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A Data Envelopment Approach to support the bid/no-bid decision of smallholder farmers on public calls participation

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Abstract Institutional markets are one of the main sources of income for smallholder farmers in Brazil. Among these markets, the National School Meal Program (PNAE) offers to the farmers the opportunity to supply food for public schools. There may exist distinct PNAE public calls for each school. The participation of the smallholder farmers in these public calls may be limited by their scarce sources. Thus, it became necessary to create a tool to support their decision whether they should or not take part in the completion of attending a public call. The objective of this paper is to propose a tool for priority setting decision. Data Envelopment Analysis (DEA) is applied to rank the public calls (where the public calls are incorporated into the model as Decision-Making Units - DMUs) using the relative efficiency as a ranking criterion, also the methodology proposed to evaluate the bid/no-bid decisions using DEA, applying the Composite Index (CI) tie-breaking method to all DMUs in the context of institutional markets for smallholder farmers, considers all efficient and inefficient DMU as a choice if profitable, which makes it also different from what was done in the literature. The final result shows a priority attending setting to the smallholder farmers, according to the efficiency rank. An empirical application for a group of smallholder farmers in the Brazilian State of Goiás is presented. The main contribution is helping smallholder farmers to make more grounded decisions and the application of DEA model in conjunction with tie-breaking technique of the composite index (Leta et al., 2005) for a bid/no-bid supporting-decision tool in a new context (institutional markets for smallholder farmers) and considering the inefficient DMUs if profitable.

Keywords: Decision Support; Data Envelopment Analysis (DEA); Institutional markets; Smallholder farmers; Brazil.

1 Introduction

In the last decades, Brazil received international recognition for successful initiatives against poverty and hunger. Though there is still a lack of academic studies regarding how these government initiatives are

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executed and how to improve their current performance, in the benefit of the most vulnerable part of society (World Food Program, 2010). Among the Brazilian initiatives, the National School Meal Program (PNAE) is believed to be the largest institutional procurement program in the world that deliberately prioritizes purchasing from the smallholder farmers (IPC-IG, 2013). Despite the existence of the PNAE, the vulnerable farmers face challenges in deciding which public calls they should apply to.

These challenges are often related to the following facts: the calls are published almost concomitantly; to the deadline for presentation of the sales projects is short; there are many schools with many products and different purchase prices for the same product; the location of each school affects the delivery cost of the products; depending on the location of the school the priority of sale of each farmer is modified according to the competitors; among others.

The participation of vulnerable farmers to government food procurement programs is often limited by scarce resources that do not allow farmers attending all public calls, so it is necessary to support them in deciding which ones to attend, considering their objectives and constraints.

The aim of this paper is to present a tool for priority setting decision using relative efficiencies from Data Envelopment Analysis (DEA) to support the decision making of smallholder farmers, regarding which public calls they should choose to apply, considering the quantitative characteristics of the calls and the qualitative that reflects the objectives of the smallholder farmers. Besides the practical objective, the paper also aims to propose a different methodology to evaluate the bid/no-bid decisions using DEA, applying the Composite Index (CI) tie-breaking method to all DMUs in the context of institutional markets for smallholder farmers and considering all inefficient DMU as a choice if profitable.

2 Literature Review

The literature of bid/no-bid is more often found in the civil construction area, regarding the contractor's decision to attend project-oriented business (Aboelmagd, 2018; Leśniak and Plebankiewicz, 2015; Lin and Chen, 2004; Wanous et al., 2003). In this context, the supporting-decision tools are usually made based on a set of criteria, such as the reputation of the company, competition, environmental risks, and resource capability (Lin and Chen, 2004). Though the first two categories of criteria may rarely be applied in a context of institutional markets, where the smallholder farmers have a preference for attending calls. The priority is due to their vulnerability and not related to their business reputation. There is few (or no) environmental competition (IPC-IG, 2013).

The construction managers may state that quantitative models are not reliable because the use of historical data is based on the assumption that competitors will present the same past bidding behavior (Lin and Chen, 2004). However, the main challenges for smallholder farmers are related to the capability of producing the requested type and quantity of the product(s), and to the profitability after producing and distributing, once the sale price is given by the public tender. The non-attendance of a winning bid may imply in punishment, such as the prohibition of the smallholder farmers to participate in future calls (IPC-IG, 2013). In this regard, quantitative decision-tools are adequate, since the data of resource criteria and institutional market sale prices are reliable.

Quantitative bid/no-bid supporting-decision tools were classified into four categories: (i) analytic hierarchy process (AHP); (ii) fuzzy approaches; (iii) multi-attributes decision making (MADM); (iv) scoring methods (Lin and Chen, 2004). While other authors classified into (i) weight model; (ii) parametric bidding model; (iii) neural network model; and (iv) fuzzy model (Leśniak and Plebankiewicz, 2015).

AHP is a determinist technique based on a pair-wise comparison of alternatives or criteria. It switches individual preferences inside ratio scale weights which can merge them as alternative linear additive weight. Among the pointed weakness of AHP, there are the difficulties to assess various relative important criteria (Aboelmagd, 2018) and to deal with how the translation and the aggregation of the linguistic measurements into usable terms for decision-making (Lin and Chen, 2004). Fuzzy-logic is an effective approach to quantify imprecise information, such as linguistic terms. In such a way that, decision-makers can reason and make decisions based on vague and incomplete data. An interested reader in this context of applications may consult Leśniak and Plebankiewicz (2015) and Lin and Chen (2004).

Scoring methods are understood as linguistic checklist used by decision-makers to evaluate criteria. As these approaches do not translate results to numeric values, fuzzy techniques, as well as weight models and parameter models were proposed as a complementary solution (Leśniak and Plebankiewicz, 2015). These approaches present the limitations of not taking into account the uncertainty associated with the mapping of one's judgment to a number and underestimating the significant influence of the evaluators' subjectivity (through subjective weight attribution) (Lin and Chen, 2004).

In this regarding, data-driven approaches, such as Data Envelopment Analysis (DEA) and neural network models, may be more adequate to reduce ambiguity because they automatically attribute weights. Neural network models accept a collection of inputs and results in a collection of outputs based on internal mapping relationship encoded in their structure and connection weights. However, one of the main pointed limitations of neural networks is the black-box feature (Wanous et al., 2003). On the other hand, DEA measures the relative efficiency of Decision-Making Units (DMUs), through the insertion of variables (usually classified as inputs and outputs) and the model automatically attributes weight. The same parameters always result in the same results. There is no obscurity about the processing mechanisms (Cook et al., 2014).

DEA may be seen or a multi-criteria decision-making tool (MCDM), where each alternative of bidding is a DMU (Cook et al., 2014). Among the authors that have applied DEA for the context of construction bidding, the most relevant for the present discussion are El-Mashaleh (2010), El-Mashaleh (2013) and Polat and Bingol (2017). The three applied the basic DEA model with constant scale (known by the acronyms CCR) and did not apply any additional technique, such as sensitivity analysis or tie-breaking.

In this regard, the present paper represents a novelty due to the application of a bid/no-bid supporting-decision tool in a new context (institutional markets for smallholder farmers) and the application of DEA model in conjunction with tie-breaking technique of the composite index (Leta et al., 2005).

3 Methodology

A decision support method, based on Data Envelopment Analysis (DEA), is presented. In DEA, the analysed units are called Decision Making Units (DMUs). A DEA rank result "1" represents a DMU with 100% efficient and a rank result "0" represents a totally inefficient DMU. All results between 1 and 0 represent a DMU that can be improved to achieve efficiency and a deeper investigation of this DEA result may point out the directions for efficiency achievement. For a bid or no/bid application, usually only 100% efficient DMUs are considered bid options (Polat and Bingol, 2017), but, in the case of this paper, all DMU (including the inefficient ones) are considered, because even inefficient DMU could be profitable. In this way, the final ranking is more important than the efficiencies.

The constant returns to scale DEA model is called CCR (acronym of Charnes et al., (1978)). It is formulated as follows:

$$\min \theta\text{-}\varepsilon\left(\sum_{i=1}^{m} S_i^{+} + \sum_{j=1}^{n} S_j^{-}\right) \quad (3.1)$$

$$\text{s.t.: } \sum_{k=1}^{w} \lambda_k x_{jk} + S_j^{-} - \theta x_{j0} = 0; \quad j=1,2,\ldots,n \quad (3.2)$$

$$\sum_{k=1}^{w} \lambda_k y_{ik} - S_i^{+} = y_{i0}; \quad i=1,2,\ldots,m \quad (3.3)$$

$$\lambda_k \geq 0 \quad (3.4)$$

Where: θ is the efficiency, S_i^{+} is the slack of the ith output, S_j^{-} is the slack of the jth input, λ_k is the contribution of the kth DMU to the DMU under analysis, x_{jk} is the jth input of the kth DMU, y_{ik} is the ith output of the kth DMU, n is the number of inputs, m is the number of outputs, w is the number of DMUs, and k=0 refers to the DMU under analysis.

One of the limitations of DEA ranking results is the high level of tied efficient DMUs (Adler and Golany, 2007; Cook et al., 2014). To overcome this limitation, the results are obtained after two steps. At the first step, a standard efficiency frontier approach is applied, where the public calls are the model's Decision-Making Units (DMUs). In the second step, an inverted efficiency frontier approach (exchanging outputs by inputs, and inputs by outputs) to obtain the composite index from the tie-breaking method proposed by Leta et al. (2005). This method of Leta et al. (2005) is formulated as follows:

$$CI=\frac{(\theta_{std}+(1-\theta_{Inv}))/2}{\max[(\theta_{std}+(1-\theta_{Inv}))/2]} \qquad (3.5)$$

Where:
CI is the composite index based on the efficiencies.
θ_{std} is the standard θ (Equation 1).
θ_{inv} is the inverted θ (calculated exchanging outputs by inputs, and vice versa).

The priority setting of attending a public call is defined by the position of the public call in the final rank (after the application of the tie-breaking method).

In the present context, each DMU is a public call of PNAE. The inputs and outputs are variables associated to the characteristics of the call (e.g., the quantity of requested product, type of requested product, price, etc.) and to the farmers' internal factors (e.g., available farmland, production costs, transportation options, and costs, etc.). The variables used in the model were the following ones, being the qualitative variables used as outputs:

- Priority in the selection process
- Perception of the chance of winning
- Need to Hire Third-Party Transportation
- Easiness of Crop Production
- Perishability of Crop
- Type of Bid
- Availability of required equipment
- Initial investment need
- Potential to reduce the cost of transportation by providing in other markets in near location.

And the quantitative variables were used to compose a measure used as the input:

- Revenue and costs (production and transport).

The measure used as input was calculated as in Equation 3.6.

$$\text{Input} = 1/(\text{Revenue} - \text{Costs}) \qquad (3.6)$$

The data was obtained from the public calls and a brainstorming from the smallholder farmers that makes the decisions (so the qualitative measures reflect their objectives). All the qualitative variables were measured as "the higher, the better" and measured in a way that it can be easily attributed by the smallholder farmers (e.g. about durability of the crop, little=1, intermediary=2, and much=3). So, these variables were considered as outputs of the model. And Input = 1/(Revenue - Costs) is measured based on the absolute profit in a simple way to behave as "the lower, the better" and, at the same time, since it is only one input, it contains the other quantitative measure (revenue), so, the same importance is given to all quantitative variables.

An empirical application using calls per school from the National School Meal Program (PNAE) and an aggregation per city was made using the model. The products, schools, and cities from the calls are in Table 1. The results are shown in the next topic.

Table 1 Product, Schools and Cities

City	School	Product
Guapó	Colégio Estadual Profa. Liodosia	pineapple, garlic, banana, lettuce, and manioc flour
Guapó	Colégio Estadual Jose de Assis	garlic, and banana
Guapó	Colégio Estadual José Feliciano	pineapple, garlic, banana, and manioc flour
Palmeiras de Goiás	Colégio Estadual Barão do Rio Branco	pineapple, garlic, banana, lettuce, and manioc flour
Indiara	Colégio Estadual de Indiara	pineapple, garlic, banana, lettuce, and manioc flour
Nova Veneza	Escola Estadual Francisco Alves	pineapple, banana, and lettuce
Aparecida de Goiania	Edital Municipal (todas escolas) de Aparecida de Goiânia	pineapple, garlic, banana, lettuce, and manioc flour
Pirenopolis	Edital Municipal (todas escolas) de Pirenopolis	pineapple, garlic, banana, lettuce, and manioc flour

4 Results and discussions

The application was made considering public calls for 8 schools, involving a total of 34 products and 6 cities in the state of Goiás, Brazil. At first, the results of this approach are the efficiencies of public calls by schools (aggregation of products), and by cities (aggregation of schools), with efficient DMUs tied in the first position. After the application of the tie-breaking method, is generated a final ranking with the better public calls to attend, using the ranking efficiency as a criterion. The findings can thus inform farmers on the calls to be prioritized for bidding.

The results by school can be seen in Table 2.

Table 2 DEA and composite index results.

City	School	Efficiency	Inverted Efficiency	1- Inverted Efficiency	Average	CI	Ranking
Guapó	Colégio Estadual Profa. Liodosia	0.1379	0.1807	0.8193	0.4786	0.4807	3
Guapó	Colégio Estadual Jose de Assis	0.0244	1.0000	0.0000	0.0122	0.0123	7
Guapó	Colégio Estadual José Feliciano	0.0446	0.5757	0.4243	0.2344	0.2355	6
Palmeiras de Goiás	Colégio Estadual Barão do Rio Branco	0.0273	0.3776	0.6224	0.3249	0.3263	5
Indiara	Colégio Estadual de Indiara	0.0424	0.2137	0.7863	0.4143	0.4161	4

Nova Veneza	Escola Estadual Francisco Alves	0.0087	1.0000	0.0000	0.0044	0.0044	8
Aparecida de Goiania	Municipal Schools from Aparecida de Goiânia	1.0000	0.0087	0.9913	0.9956	1.0000	1
Pirenopolis	Municipal Schools from Pirenopolis	0.0892	0.0977	0.9023	0.4957	0.4979	2

As it can be seen, the public call of Aparecida de Goiânia is the most efficient DMU after tie-breaking, the public call of Pirenópolis is the second one, while one of the public calls of Guapó is on the third position (and the other two among the three last).

The results by city, i.e. aggregating all the schools of a city, can be seen in Table 3.

Table 3 Aggregated results of DEA and IC (by city)

City	Efficiency	Inverted Efficiency	1- Inverted Efficiency	Average	CI	Ranking
Guapó	0.5891	0.1020	0.8980	0.7435	0.7468	2
Palmeiras de Goiás	0.0273	0.3776	0.6224	0.3249	0.3263	5
Indiara	0.0424	0.2137	0.7863	0.4143	0.4161	4
Nova Veneza	0.0087	1.0000	0.0000	0.0044	0.0044	6
Aparecida de Goiania	1.0000	0.0087	0.9913	0.9956	1.0000	1
Pirenopolis	0.0892	0.0977	0.9023	0.4957	0.4979	3

Table 3 also shows Aparecida de Goiânia in the first position. It indicates that whether the smallholder farmers need to choose only one call, it, definitively, should be Aparecida de Goiânia. Guapó is in the second position, while Pirenópolis is in the third position.

Hence, it indicates that whether the smallholder farmers need to choose two calls, besides Aparecida de Goiânia, the second one could be Guapó or Pirenópolis. If they win in three schools of Guapó, it would have fewer transportation costs, because of the near locations, and better qualitative aspects that reflect their objectives besides the profit.

It is also interesting making a comparison between efficiency rankings and data rankings. Table 4 shows the rankings of the model results and the revenue ranking.

Table 4 Comparison between rankings

City	Ranking (Revenue)	Ranking (CI)
Guapó	3	2
Palmeiras de Goiás	5	5
Indiara	4	4
Nova Veneza	6	6
Aparecida de Goiania	1	1
Pirenopolis	2	3

According to Table 4, despite the similarities between the rankings, the second and third positions are exchanged. It means that, despite the quantitative measure being the only input and eventually the most important variable for the model, because it will always have a weight > 0, so, it will not lead to the exact same ranking, showing the importance of the qualitative measures.

5 Conclusions

A new methodology with DEA approach considering even inefficient DMUs if profitable was proposed to support small farmers on the bid/no-bid decision regarding the attendance of public calls of the National School Meal Program (PNAE) in Brazil. It consists in also considering the inefficient DMUs as a choice, so the ranking is more important than the efficiency. It also considers qualitative measure in regard of the objectives of the smallholder family farmers other than only quantitative measure.

Depending on the objectives of the smallholder family farmers, a ranking considering all DMUs after tie-breaking in the context of institutional markets for smallholder farmers is more important than the status of the (efficient) DMU.

The decision-support method can help farmers to identify most profitable public calls with a better chance of winning the bid. This model can be applied to other regions of Brazil (as well as other developing countries) to improve the income of family farmers across the country, contributing to the increase their standard of living.

Suggestions for future research are considering more than one city in a route like in a DEA-Routing model, and using other composite measures.

6 References

Aboelmagd, Y.M.R. (2018), “Decision support system for selecting optimal construction bid price”, *Alexandria Engineering Journal*, Vol. 57 No. 4, pp. 4189–4205.

Adler, N. and Golany, B. (2007) ‘PCA-DEA’, in Modeling Data Irregularities and Structural Complexities in Data Envelopment Analysis. Boston, MA: Springer US, pp. 139–153. doi: 10.1007/978-0-387-71607-7_8.

Chisala, M. L. (2017) ‘Quantitative Bid or No-Bid Decision-Support Model for Contractors’, Journal of Construction Engineering and Management. doi: 10.1061/(ASCE)CO.1943-7862.0001407.

Cook, W.D., Tone, K. and Zhu, J. (2014), “Data envelopment analysis: Prior to choosing a model”, *Omega (United Kingdom)*, Vol. 44, pp. 1–4.

El-Mashaleh, M.S. (2010), “Decision to bid or not to bid: a data envelopment analysis approach”, *Canadian Journal of Civil Engineering*, Vol. 37 No. 1, pp. 37–44.

El-Mashaleh, M.S. (2013), “Empirical Framework for Making the Bid/No-Bid Decision”, *Journal of Management in Engineering*, Vol. 29 No. 3, pp. 200–205.

IPC-IG. (2013), “Structured Demand and Smallholder Farmers in Brazil: the Case of PAA and PNAE”.

Leśniak, A. and Plebankiewicz, E. (2015), “Modeling the Decision-Making Process Concerning Participation in Construction Bidding”, *Journal of Management in Engineering*, Vol. 31 No. 2, p. 04014032.

Leta, F.R., Mello, J.C.C.B.S. de, Gomes, E.G. and Meza, L.A. (2005), “Métodos de melhora de ordenação em DEA aplicados à avaliação estática de tornos mecânicos”, *Investigação Operacional*, Associação Portuguesa de Investigação Operacional, Vol. 25 No. 2, pp. 229–242.

Lin, C.-T. and Chen, Y.-T. (2004), “Bid/no-bid decision-making – a fuzzy linguistic approach”, *International Journal of Project Management*, Pergamon, Vol. 22 No. 7, pp. 585–593.

Polat, G. and Bingol, B.N. (2017), “Data Envelopment Analysis (DEA) Approach for Making the Bid/No Bid Decision: A Case Study in a Turkish Construction Contracting Company”, *Scientia Iranica*, Vol. 24 No. 2, pp. 497–511.

Wanous, M., Boussabaine, H.A. and Lewis, J. (2003), “A neural network bid/no bid model: the case for contractors in Syria”, *Construction Management and Economics*, Taylor & Francis Group , Vol. 21 No. 7, pp. 737–744.

World Food Program. (2010), “Brazil’s President Lula Honoured For Fighting Hunger”, available at: https://www.wfp.org/stories/brazils-president-lula-honoured-wfp-champion-against-hunger (accessed 3 November 2019).