Nonparametric Modelling of Co_2 Emission Quota

Alfons G.J.M. Oude Lansink

Wageningen University, Business Economics*

Abstract

Dutch glasshouse firms are facing the introduction of a system of tradable CO_2 emission quota. Also, the firms will be faced with a cut of CO_2 emissions of approximately 5% by the year 2010. This paper employs a nonparametric method for modeling tradable CO_2 emissions of Dutch glasshouse firms. The method is capable of generating shifts in CO_2 emissions across the sample of firms. Also, changes in volumes of outputs produced and inputs used are computed. Results show that firms using a conventional heating technology will be net purchasers of CO_2 emissions, whereas firms using more advanced heating technologies will sell part of their emission quota.

Keywords: DEA, CO_2 emissions, tradable emissions, non-parametric modelling.

Introduction

The Dutch glasshouse industry is an important user of energy and accounts for approximately 4% of greenhouse gas emissions in the Netherlands. In 1995, the Dutch glasshouse industry made a covenant with the government aiming at reducing the use of energy. In the covenant, the Dutch glasshouse industry has to improve its energy efficiency by 65% in 2010 compared to the level of 1980 (Stuurgroep Landbouw en Milieu, 2000). The Dutch glasshouse industry may improve its energy efficiency by investing in new energy saving technologies or, alternatively by improving the efficiency of the current production potential. Information about the environmental performance of glasshouse firms can be used for assessing the potential for reducing the use of energy and emissions of carbon dioxide (CO_2) using different current available energy saving technologies. This information can be useful in guiding the process of energy efficiency improvement under the covenant and reduction of CO_2 emissions as required under the Kyoto protocol.

* Hollandseweg 1, 6706 KN Wageningen, Phone: +31-317-485194; E-mail: Alfons.oudelansink@wur.nl.

Currently, the glasshouse sector is facing the introduction of a system of tradeable CO_2 emissions and the maximum allowed CO_2 emission level for the glasshouse industry as a whole will be cut by approximately 5% (LTO, 2005). The extent to which quota are redistributed by allowing for trade critically depends on the variation in the firm-specific marginal value of CO2 quota. Marginal values are likely to differ across firms, due for example to differences in technology and managerial performance. Technological differences and differences in managerial performance between firms are frequently measured by technical efficiency. Therefore, the size of marginal abatement costs may be closely related to technical efficiency (Oude Lansink, 2003) and profitability (Brannlund et al., 1998). However, the relationship between technical efficiency and marginal abatement costs is still a largely neglected area of research.

Tradeable emission rights have been frequently modelled in the literature using parametric approaches based on micro-econometric models (see e.g. Boots et al., 1997). Oude Lansink (2003) used a parametric approach for modelling CO_2 emissions. However, the parametric approach and consequently the computation of the marginal value of quota is restricted by the functional form employed.

The Data Envelopment Analysis (DEA) approach has been proposed as a nonparametric method for evaluating producers performance in the presence of adverse environmental impacts (e.g., Färe et al., 1989; Ball et al., 1994; Tyteca, 1997). Färe et al. (1989) modify the efficiency measures proposed by Färe, Grosskopf and Lovell (1985) to allow for an asymmetric treatment of desirable and undesirable outputs. Following Färe et al., (1989) and Pittman (1983), Ball et al. (1994) adjust a conventional measure of total factor productivity growth by incorporating undesirable outputs in the production process. The DEA approach is attractive for its flexibility and computational ease. Moreover, it avoids assumptions on the functional form of the investigated relationships. A disadvantage of the DEA method is that it likely confounds efficiency with errors in the data that result from e.g. stochastic events (weather) or measurement of variables. Levring Andersen and Bogetoft (2003) applied DEA to model tradable quota in fisheries.

The objective of this paper is threefold. First, following Levring Andersen and Bogetoft, it develops a nonparametric approach to modelling tradable CO_2 emissions in the Dutch glasshouse industry. The approach adopted in this research allows for computing the redistribution across firms of CO_2 emissions. Moreover, the approach allows for computing changes in volumes of variable inputs and outputs as a result of quota trade and the reduction of the total CO_2 quota level by 5%. Second, this paper analyses the relation between various efficiency measures and quota trade. Third, this paper investigates the relation between heating technologies and demand for additional CO_2 quota.

The remainder of this paper is structured as follows. The next section presents the DEA models that are used for modelling (tradeable) CO_2 emissions. This is followed by a discussion of data. Next the results are presented and the paper concludes with comments.

DEA models for CO2 emissions

The discussion of the DEA models starts from a set of observations of firms in a sample that use a *vector* of desirable variable inputs (x^v), CO_2 emissions (w) and a *vector* of fixed inputs (x^f) to produce a desirable output (y).

Input-oriented overall technical efficiency for each firm i, $i=1, \dots, N$, is calculated from the following non-linear programming problem:

$$
\begin{aligned}
&\min_{\theta_w, \lambda} \theta_w \\
&\text{s.t.} \quad -y_i + Y\lambda \geq 0 \\
&\qquad \theta_w x_i^v - X^v\lambda \geq 0 \\
&\qquad \theta_w w_i - W\lambda \geq 0 \\
&\qquad \theta_w x_i^f - X^f\lambda \geq 0 \\
&\qquad N1'\lambda = 1 \\
&\qquad \lambda \geq 0
\end{aligned}
\tag{1}
$$

where θ_w is the overall technical efficiency score ($\theta_w \in [0,1]$) for the i-th firm under the assumption of weak disposability of CO_2 emissions, Y is the ($1xN$) vector of observed outputs, X^v is the matrix of observed desirable variable inputs, W is ($1xN$) vector of CO_2 emissions, X^f is the matrix of observed fixed inputs and λ is a $Nx1$ vector of intensity variables (firm weights). The value of the firm weights identifies the firms that determine the production frontier. The constraint $N1'\lambda=1$ (with $N1$ being an $Nx1$ vector of ones) implies the sum of the lambda's equals one and allows for a variable returns to scale (VRS) technology. Overall technical efficiency represents the maximum proportional reduction of all inputs subject to the constraints imposed by the observed outputs and the technology.

Using the notion of subvector efficiency proposed by Färe, Grosskopf and Lovell (1994), CO_2 technical efficiency is calculated for each firm i by solving the following problem:

$$
\begin{aligned}
&\min_{\gamma_w^c, \lambda} \gamma_w^c \\
&\text{s.t.} \quad -y_i + Y\lambda \geq 0 \\
&\qquad x_i^v - X^v\lambda \geq 0 \\
&\qquad \gamma_w^c w_i \geq W\lambda \\
&\qquad x_i^f - X^f\lambda \geq 0 \\
&\qquad N1'\lambda = 1 \\
&\qquad \lambda \geq 0
\end{aligned}
\tag{2}
$$

where γ_W^C is the CO_2 technical efficiency score for firm *i* and all the other variables are defined as before. CO_2 technical efficiency represents the maximum contraction of this input, holding outputs and other inputs constant. Therefore, the CO_2 efficiency model involves finding a frontier that minimises the quantity of CO_2 emissions.

Profit efficiency is computed by solving the LP problem in (3).

$$\begin{aligned}
&\underset{\lambda, x_i^{*v}, y_i^*, w_i^*}{Max} \; p \cdot y_i^* - r \cdot x_i^{*v} \\
&s.t. \quad -y_i + Y\lambda \geq 0 \\
&\qquad x_i^{*v} - X^v\lambda \geq 0 \\
&\qquad w_i^* - W\lambda \geq 0 \\
&\qquad x_i^f - X^f\lambda \geq 0 \\
&\qquad N1'\lambda = 1 \\
&\qquad \lambda \geq 0
\end{aligned} \tag{3}$$

where x^{*v} and y^* denote variable input and output quantities that maximise variable profit, defined as revenue minus costs of variable inputs. Profit efficiency is computed as the ratio of actual and maximum obtainable profit: π_i / π_i^*, where π_i is actual profit defined as $p \cdot y_i - r \cdot x_i^v$ and π_i^* is actual profit defined as $p \cdot y_i^* - r \cdot x_i^{*v}$.

$$\begin{aligned}
&\underset{\lambda, x_i^{*v}, y_i^*, w_i^*}{Max} \sum_{i=1}^{N} p \cdot y_i^* - r \cdot x_i^{*v} \\
&s.t. \quad -y_i^* + Y\lambda \geq 0 \quad \forall i \\
&\qquad x_i^{*v} - X^v\lambda \geq 0 \quad \forall i \\
&\qquad w_i^* - W\lambda \geq 0 \quad \forall i \\
&\qquad N1'w_i^* \leq \overline{W} \quad \forall i \\
&\qquad x_i^f - X^f\lambda \geq 0 \quad \forall i \\
&\qquad N1'\lambda = 1 \quad \forall i \\
&\qquad \lambda \geq 0 \quad \forall i
\end{aligned} \tag{4}$$

The fourth constraint ensures that the sum the CO_2 emission quota across all firms in the sample does not exceed the maximum total emission level $\overline{W}$. The difference between the variable input and output volumes computed in (4) and (3) indicates the change in the input-output mix as a result of the introduction of system of tradable quota and $\overline{W}$.

Data

Data on specialised vegetables firms covering the year 1995 come from a stratified sample of Dutch glasshouse firms keeping accounts on behalf of the LEI accounting system. The firms typically remain in the panel for a maximum of eight years, so the panel is incomplete. Firms rotate in and out the sample to avoid a selection bias which arises when firms improve their performance by their presence in the accounting system. The data set used for estimation contains 73 firms.

One output and six inputs (energy, materials, services, structures, machinery and installations and labour) are distinguished. Output consists mainly of vegetables. Other outputs included are fruits, potplants and flowers. Energy consists of gas, oil and electricity, as well as heat deliveries by electricity plants. Materials consist of seeds and planting materials, pesticides, fertilisers and other materials. Services are those provided by contract workers and from storage and delivery of outputs.

Fixed inputs are structures (buildings, glasshouses, land and paving), machinery and installations and labour. Labour is measured in quality-corrected man years, and includes family as well as hired labour. Labour is assumed to be a fixed input because a large share of total labour consists of family labour. Flexibility of hired labour is further restricted by the presence of permanent contracts and by the fact that hiring additional labour involves search costs for the firm operator. The quality correction of labour is performed by the LEI and is necessary to aggregate labour from able-bodied adults with labour supplied by young people (e.g., young family members) or partly disabled workers. Capital in structures, machinery and installations is measured at constant 1985 prices and is valued in replacement costs[1].

Data on CO_2 emissions have been obtained from the LEI and are measured as tons of CO_2 emission per year. CO_2 emissions are calculated from physical quantities of fossil fuels (mainly methane gas) that are used for heating and CO_2 fertilisation in the glasshouse (see Cordenier (1999) for more details). Therefore, CO_2 emissions and energy are independent factors, since energy consists of components that do not cause CO_2 emissions on the firms, i.e. heat delivery and electricity. The CO_2 emissions are partly incorporated in plants because CO_2 serves as a fertiliser. Therefore, the data overestimate the true CO_2 emissions, although the degree of overestimation is small (Cordenier, 1999).

Tornqvist price indexes are calculated for output and the three composite variable inputs with prices obtained from the LEI-DLO/CBS. The price indexes vary over the years but not over the firms, implying differences in the composition of inputs and output or quality differences are reflected in the quantity (Cox and Wohlgenant, 1986). Implicit quantity indexes are generated as the ratio of value to the price index.

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[1] The deflators for capital in structures and machinery and installations are calculated from the data supplied by the LEI accounting system. Comparison of the balance value in year t and the balance value in year t-1 gives the yearly price correction used by the LEI. This price correction is used to construct a price index for capital and a price index for machinery and installations. These price indices are used as deflators.

The firms in the sample use different heating technologies. Most firms (55%) use traditional heating based on the use of a central heating boiler; 31% of the firms use traditional heating in combination with heat storage and 10% and 4% of the firms in the sample use co-generators[2] and heat deliveries by electricity generating plants, respectively. A more detailed description of the data can be found in Table 1.

Table 1. Variables and Descriptive Statistics.

Variable	Dimension	Mean	Standard Deviation
Output	100.000 Guilders	12.48	7.76
Energy	100.000 Guilders	2.00	1.31
Materials	100.000 Guilders	1.67	1.13
Services	100.000 Guilders	1.06	0.59
Structures	100.000 Guilders	10.99	7.75
Machinery and Installations	100.000 Guilders	3.65	2.89
Labor	Man years	7.60	4.19
CO_2 Emission	1.000 Ton	15.00	10.0

Results

Solutions have been obtained for all models (1)-(4) and for all firms in the sample using the program GAMS. The LP model in (4) assumes that the firms in the sector are faced with a 5% overall cut in CO_2 quota.

Results in Table 2 show that buyers of CO_2 quota have a higher technical and CO_2 efficiency than sellers of CO_2 quota. The profit efficiency of buyers and sellers is approximately the same. Buyers purchase, on average 11.953 thousand tons of CO_2, whereas the average volume sold by sellers equals 9.459 thousand tons.

Table 2. Efficiency and traded CO2 emissions for buyers and sellers of CO_2 emission quota.

	Technical Efficiency	CO_2 efficiency	Profit Efficiency	Net purchase CO_2
Buyers	0.913	0.727	0.788	11.953
Sellers	0.894	0.646	0.803	-9.459

Table 3 shows that buyers of quota increase their volume of output by 10%, which is at the cost of a substantial (44.8%) increase in the use of energy. Increases in the volumes of materi-

[2] Co-generators are installations that combine the generation of electricity and heat.

als and services are smaller. Sellers of CO_2 quota reduce the volume of output by 7.8 % and reduce their demand for energy by 32.3%.

Table 3. Change in outputs and variable inputs for buyers and sellers of CO2 emission quota.

	Output	Energy	Materials	Services
Buyers	0.101	0.448	0.014	0.203
Sellers	-0.078	-0.323	-0.002	-0.180

Results in Table 4 provide insight in the impact of heating technologies on behaviour in the market for CO_2 emissions. Firms using heating boilers, on average, purchase 1.175 thousand tons of CO_2. Firms using more energy saving technologies, on average sell CO_2 quota. Firms using a heating boiler have a CO_2 efficiency that is lower than the CO_2 efficiency of firms using more advanced technologies.The overall technical efficiency of firms using a central heating boiler is high.

Table 4. Efficiency and traded CO_2 emissions for firms with different heating technologies.

	Technical Efficiency	CO_2 efficiency	Profit Efficiency	Net purchase CO_2
Heating boiler	0.986	0.657	0.743	1.175
Boiler + storage	0.920	0.777	0.847	-0.974
Co-generator	0.905	0.683	0.843	-2.640
Heat delivery	0.998	0.995	0.945	-0.526

Results in Table 5 show the impact of tradeable CO_2 quota and the reduction of the CO_2 quota for the whole sector by 5% on volumes of outputs and variable inputs of firms with different heating technologies. Firms using heating boilers, on average increase their output volume by 9.4% and increase their use of energy by 42.1%. The impact for firms using more advanced heating technologies is much smaller, particularly for firms using heat delivery. Firms using co-generators sell a relatively large quantity of CO_2 quota; the impact on volumes of output and demand for energy is, nevertheless small.

Table 5. Change in outputs and variable inputs for firms with different heating technologies.

	Output	Energy	Materials	Services
Heating boiler	0.094	0.421	0.026	0.194
Boiler + storage	0.003	0.034	-0.043	0.035
Co-generator	-0.011	-0.049	0.040	-0.118
Heat delivery	0.000	-0.022	-0.003	-0.057

Conclusions

This paper employs a nonparametric method for modelling tradable CO_2 emissions of Dutch glasshouse firms. The method is capable of generating shifts in CO_2 emissions across the sample of firms. Also, changes in volumes of outputs produced and inputs used are computed. The method is applied to a sample of vegetables firms in the Netherlands.

Results show that firms using a conventional heating technology will be net purchasers of CO_2 emissions, whereas firms using more advanced heating technologies will sell part of their emission quota. Net purchasers of CO_2 emission have a higher technical and CO_2 efficiency than sellers of quota. However, the profit efficiency of buyers and sellers is approximately equal.

The method developed in this paper provides a flexible tool for analysing the relation between various efficiency measures and behavior in the market for CO_2 emissions. The application is restricted to a sample of vegetables producers. In the system that will be designed for the glasshouse industry, these firms are also able to trade with firms specialised in potted plants and cut flowers. Future research should consider trade with other sectors of the economy. This is because these options affect the price of CO_2 quota and may result in an overall expansion or contraction of the sector.

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