Reallocating Agricultural Greenhouse Gas Emission in EU15 Countries

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Abstract

This research work uses an alternative approach for modeling agricultural greenhouse gas emissions as an undesirable output, based on the zero sum gains DEA model (ZSG-DEA BCC model). This approach reallocates agricultural greenhouse gas emissions among EU15 countries. The reallocation analysis of greenhouse gas emissions permits countries that increase their emissions negotiate the emissions reduction with the others. This negotiation process might create a quota trade system for agricultural activity.

Keywords: DEA, Zero Sum Gains, Movement along the Efficient Frontier, Smoothed Frontier, Greenhouse Gas Emissions

1. Introduction

Human activities have altered the chemical composition of the atmosphere through the build-up of greenhouse gases and contributed to climate change which is one of the greatest challenges in our time. A long-term cooperative action among all countries is required to prevent carbon dioxide, methane and nitrous oxide which are for climate change. Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide have increased by 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by 15%.

Agriculture is a major source of greenhouse gas emissions and has contributed 14% of global emissions (FAO, 2009). When combined with related land used changes, including deforestation, this share becomes more than one-third of the total greenhouse gas emissions. Reducing and removing emissions from agriculture, while ensuring food security and enabling economic growth will need to form part of an urgent global effort to combat climate change.

The Kyoto Protocol was established in December 1997 to achieve the objective of the United Nations Framework Convention on Climate Change, which proposes the greenhouse gas emissions in atmosphere must be set at concentrations that do not affect life on Earth. The 2009 Copenhagen Accord suggests the necessity of deep cuts in global emissions according to science, and as documented by IPCC Fourth Assessment Report to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius.

The objective of this research work is to present a fair allocation of agricultural greenhouse gas emissions among EU15 countries, contributing to the Kyoto Protocol and the 2009 Copenhagen Conference objectives, which is to stabilize greenhouse gases concentration in the atmosphere and/or carbon quotas trade that do not affect the global emission which is indispensable to sustainable development. This research work considers that the maximum emissions concentration is the agricultural greenhouse gas emissions of the EU15 countries in 2007, while fair allocation means that it is one with which all countries become 100% DEA efficient, that is lie on the uniform frontier.

2. Methodology

DEA modeling in the presence of undesirable outputs can be seen in works by Färe *et al* (2000, 2003, 2004), Lovell *et al* (1995), Grosskopf (1995), Seiford and Zhu (2002), Thanassoulis (1995) and Gomes (2003). This research work uses an alternative approach to modeling undesirable outputs, based on the zero sum gains DEA models (Gomes *et al*, 2008). The Zero Sum Gains DEA model (ZSG-DEA model) represents a situation similar to a zero sum game (Osborne and Rubinstein, 1999), where all that was gained (lost) by one of the players must be lost (gained) by the others, that is the net gains sum must be equal to zero. In opposition to the traditional DEA models, the way one DMU reaches its target in the efficient frontier implies changing the frontier through the use of strategies in DEA targets searching in a smoothed frontier (Gomes and Lins, 2008). Gomes *et al* (2003) proposed strategies in DEA targets searching, with emphasis on the proportional reduction strategy. According to this strategy, the inefficient DMU searching for efficiency must lose some input (or alternatively receive some quantity of output). In order to keep the total sum constant, the other DMUs must receive that amount of input (lose that quantity of output) proportionally to their original values of that input (output) (Gomes and Lins, 2008).

The formulation of the ZSG-DEA BCC model, output-oriented, is presented for a DMU_o:

$$
\begin{aligned}
&Max \quad h_{Ro} \\
&\text{Subject to} \\
&\sum_j \lambda_j \, x_j \le x_o \\
&h_{Ro} y_o \le \sum_j \lambda_j \, x_j \left(1 \quad - \frac{y_o (h_{Ro} - 1)}{\sum_{j \neq 0} y_j}\right) \\
&\sum_j \lambda_j \; = 1 \\
&\lambda_j \; \ge \; 0
\end{aligned}
$$

Where h_{Ro} is the DMU_o efficiency under the restriction that the output sum must be constant; x_j and y_j are the inputs and outputs original values, respectively; x_o and y_o are the inputs and outputs for the DMU_o; the λ_j are DMU contributions to the efficient projections. This formulation includes the convexity restriction $\sum_j \lambda_j = 1$ for the the ZSG-DEA BCC model.

The traditional DEA model has multiple optimal solutions in the extreme-efficient DMUs. This is a drawback in several solutions. The frontier is piece-wise, meaning that for the extreme-efficient DMUs there is no tangent plane to the DEA frontier, as these DMUs are the cusps of the faces. The solution consists in changing the original frontier by another with continuous partial derivatives in every point and being as close as possible to the original one. A smoothed frontier with similar properties to the original one is obtained, but with tangent planes at all points (Soares de Melo *et al*, 2004).

For the case of one output and two inputs, the traditional frontier of DEA approach is substituted for a polynomial as follows:

$$z = a + b\,x + c\,y + d\,x\,y + e\,x^2 + f\,y^2 + \ldots$$

Where z represents the output and x and y are the inputs. The polynomial should have the smallest degree. The polynomial degree is a function of the number of the extreme-efficient DMUs.

The formulation of the smoothed ZSG-DEA BCC model for one output and two inputs is as follows:

$$Min \quad \left\{ \int_{x_{min}}^{x_{max}} \int_{y_{min}}^{y_{max}} \left[1 \quad + \left(\frac{\partial z}{\partial x}\right)^2 \left(\frac{\partial z}{\partial y}\right)^2 \right] dxdy \quad \right\}$$

Subject to

$$z \quad (x_{effi}, y_{effi}) = z_{effi}$$

$$\frac{\partial z}{\partial x}(x_{max}, y_{max}) \geq 0$$

$$\frac{\partial z}{\partial y}(x_{max}, y_{max}) \geq 0$$
$$e, f, \ldots \leq 0$$

Where z represents the polynomial which will substitute the traditional DEA frontier; x_{min}, x_{max}, y_{min} and y_{max} represent the smallest and the greatest value of each input;

This model calculates the polynomial coefficients and we will write the smoothed frontier equation. In this smoothed frontier equation, the efficient DMUs find new values for their outputs in the ZSG-DEA BCC model where the gain should be equal to the lost of the other DMUs, that is the net gains sum must be equal to zero. The movement along the smoothed frontier should be the shortest path to the cut plane where z is equal to z_N which is the solution of the problem. The z_N is the new output value. Considering the Euclidian distance, we can calculate the minima changes for their inputs. Therefore, for each one of the DMU_j whose values have changed, it is developed the following mathematical programming model to calculate the new values of x_N and y_N for the inputs.

$$Min \;\; (x_o - x_N)^2 + (y_o - y_N)^2 + (z_o - z_n)^2$$
Subject to
$$a + b\,x + c\,y + d\,x\,y + e\,x^2 + f\,y^2 = z_N$$
$$x, y \geq 0$$

These model results, in the ZSG-DEA BCC model paradigm, show that all DMUs change their inputs to adjust to the changes of their outputs.

3. Data and Information

Agricultural production not only uses environmental resources as inputs but also puts pressure on the environment by emitting pollutants such as greenhouse gas emissions and therefore contributes to climate changes. The variables used in this study are the livestock units (in units), the utilized agricultural area (in hectares) and the agricultural greenhouse gas emissions (in tones of equivalent carbon) for EU15 countries. The livestock units include various categories of livestock. The utilized agricultural area is the total arable land, permanent grassland and land used for permanent crops, excluding unutilized land, woodland and land occupied by buildings, farmyard, tracks and ponds, etc. The agricultural main source of agricultural greenhouse gas emissions are the enteric fermentation in ruminant animals (cattle, sheep and goats), which account for 72% of methane (CH_4) emissions from agriculture; soil denitrification, which produces 88% of nitrous oxide (N_2O) emissions from agriculture; and, manure decomposition, which is responsible for 27% of CH_4 and 12% of N_2O emissions from agriculture. Since these different agricultural greenhouse gas emissions have different global warming potential, the data are expressed in terms of CO_2-equivalent (CO_2 having a global warming potential equal to 1) in order to make them comparable. The values of each variable for each EU15 country were collected for the 2007 year from Agricultural Statistics – Main Results published by Eurostat in 2008 and 2009 editions.

4. Results

Model results show that four DMUs were efficient in the BCC DEA model: France, the Netherlands, Luxembourg and Sweden (Table 1). These efficient units contribute 33.2% to the total agricultural greenhouse gas emissions. Inefficient DMUs are in the cooperation group in the ZSG-DEA paradigm.

Countries	Greenhouse gas emissions	DEA BCC efficiency	GHG emissions after reallocation	DEA BCC efficiency after reallocation
France	95.728	1.000	41.228	1,000
UK	43.216	0.782	54.273	0.998
Germany	51.479	0.806	67.336	0.999
Italy	37.211	0.878	41.855	0.999
Spain	46.426	0.754	70.889	0.999
Ireland	17.748	0.870	20.172	0.998
Holland	18.423	1.000	7.934	1,000
Denmark	10.072	0.663	15.145	1,000
Greece	11.298	0.931	12.019	0.999
Belgium	9.621	0.851	11.455	0.997
Portugal	7.638	0.810	9.481	0.999
Luxembourg	0.711	1.000	0.306	1,000
Austria	7.949	0.797	9.750	0.999
Finland	5.530	0.995	6.005	0.999
Sweden	8.431	1.000	3.631	1,000
Total	371.481		371.481	

Table 1 – DEA BCC efficiency and reallocation by ZSG-DEA model

Source: Model results

Analyzing the DMUs UK and Spain, we see that, as Spain had low livestock units and utilized agricultural area and had agricultural greenhouse gas emissions almost the same order of UK, the former is more efficient than Spain. It is possible to get other analyses for other DMUs. Using the smoothed frontier for the 3-dimensional DEA BCC scores, we determine new targets for the ZSG-DEA BCC model, with the reallocation of the agricultural greenhouse gas emissions among EU15 countries. A uniform BCC DEA frontier is built, where all DMUs are 100% efficient. After the emissions reallocation, all DMUs became efficient (Table 1). The greenhouse gas emissions after reallocation (ZSG-DEA results) might be seen as a first approach for the quotas trade process. If some countries of the Kyoto Protocol Annex I aim to become efficient, they will increase their emissions values, at the expenses of the decrease of others.

5. Conclusions

The ZSG-DEA BCC model benefits the countries that work at the optimal scale operation and punishes the ones that are not operating on the optimal scale. It can see that France must decrease its emissions and should search for partners that want or can reduce their emissions, in order to keep the global emission unchanged.

Germany and Italy, according to ZSG-DEA model, may increase their emissions, and still remain efficient; therefore they can trade their excess quota. So, it is possible to propose a quota trade process, as countries that can increase their emissions must negotiate the emissions reduction with the others.

The ZSG-DEA model brings a theoretical innovation very appropriate to the concept of the flexible mechanisms: a basic scenario for emission reallocation that ensures global efficiency and a carbon market for trading the excess quotas among countries. This quota trade process might work because agricultural emissions have to fall further, as a result of increasing social pressure and the EU´s high emissions reduction targets in agricultural activity.

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