.57	13,792	9,244	0.88	1.00	1
	50	371	90	7	30,629	20	121,562	4	10	25	0.57	9,493	58,591	1	1	1
	51	80	30	3	7,181	0	104,825	1	5	13	0.67	22,373	24,347	1	1	1
	52	80	69	20	36,280	35	211,493	0	40	0	0.33	–	21,964	0.42	0.51	1
	53	460	91	15	–	5	–	27	10	51	0.57	330,176	70,004	1	1	1
	54	170	86	15	50,319	80	267,498	1	70	18	0.57	58,282	10,857	0.85	0.86	0.88
	55	100	64	12	22,576	50	126,130	0	20	7	0.53	8,438	–	0.59	0.82	1
	56	826	190	29	184,197	310	966,452	27	150							
Expansão	57	276	120	31	39,990	50	236,937	3	276	26	0.67	47,787	88,914	0.92	1	1
	58	280	145	52	50,600	50	312,965	3	40	28	0.67	43,982	39,114	0.63	0.93	0.98
	59	27	8	5	5,600	27	43,276	0	10	2	0.50	3,537	8,096	1	1	1
	60	45	25	7	11,500	20	68,577	2	20	7	0.67	7,110	5,390	1	1	1
	61	65	17	6	8,000	2	79,207	0	3	0	0.33	14,612	2,571	1	1	1
	62	196	196	16	37,300	170	176,354	39	10	25	0.53	43,352	29,783	0.87	0.95	1
	63	120	74	11	26,600	120	135,333	8	10	12	0.53	37,167	15,380	0.68	0.79	0.80
	64	225	161	10	22,000	225	195,960	23	15	24	0.53	68,320	26,545	0.72	0.80	0.80
	65	768	253	16	144,100	57	851,718	0	30	91	0.65	200,264	47,008	1	1	1
	66	279	120	30	63,475	8	289,722	1	30	32	0.64	89,783	27,546	0.89	1	1
	67	247	97	19	25,700	49	246,415	14	40	27	0.67	82,578	34,171	0.71	0.92	0.93
	68	459	135	25	88,085	2	416,509	15	70	45	0.63	131,610	72,628	0.71	1	1
	69	116	41	8	14,400	0	114,255	3	40	16	0.67	18,472	6,550	0.98	1	1
	70	420	109	30	69,400	28	263,292	0	38	29	0.60	114,388	62,223	1	1	1
	71	161	50	10	26,000	0	139,889	0	27	8	0.48	56,873	10,978	0.86	0.86	1
	72	266	61	29	67,560	5	242,392	0	40	18	0.63	130,776	24,284	1	1	1
	73	205	40	8	21,900	0	112,351	0	24	10	0.63	81,040	16,835	1	1	1
	74	27	29	2	18,000	28	82,989	0	10	6	0.63	–	30,820	1	1	1
	75	74	48	5	24,700	0	91,470	0	15	11	0.63	21,559	17,299	1	1	1
	76	98	18	9	14,000	0	70,432	0	15	5	0.60	36,734	7,428	1	1	1
	77	125	22	4	22,800	11	115,782	7	0	11	0.64	28,014	16,299	1	1	1
	78	233	73	18	38,000	80	185,515	0	120	18	0.63	22,111	33,105	0.86	0.94	0.98
	79	224	94	28	52,800	87	264,469	10	150	20	0.53	23,526	58,239	0.70	0.75	1
	80	830	138	25	48,000	28	490,695	36	25	39	0.60	83,563	50,679	0.52	0.91	0.95
	81	99	23	10	19,000	7	50,566	10	10	10	0.67	20,181	7,988	1	1	1
	82	250	144	30	63,000	300	307,497	30	40	33	0.75	55,288	32,240	0.77	1	1
	83	252	123	30	95,000	80	560,196	10	62	50	0.67	34,359	79,427	1	1	1
	84	150	100	18	–	50	–	24	0	14	0.50	19,362	4,491	1	1	1
	85	141	122	15	40,800	0	249,756	19	12	11	0.63	21,956	10,132	0.54	0.95	1
	86	161	73	10	15,000	0	75,500	0	50	3	0.48	45,141	47,353	1	1	1
	87	1,038	358	83	216,722	100	865,711	0	110	56	0.50	213,991	177,296	0.80	1	1
	88	288	420	68	153,000	70	601,476	18	180	4	0.35	64,431	141,796	0.99	1	1
	89	375	44	3	63,000	0	192,500	3	0	0	0.00	182,533	53,568	1	1	1
	90	190	49	0	29,900	0	–	0	0	0	0.00	2,400	480	1	1	1

Table 7
Expansion and projection of DMU 11 production plans considering managerial, technical, and productive inefficiencies

				INPUTS								OUTPUTS			
				HACULT	ADULTOS	JTABOI	C$TINC	PCHA	I$TINC	FINDIVL	CALHA	FALMTOK	ALIMpond	LAV$VE	PEC$VE
Managerial			Weights												
inefficiency	Reference DMUs	6	0.01	750	148	21	43,000	750	767,913	37	600	45	0.60	344,335	57,223
$(1/\psi)$		16	0.11	1400	342	48	153,900	400	804,916	64	600	49	0.83	287,166	74,684
		20	0.69	120	80	23	30,070	0	173,093	0	20	23	0.67	43,340	0
		23	0.04	378	41	0	0	120	49,126	18	120	18	1.00	74,201	72,253
		33	0.05	370	205	20	90,000	80	355,036	0	120	50	0.67	72,870	6,681
		53	0.1	460	91	15	0	5	0	27	10	51	0.57	330,176	70,004
	DMU 11 $1/\psi = 0.73$		Observed	500	174	28	43,000	150	568,223	35	100	22	0.50	77,422	13,841
			Expanded									27.8	0.63	98,003	17,520
			Projected	324	115	24	42,607	61	235,371	11	98	30	0.69	104,566	19,012
			Difference	176	59	4	393	89	332,852	24	2	− 8	− 0.19	− 27,143	− 5,171
Technical			Weights												
inefficiency	Reference DMUs	16	0.02	1400	342	48	153,900	400	804,916	64	600	49	0.83	287,166	74,684
$(1/\varphi)$		23	0.65	378	41	0	0	120	49,126	18	120	18	1.00	74,201	72,253
		53	0.11	460	91	15	0	5	0	27	10	51	0.57	330,176	70,004
		65	0.22	768	253	16	144,100	57	851,718	0	30	91	0.65	200,264	47,008
	DMU 11 $1/\varphi = 0.57$		Observed	500	174	28	43,000	150	568,223	35	100	22	0.50	77,422	13,841
			Expanded									38.6	0.88	135,828	24,282
			Projected	493	99	6	34,780	99	235,408	16	98	38	1.00	134,352	66,500
			Difference	7	75	22	8,220	51	332,815	19	2	− 16	− 0.50	− 56,929	− 52,660
Productive			Weights												
inefficiency	Reference DMUs	41	0.24	205	220	22	79,792	100	654,625	43	150	54	0.57	29,663	23,248
$(1/\Theta)$		51	1.63	80	30	3	7,181	0	104,825	1	5	13	0.67	22,373	24,347
		53	0.63	460	91	15	0	5	0	27	10	51	0.57	330,176	70,004
		83	0.13	252	123	30	95,000	80	560,196	10	62	50	0.67	34,359	79,427
	DMU 11 $1/\Theta = 0.30$		Observed	500	174	28	43,000	150	568,223	35	100	22	0.50	77,422	13,841
			Expanded									73.3	1.70	258,075	46,136
			Projected	502	175	24	43,205	38	400,801	30	59	73	2.11	256,065	99,693
			Difference	− 2	− 1	4	− 205	112	167,422	5	41	− 51	− 1.17	− 178,643	− 85,852

analysis and space limitations herein, a representative DMU (number 11) is used to illustrate the use of DEA to establish specific efficiency-enhancing goals. DMU 11 exhibits productive inefficiency ($1/\Theta = 0.30$) due to inadequate scale ($1/\Theta \neq 1/\varphi = 0.57$), inadequate production mix ($1/\psi = 0.73 \neq 1/\varphi$), and inadequate managerial practices ($1/\psi = 0.73 \neq 1$). The decision-making-process to eliminate these inefficiencies should be hierarchical, i.e., efficiency-enhancing goals should be established first for managerial inefficiencies, then for technical inefficiencies and finally for productive inefficiencies.

Table 7 shows the establishment of efficient goals for DMU 11 considering its managerial, technical, and productive inefficiency levels. The observed values are presented, as well as the highest equi-proportional output expansion attainable by eliminating only the causes of the respective inefficiencies, and the projected levels of attainable efficiency obtained through the weighted combination of the production plans of reference settlements.

With this information, the analyst might identify specific potential inquiry topics, action steps, and tradeoffs to establish attainable objectives, which would lead to higher efficiency levels. For example, from the productivity inefficiency portion of the table, there is indication that INCRA individual infrastructure loans are being inefficiently utilized (the projected amount for I$TINC is 400,801 rather than 568,223) and that area planted with conservationist practices might be excessive – PCHA's projected amount is 38 rather than 150 (with the caveat that these conservationist practices have long maturation periods and therefore their effects might only be reflected in output measurements after a certain length of time, thus leading to the desirability for even closer analysis of this variable in this particular settlement), while land and labor parameters (HACULT and ADULTOS) should remain unchanged. Similar analyses can be made for each of the other inefficient settlements.

7. Concluding remarks

This paper presented a methodology that contributed to agrarian reform settlement improvement through the identification of the most important success factors for relocated families, leading to an increase in the chance both of autonomous integration to the market economy and of definitive entitlement by these relocated families as well as an increase in the predictability of future settlement success. We believe this paper presents a valuable example of an application of OR for development because proven techniques based on DEA had significant social impact.

First, the methodology permitted the objective multidimensional comparison among different agrarian reform settlements not only from a strictly productivity-oriented standpoint, but also from a social inclusion point of view through the introduction of social development output variables. Second, the methodology provided unbiased technical objectivity that allowed the different constituencies to reach a consensus on settlement comparisons when originally there were significant differences in perceptions. Third, through the methodology best settlement practices could be identified, investigated, and disseminated, raising the performance of less efficient sites. As described in Section 6.5 above, DEA not only provides objective and unbiased performance evaluation, but also permits the establishment of realistic goals for less efficient settlements. Finally, the sheer magnitude of the resources involved in agrarian reform as well as its potential importance as a long-term wealth redistribution mechanism make this a very attractive target area for the use of OR techniques. In developing countries the scarcity of resources is an undeniable reality, and it is essential that every effort be made to guarantee the greatest return for every dollar invested in social programs.

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