Testing Porter's Hypothesis: A Stochastic Frontier Panel Data Analysis of Dutch Horticulture

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TESTING PORTER'S HYPOTHESIS: A STOCHASTIC FRONTIER PANEL DATA ANALYSIS OF DUTCH HORTICULTURE

Abstract:
We propose a test of the Porter hypothesis for the Dutch horticulture sector, using a stochastic production frontier analysis allowing for an inclusion of policy variables to account for the effect of environmental policy of firm performance. We find considerable heterogeneity in the way firms react to environmental policy measures. Our estimation results indicate, for example, that a 1997 voluntary agreement covering energy, nutrient and pesticides use enhances technical efficiency of vegetable and plants growers, contrary to specialised flower growers. Specialised flower growers, however, did react to the 1993 multi-year agreement on energy reduction, contrary to vegetable and plant growers. Summarising, our findings are mixed but do not seem to reject the anecdotal evidence mentioned by Porter and Van der Linde (1995b) that Dutch horticulture firms' performance increased due to increased environmental stringency.

JEL codes: D24, Q12, Q50

Keywords: firm performance, environmental stringency, technical efficiency

1. Introduction

Environmental economists schooled in the neoclassical tradition are tempted to assume that environmental policy endangers the competitiveness of (domestic) firms compared to (foreign) competitors that are not subject to such policy. The main reason for this is that environmental policy shifts formerly external costs back on to the firm burdening it relative to competing firms exposed to less strict environmental regulations. Porter (1991) launched a completely opposing view in what is nowadays called the Porter hypothesis: *"Strict environmental regulations do not inevitably hinder competitive advantage against foreign rivals, they often enhance it" (Porter 1991, p. 162)*

As pointed out by Gabel and Sinclair-Desgagné (1995, 2001) the precise meaning of the Porter hypothesis is unclear in as far as the positive impact on private costs is concerned[i]. In an attempt to elucidate the Porter hypothesis they distinguish the following variants:

-Enhanced competitiveness due to environmental policy-induced demand for complementary products and services. Environmental policy frequently requires the development of new products that reduce emissions or products that use less inputs. In this context Porter gives examples such as exports of relatively benign pesticides from the restrictive US to countries that do not have such regulations in place. Gabel and Sinclair-Desgagné observe that the present kind of situations are not really win-win because in the importing country private costs increase;

-Relatively enhanced competitiveness of the regulated firm due to the first-mover advantage. In this case strict environmental regulations will raise the costs of domestic firms subject to them but but due to learning effects less so than for firms in countries that implement similar regulations at a later stage. Again, according to Gabel and Sinclair-Desgagné (1995) this is not a win-win situation because the costs on the private sector rise even though some firms and possibly countries benefit at others´ expense[ii].

-Absolute cost reduction for the regulated firm. Hence environmental policies are potential win-win policies that simultaneously reduce the firm's private costs as well as the external costs in the form of environmental degradation.

It is the last variant that is truly win-win. For this variant to hold Gabel and Sinclair-Desgagné (2001) mention the following sufficient conditions:

(i) The firm is operating inside its cost-efficiency frontier ex ante, which implies that there is an organisational failure in the firm in the form of e.g., perverse incentives, hidden actions, imperfect information, strategic behaviour and moral hazard.

(ii) Environmental regulations stimulate a sufficiently large improvement in productive efficiency to outweigh the internalised costs.

(iii) Conditions (i) and (ii) are systematically rather than incidentally true. For this requirement to be met more empirical evidence is required than the anecdotal evidence provided by Porter

According to Gabel and Sinclair-Desgagné the underlying mechanism of the Porter hypothesis is that new environmental policy provokes a radical restructuring and reorganisation in the firm. Initially the firm's organisational structure is such that the firm is cost minimising. With the passage of time, relative prices, regulatory conditions and the firm's competitive situation change. Cost-minimisation requires the firm to adapt to the changing circumstances. If the organisational structure could be changed frequently, in small steps and at negligible cost, the firm would do so. However, these conditions are rarely, if ever, met in practice. Therefore, adaptation will only take place occasionally, and if total benefits of adaptation outweigh total adaptation costs. Another obstacle to adaptation is organisational failure that prevents the firm from reacting to opportunities or threats, contrary to an unconstrained firm. New environmental regulations that are stringent enough would impact on the adaptation costs and benefits or create strong incentives to deal with organisational failure. In both cases the firm has an incentive to reoptimise its internal structure. Porter and van der Linde (1995a) argue that lax regulations allow firms to adapt incrementally whereas strict policies promote substantial innovations which in its turn stimulates competitiveness:

"By stimulating innovation strict environmental regulations can actually enhance competitiveness" (Porter and Van der Linde 1995, p.98).

Porter and Van der Linde (1995a) give 6 reasons why regulation might promote innovation. These include that regulation makes firms aware of technical inefficiencies and reduces uncertainty about profitability of environmental investments. Moreover, with stringent regulation more benefits in terms of innovation offsets can be expected than with lax regulation.

In spite of the fact that Porter amply quotes anecdotal evidence (including evidence from Dutch horticulture) the hypothesis is still very much debated. One of the reasons for this is that not much systematic empirical work has been done in this area. The empirical research that has been done can be categorised as follows. Firstly, there is a literature studying the relationship between strictness of environmental regulation and competitiveness as measured by export performance at the national or the industry level. An often-used indicator of strictness of environmental regulation is PACE (Pollution Abatement Capital Expenditures). If a negative impact of PACE on export performance is found, then this could be interpreted as direct support for notably the second variant of the Porter hypothesis (see e.g., Mulatu 2004 for an assessment of this approach). Secondly, differences in environmentally related patents between regulated and unregulated firms can be analysed. Empirical evidence that regulated firms outperform unregulated ones provides support for notably the first and second variant. This line of research was initiated by Lanjouw and Mody (1996) and was pursued further by Jaffe and Palmer (1997), Taylor et al. (2003) and De Vries and Withagen (2004).

In the present paper we develop a third approach, with a focus on the third variant. Earlier contributions in this strand of literature use productivity indices to measure the effect of environmental regulation on efficiency (see Nakanoi, 2003). We use a stochastic frontier framework, that will be applied to Dutch horticulture. This is a very interesting sector in relation to the Porter hypothesis. In Porter and Van der Linde (1995b) Dutch horticulture is also used as an example where environmental policy has induced major innovation. And, in a recent speech the Dutch Minister of Agriculture, Nature Management and Fisheries argues as follows. "According to Porter the floriculture sector is the only real cluster of international importance in the Netherlands. The whole chain in our horticulture cluster is a close-knit and innovative one. We make optimal use of the Netherlands' natural advantages: its favourable location and a marine climate that is eminently suitable for greenhouse horticulture. We also profit from a very extensive range of products, a robust sector chain and the fact that horticulture here lays claim to only a limited amount of space in a tiny country with no space to spare. To give you an idea of the strong spirit of innovation in the Netherlands: in 2001 alone we registered 600 new varieties; we have also created the Greenhouse of the Future, which employs the most advanced mechanisation and computerisation" (Veerman, 2002). For the horticulture sector a panel data set is available that allows for a detailed analysis of technical efficiency. Tests of the third variant of the Porter hypothesis using a stochastic frontier framework are currently missing in the literature.

The main finding of this paper is that increasing environmental stringency increases technical efficiency in several subsectors of horticulture thereby lending support for the third variant of the Porter hypothesis. A related but striking result is the considerable heterogeneity in firm response to environmental stringency.

The organisation of this paper is as follows. Section 2 presents a theoretical discussion of the incorporation of environmental policy in a stochastic production frontier framework. Section 3 describes the data and the econometric model used. Section 4 discusses the estimation results. Conclusions and directions for future research follow in Section 5.

2. Stochastic production frontier analysis and environmental policy

The use of stochastic frontier models has become increasingly widespread in applied economic analyses.[iii] The motivation for using stochastic frontier models lies in evidence as well as in theory. Kumbhakar and Lovell (2000) claim that a lot of empirical evidence "suggests that not all producers are always so successful in solving their optimisation problems" and "not all producers are technically efficient" (o.c. p.2). Early theoretical contributions are from Hicks (1935) and Williamson (1964). Hicks argues that "The best of all monopoly profits is a quiet life" (o.c. p. 8). Williamson puts forward that managers rather maximise their own utility, including emoluments and profits, than profits per se.

The notion of frontier has different meanings. It may refer to technical efficiency (being at the boundary of the production set) or to allocative efficiency (cost minimisation or profit maximisation). Earlier work in the empirical literature focuses on the estimation of measures of technical efficiency, and on both technical and allocative efficiency (see Battese, 1992; Coelli et al., 1998; Bauer, 1990). For our purpose we are interested in more recent models that allow for incorporation of exogenous variables that might affect efficiency (Kumbhakar et al., 1991; Reifschneider and Stevenson 1991; Huang and Liu 1994; Battese and Coelli 1995; and Hadri et al. (2003)). These exogenous variables are factors not under control of the producer that nevertheless do have an effect on the performance of the firm. In the case at hand environmental policy is such a variable. Testing the Porter hypothesis within this context requires thus two steps. The first is the specification of a stochastic frontier production function to estimate the technical efficiency of producers. The second component is the specification and incorporation of policy variables and possibly other exogenous variables which are not at the discretion of the producer, yet affect the technical performance of firms.

The model employed in the present study is based on Coelli and Battese (1995), and Hadri et al. (2003). It can be described as follows. Consider N firms indexed by $i = 1,2,...,N$ that are observed over T periods, with periods indexed by $t = 1,2,...,T$. Each firm produces a single output using K inputs. In our model the inputs are capital, labor, energy, pesticides, nutrients (see the next section for a detailed presentation of the data set). It is quite common to assume a Cobb-Douglas technology[iv], with output y_{it} and inputs X_{it} (a K-vector) in natural logarithms. The model to be estimated is

$$(1) \qquad y_{it} = X_{it}\beta + w_{it} - v_{it}, \quad i = 1,2,...,N; t = 1,2,...,T .$$

Here β is the unknown K-vector of production elasticities, assumed common to all producers. The variables w_{it} and v_{it} are error terms with the following properties. The terms w_{it} are iid and are independent of the terms v_{it}. The v_{it}'s play a crucial role in the sense that they incorporate producer-specific and time-specific variation from the frontier. It is assumed that the v_{it}'s are independently distributed and can be modelled as

$$(2) \qquad v_{it} = Z_{it}\gamma + \varepsilon_{it}$$

where Z_{it} is an M-vector of firm specific time-varying variables not controlled by the producer, γ is an unknown M-vector to be estimated and ε_{it} is an error term following a truncated normal distribution with mean value 0 and variance σ_{ε}^{2} where the truncation point varies with $Z_{it}\gamma$ such that $v_{it} \geq 0$.

The technical efficiency of producer i $(i = 1,2,...,N)$ can then be defined as

$$TE_{it} = \exp\{-v_{it}\} \tag{3}$$

Therefore, the smaller v_{it} the closer the producer is to its production frontier.

Under the assumptions made the statistical properties of the model are well documented (see e.g., Hadri et al. 2003). For example, the conditional expectation of v_{it} given ε_{it} is

$$E[v_{it} | \varepsilon_{it}] = \mu_{it} + \sigma \frac{\varphi(\mu_{it} / \sigma)}{\Phi(\mu_{it} / \sigma)} \tag{4}$$

where $\sigma := \frac{\sigma_w \sigma_v}{\sigma_w + \sigma_v}$, $\mu_{it} := \frac{\sigma_w Z_{it} \gamma - \sigma_v^2 \varepsilon_{it}}{\sigma_w^2 + \sigma_v^2}$ and φ and Φ are the standard normal density and distribution.

In the sequel we employ the framework outlined above and apply it to Dutch horticultural firms. Among the explanatory Z variables of the technical efficiency model are indicators of environmental stringency, and managerial or organisational characteristics of production (see Battese and Coelli, 1995; Wilson et al., 2001; Trip et al., 2002). Suppose that the coefficient corresponding to environmental stringency (say γ_1) is negative and statistically significant. Then increased stringency decreases the expected value of v_{it} and therefore brings the firm closer to its production frontier. This provides support for the hypothesis that stringency of environmental policy is reducing X-inefficiency. Of course, there are many caveats. One is that environmental policy is usually generic and not aimed at individual firms, so that we cannot obtain firm-specific impacts. Moreover, the notion of stringency is very difficult to capture in general, and for this specific industry as well, as will be explained in the next section.

3. Data

The data on horticulture firms cover the period 1991-1999. They are from two sources a stratified sample of Dutch greenhouse firms included in the so called Farm Accountancy Data Network (FADN) and from a survey on environmental program participation. The FADN is a rotating panel giving an unbalanced panel data set (see for a discussion of the sampling technique Poppe, 2004). The data include information on financial performance, production techniques, crop types, physical and monetary output measures, and energy use for 417 firms and 1727 observations. Table 1 and Table 2 provide information on the number of firms per year, and the number of observations per firm, respectively. Crop types have been aggregated into three crop systems: flowers, plants and vegetables.

Table 1: Number of observations per year by crop system

Year	*Number of firms*			
	Total	Flowers	Plants	Vegetables
1991	189	72	45	72
1992	187	72	45	70
1993	184	70	45	69
1994	179	68	45	66
1995	200	71	57	72
1996	199	72	56	71
1997	206	75	58	73
1998	193	72	53	68
1999	190	71	52	67

Table 2: Number of observations per firm by crop system

Number of Observations per firm	*Number of firms*			
	Total	Flowers	Plants	Vegetables
1	20	7	5	8
2	30	9	7	14
3	107	44	27	36
4	92	34	25	33
5	87	31	26	30
6	65	25	18	22
7	5	0	0	5
8	1	0	0	1
9	10	5	2	3

The variables, their measurements units and means and standard deviations are given in Table 3. The inputs are land, labour, energy, capital, pesticides and nutrients, all measured in natural logarithms. Land is expressed in hectare, labour in full time equivalents (fte). Energy use consisting of gas, oil, electricity, and heat deliveries is expressed in gas equivalents. The energy data are corrected for average temperature per year. Capital input is measured by its replacement value. Pesticides and nutrients are expressed in monetary terms. This also holds for output. All costs and revenues are deflated to 1995 values. We include Hicks-neutral technical change in the production frontier indicating autonomous changes in the level of technical inefficiency.

There are firms that change crop type over time as well as firms that produce more than one crop. This heterogeneity poses a problem in the econometric analysis where we prefer to have homogeneous firms with respect to their main activity. We deal with these problems as follows. First, we delete firms that changed their main crop type over time[v]. Secondly, for each year and each firm we determine the main crop type by calculating the maximum revenue share of each crop in total production value. After identifying the main crop type we determine the main crop system: vegetables, flowers and plants. At first instance, these are used as dummies in a pooled model in the empirical analysis to account for sectoral differences. The motivation for the aggregation is to reduce the number of parameters to be estimated creating groups preferably with small within-group variation and large between-group variation in production techniques. We shall test whether or not the data support pooling. If not, we proceed on the basis of models on crop system. Preferably, one would like to disaggregate the crop systems and test for structural differences across individual crop types also. The limited number of observations for each specific crop prevents this. Note, however, that production techniques differ particularly between crop systems and much less within crop systems, so that within-crop system heterogeneity does not seem to create difficulties.

For the interpretation of the results of the econometric analysis it is also of interest to know to what extent firms jointly produce vegetables, flowers and plants. The data indicate that of those firms specialised in vegetables 5 % produce flowers and 1 % plants also; of those specialised in flowers 5 % produce vegetables and 12 % plants too; and of those specialised in plants, 1 % produced vegetables and 6 % flowers as well. Therefore, compared with specialised flower growers, firms specialised in vegetables or plants less often have joint production systems. Furthermore, compared with joint plant and flower production systems, joint vegetables and flowers or joint vegetables and plants production systems are less frequent. In summary, joint production across crop systems is rather uncommon mainly the result of the rather distinct production systems needed for the different crop systems.

Table 3 Summary statistics

Variable	*Description*	*Total*		*Flowers*		*Plants*		*Vegetables*	
		Mean	St.err.	Mean	St.err.	Mean	St.err.	Mean	St.err.
LQTOT	Log of output (in Dfl. x1000)	6.76	0.82	6.71	0.85	6.93	0.86	6.70	0.75
LLAND	Log of land (in hectare)	0.12	0.67	0.09	0.66	-0.08	0.76	0.28	0.54
LLABOR	Log of labor (in fte)	1.78	0.66	1.75	0.68	1.77	0.69	1.81	0.61
LENERGY	Log of physical energy (in natural gas equivalents x1000)	6.14	0.96	6.04	0.97	5.99	0.85	6.35	0.98
LCAPITAL	Log of replacement value of capital (in Dfl x1000)	7.56	0.71	7.61	0.69	7.50	0.90	7.55	0.55
LPESTICIDE	Log of pesticides (in Dfl. x1000)	2.31	1.03	2.54	1.10	1.84	1.04	2.41	0.80
LNUTRIENT	Log of nutrients (in Dfl. x1000)	2.24	1.13	1.95	1.03	1.73	1.06	2.91	0.94
TREND	Trend (1991=1 … 1999=9)	5.05	2.57	5.02	2.59	5.20	2.53	4.98	2.58
AGE	Age of the managing director (in years)	45.8	9.96	45.7	9.39	45.9	10.0	45.75	10.5
AMANAGER	Number of managers (including managing director)	1.49	0.74	1.51	0.76	1.51	0.77	1.46	0.69
FAMFIRM	Dummy (1 for family-owned firm; 0 otherwise)	0.87		0.86		0.78		0.94	
EIA PROGRAM	Dummy (1 for EIA participation; 0 otherwise)	0.09		0.10		0.11		0.07	

We now turn to environmental policy. Dutch horticulture is subject to a number of environmental policy measures imposed by the Ministry of Agriculture, Nature and Food Quality and the Ministry of Spatial Planning, Housing and the Environment. Environmental policy measures for Dutch horticulture relate mainly to the reduction of CO_2-emissions. Horticulture accounts for about 80% of total energy use associated with the agricultural sector and 5% of national energy use (Netherlands Court of Audit 2002). To reduce energy intensity a covenant was negotiated between the horticulture sector and the government in 1993, entailing a 50% reduction in 2000 relative to 1980. A dummy PROG1 is included to indicate the 1993 agreement[vi]. More recently, in 1997 another voluntary agreement (GLAMI) was reached on energy, pesticides, and nutrient reduction for the period 2000-2010. The agreement entails detailed reduction norms per crop type. It became compulsory in 2002 (GLAMI, 2000). Table 4 gives the goals for 2010 per input. Although compulsory outside the observation period, firms anticipated as from 1997, which is well before the end of the time span we observe. A dummy PROG2 is included to indicate the 1997 agreement[vii].

Table 4. 1997 GLAMI agreement

Input	*Goal for 2010*
Energy	65% reduction relative to 1980
Pesticides	Vegetables: 72% reduction relative to the average use during 1984-1988 Flowers: 88% reduction relative to the average use during 1984-1988 Plants: 88% reduction relative to the average use during 1984-1988
Nutrients	95% reduction relative to 1980

Source: GLAMI (2000).

The Ministry of Agriculture, Nature and Food Quality has a number of instruments associated with these voluntary agreements that may affect the production efficiency of horticulture firms like taxes, subsidies, and information services. MIA and VAMIL (since 1993) are environmental investment subsidies relating to a broad set of capital goods to reduce the use of, amongst others inputs, energy, pesticides and nutrients (VROM, several years). EIA (since 1997) allows firms to deduct 15-55% of total investment or depreciate specific environmental investments at will (Senter, 2003). In addition, specific subsidies on co-generating heating systems are in place since late 1997. Also, Dutch horticulture benefits from implicit subsidies through low-VAT tariffs on energy, pesticides and nutrients. In 1996, an energy tax (REB) was introduced. The effect on energy prices was negligible, because like other large energy-intensive industries with a MJA, Dutch horticulture was exempted from the energy tax. Thus, there will be no effect on production efficiency (ECN, 2002). Some of these measures are candidates to be taken into account in the analysis, particularly because of another data set on EIA Program participation. However, this data set is far from ideal because of incomplete information on a subset of our 1991-1999 sample. The reason for this is that firms are asked about EIA Program participation on a retrospective basis in 2002. As part of the firms rotate in and out of the sample we lack information on those firms who moved out of the sample between 1997-2002[viii].

4. Estimation results

The stochastic frontier panel data model is specified as follows

$$LQTOT_{it} = \beta_0 + \beta_1 LCAPITAL_{it} + \beta_2 LLABOR_{it} + \beta_3 LENERGY_{it}$$

(4)

$$+ \beta_4 LPESTICIDE_{it} + \beta_5 LNUTRIENTS_{it} + \beta_6 TREND_{it} + w_{it} - v_{it},$$

with w_{it} and v_{it} specified as in section 2. The technical efficiency model reads:

$$(5) \qquad E[v_{it}] = \gamma_0 + \gamma_1 FIRM_{it} + \gamma_2 PROG_t + \gamma_3 EIA_{it} + TREND_{it}$$

with firm-specific, time-varying variables AGE (of the farmer), AMANAGER, and FAMFIRM included in the vector FIRM to capture firm-specific variation in managerial and organisational structure. The meaning of these variables is given in Table 3. We also include PROG time-varying dummies indicating environmental policy regimes, and EIA an exogenous firm-specific, time-varying EIA Program participation variable.

The estimates of $\vartheta := (\beta, \gamma, \sigma_w, \sigma_v)$ are obtained by means of maximum likelihood. On the basis of these estimates one can obtain estimates and associated confidence intervals of producer-specific time-variant technical efficiency. The estimates are obtained using the 4.1c Version of FRONTIER (Coelli, 1992).

The results are presented in table 5 where standard errors are given within brackets. First, we test for the presence of technical inefficiency. At the bottom of Table 5 log-likelihood values and Likelihood Ratio (LR) statistics for the presence of technical inefficiency[ix] are presented, together with information on the number of observations. The LR statistic in Table 5 gives the test statistics, with degrees of freedom in parenthesis, for the null hypothesis of no technical inefficiencies in production. The LR test rejects the hypothesis of no technical inefficiencies. Second, we tested the hypothesis that the frontier models are the same for each crop system. That is, we tested whether structural differences in production structure exist, by testing a pooled model versus separate models for flowers, plants and vegetables. The likelihood ratio test rejects the hypothesis of a pooled model. The LR test statistic equals 934 and is larger than the critical value for the Chi-square distribution at size 0.05 and 17 degrees of freedom of 27.85. Note, that the coefficient of LNUTRIENTS in the pooled model in column one of Table 5 has the wrong sign, as one would expect a positive effect of inputs on output. Controlling for heterogeneity in production structure between crop systems[x] reveals the expected sign (see Table 5). In the remainder of this section we therefore discuss the results of the theoretically preferred models[xi].

The production frontier model results indicate that production is increasing in both fixed and variable inputs. The output elasticity of variable inputs is lower compared with the fixed inputs. The output elasticity of Energy, LENERGY, is higher than that of other variable inputs, LPESTICIDE and LNUTRIENT. The sum of these estimates indicates increasing returns to scale for each and every crop system. Note also the significant TREND in output of about 3 to 4 percent yearly[xii]. The estimates furthermore suggest significant structural differences in production structure between crop systems; the output elasticity of LCAPITAL varies considerably, ranging from 2% for plants and 50% for flowers, respectively. A closer inspection of the production systems suggest that this might be related to heterogeneity within crop systems not accounted for[xiii].

The technical efficiency model indicates significant differences between firms and across time. Table 6 shows mean technical efficiency scores by sector and year. Mean technical efficiency varies from 0.77 for plants (in 1995 and 1996), to 0.94 for vegetables in 1991.

Also, parameter estimates of the technical efficiency model (as shown in Table 5) indicate structural differences between crop systems. Particularly interesting for our purposes is the effect of EIA PROGRAM on technical efficiency across crop system. In general EIA PROGRAM reduces technical inefficiency although not always statistically significant. Summarising, our findings are mixed but do not seem to reject the hypothesis that firm performance increased due to environmental agreements aiming at stronger environmental stringency. These findings do no change when considering more flexible specifications as the Translog (see Appendix A Table A1).

Furthermore, the estimates indicate firm-specific heterogeneity in technical efficiency. Family operated farms for example perform less efficiently relative to not-family operated farms (Inc.). Furthermore, the estimates suggest that firms' time horizon as summarised in AGE are important as well in explaining technical efficiency[xiv]. Summarising, part of the heterogeneity between firms can be explained by managerial and organisational factors.

Table 5 Estimates of Cobb-Douglas Stochastic Frontier Panel Data Models

Variable	Pooled	Flowers	Plants	Vegetables
Production frontier				
CONSTANT	1.74** (0.19)	2.11** (0.38)	4.46** (0.35)	3.60** (0.32)
LLAND	0.09** (0.03)	0.13** (0.05)	0.27** (0.05)	0.29** (0.04)
LLABOR	0.44** (0.02)	0.29** (0.04)	0.40** (0.03)	0.24** (0.03)
LENERGY	0.33** (0.02)	0.09** (0.04)	0.31** (0.04)	0.30** (0.02)
LCAPITAL	0.24** (0.02)	0.48** (0.05)	0.02 (0.03)	0.11** (0.04)
LPESTICIDES	0.01 (0.01)	0.04** (0.02)	0.01 (0.02)	0.03* (0.02)
LNUTRIENTS	-0.07** (0.01)	0.04 (0.03)	0.05** (0.02)	0.07** (0.02)
TREND	0.04** (0.00)	0.04** (0.01)	0.03** (0.01)	0.03** (0.01)
Technical efficiency				
CONSTANT	-6.20** (0.54)	-9.90** (0.80)	-8.44** (3.15)	-10.0** (0.35)
AGE	0.07** (0.01)	0.15** (0.01)	-0.01** (0.01)	0.02** (0.00)
FAMFIRM	1.64** (0.12)	1.10** (0.15)	3.96** (1.54)	0.28** (0.13)
AMANAGER	-0.54** (0.07)	-0.40** (0.10)	0.70 (0.25)	-0.24** (0.09)
TREND	-0.09* (0.02)	-0.19* (0.07)	-0.02 (0.04)	0.01 (0.01)
EIA PROGRAM	-0.79** (0.11)	-0.10 (0.41)	-0.45 (0.30)	-0.73** (0.31)
$S^2 = S_v^2 + S_u^2$	0.66** (0.08)	0.77** (0.07)	1.72** (0.61)	0.05** (0.01)
S_u^2/ S^2	0.88** (0.02)	0.92** (0.01)	0.97** (0.01)	0.51** (0.11)
Log-likelihood	-475	-134	-102	+171[xv]
Number of observations	1511	554	404	553
Number of cross-sections	401	148	105	148
Number of time periods	9	9	9	9
LR statistic	204(7)	180 (7)	63 (7)	52 (7)

Notes: *, ** significant at 5% and 1%, respectively.

Table 6. Mean Technical Efficiency Scores for Dutch Horticulture by Sector and Year

	Flowers	Plants	Vegetables
Overall Mean	.83 (.11)	.80 (.12)	.90 (.06)
Mean 1991	.80 (.17)	.82 (.09)	.94 (.03)
1992	.83 (.09)	.81 (.11)	.90 (.05)
1993	.82 (.10)	.81 (.12)	.88 (.06)
1994	.82 (.10)	.81 (.11)	.90 (.06)
1995	.82 (.12)	.77 (.16)	.89 (.07)
1996	.84 (.09)	.77 (.14)	.89 (.06)
1997	.87 (.06)	.82 (.09)	.93 (.06)
1998	.86 (.07)	.82 (.11)	.91 (.09)
1999	.85 (.09)	.82 (.10)	.91 (.08)

5. Conclusions

This paper proposed a test of the Porter hypothesis for the Dutch horticulture sector, using a stochastic production frontier analysis. We started our analysis with a theoretical exposition, where the usual model is extended by exogenous policy variables to account for the effect of environmental policy of firm performance. After having described the data we discussed our empirical model and presented our results.

Our main conclusion is that there is considerable heterogeneity in the way firms react to policy measures designed to increase environmental stringency. The estimation results indicate, for example, that the 1997 voluntary agreement increase technical efficiency of vegetable and plants growers contrary to specialised flower growers. Specialised flower growers' technical efficiency increased, however, after the 1993 multi-year agreement on energy reduction, contrary to vegetable and plant growers. It should be stressed that these results depend on the specific environmental stringency measure used. Future research will consider more specific and if possible individual-specific environmental stringency measures. One of such individual measure we currently investigate is whether we can include firms' participation in the EIA program, Demo/experimental programs and Information programs.

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Appendix A Translog specification

Suppose we assume a Translog technology with output y_{it} and inputs X_{it} (a K+K^2-vector) in natural logarithms. The Translog is consistent with a well-behaved production function with positive marginal product, diminishing marginal product, and positive output elasticity of inputs. The model to be estimated is

$$\text{(A1)} \qquad y_{it} = f(X_{it};\beta) + w_{it} - v_{it}, \qquad i = 1,2,...,N; t = 1,2,...,T .$$

The variables w_{it} and v_{it} are error terms with the following properties. The terms w_{it} are iid and are independent of the terms v_{it}. The $v_{it}'s$ play a crucial role in the sense that they incorporate producer-specific and time-specific variation from the frontier. It is assumed that the $v_{it}'s$ are independently distributed and can be modelled as

$$\text{(A2)} \qquad v_{it} = Z_{it}\gamma + \varepsilon_{it}$$

where Z_{it} is an M-vector of firm specific time-varying variables not controlled by the producer, γ is an unknown M-vector to be estimated and ε_{it} is an error term following a truncated normal distribution with mean value 0 and variance σ_{ε}^2 where the truncation point varies with $Z_{it}\gamma$ such that $v_{it} \geq 0$.

The parameter estimates of the Translog specification is given in Table A1. Associated input elasticities are calculated from partial differentiation of the production frontier. The elasticity is given by

$$\text{(A3)} \quad E_j = \frac{\partial y}{\partial x_j} = \beta_j + \sum_k \beta_{jk} X_k + \beta_j TREND,$$

that varies across firms and over time, and often evaluated at the mean. The estimate of returns to scale is calculated as the sum of the input elasticities

$$\text{(A4)} \quad RTS = \sum_j E_j .$$

Table A1. Estimates of Translog Stochastic Frontier Panel Data Models

Variable	Pooled		Flowers		Plants		Vegetables	
Production frontier								
CONSTANT	12.38**	(1.07)	23.94**	(1.14)	13.03**	(4.62)	17.82**	(1.17)
LLAND	3.74**	(0.49)	2.09*	(0.92)	6.79**	(1.29)	0.59	(0.99)
LLABOR	1.44**	(0.45)	-0.37	(0.95)	1.42*	(0.88)	5.20**	(0.96)
LENERGY	-0.47**	(0.23)	-0.85	(0.55)	-0.44	(0.75)	-1.43**	(0.44)
LCAPITAL	-2.78**	(0.23)	-3.97**	(0.41)	-2.46**	(0.75)	-3.23**	(0.41)
LPESTICIDES	0.67**	(0.26)	1.49**	(0.44)	-0.44	(0.49)	0.01	(0.81)
LNUTRIENTS	-0.47**	(0.18)	1.67**	(0.36)	-1.17**	(0.39)	0.40	(0.47)
TREND	-0.09*	(0.06)	0.14	(0.13)	-0.24**	(0.10)	-0.17	(0.10)
LLABOR2	0.18**	(0.04)	0.14	(0.08)	0.21**	(0.05)	0.15**	(0.06)
LCAPITAL2	0.24**	(0.02)	0.20**	(0.05)	0.20**	(0.04)	0.15**	(0.04)
LLAND2	0.32**	(0.05)	0.09	(0.11)	0.62**	(0.13)	-0.18*	(0.11)
LENERGY2	0.09**	(0.02)	0.02*	(0.04)	0.08	(0.05)	-0.05*	(0.03)
LPESTICIDES2	0.04**	(0.01)	0.15**	(0.02)	0.02*	(0.02)	0.04*	(0.02)
LNUTRIENTS2	-0.02**	(0.01)	0.04*	(0.02)	0.01	(0.09)	-0.07*	(0.02)
LLABORxLCAPITAL	-0.04	(0.06)	0.15	(0.12)	0.01*	(0.02)	-0.45**	(0.11)
LLABORxLLAND	-0.03	(0.08)	-0.50**	(0.13)	0.13	(0.09)	0.10	(0.11)
LLABORxLENERGY	-0.20**	(0.05)	-0.18*	(0.09)	-0.30**	(0.15)	-0.19*	(0.08)
LLABORxLPESTICIDES	-0.11**	(0.03)	0.02	(0.06)	-0.11**	(0.10)	-0.04	(0.06)
LLABORxLNUTRIENTS	-0.01	(0.03)	0.02	(0.07)	-0.07*	(0.05)	0.21**	(0.07)
LLABORxTREND	-0.00	(0.08)	-0.01	(0.02)	-0.01	(0.04)	0.01	(0.01)
LCAPITALxLAND	-0.40**	(0.07)	-0.13	(0.11)	-0.90**	(0.01)	0.22	(0.14)
LCAPITALxLENERGY	0.01	(0.04)	0.22**	(0.08)	0.04	(0.15)	0.19**	(0.07)
LCAPITALxLPESTICIDES	-0.09**	(0.04)	-0.29**	(0.07)	0.07	(0.08)	-0.02	(0.12)
LCAPITALxLNUTRIENTS	0.03	(0.03)	-0.22**	(0.04)	0.20**	(0.07)	-0.18*	(0.05)
LCAPITALxTREND	0.02**	(0.01)	-0.02	(0.02)	0.04**	(0.05)	0.02	(0.01)
LLANDxLENERGY	-0.12**	(0.04)	0.20**	(0.10)	-0.13	(0.01)	-0.16*	(0.08)
LLANDxLPESTICIDES	0.07*	(0.04)	-0.05	(0.07)	-0.00**	(0.00)	-0.09	(0.11)
LLANDxLNUTRIENTS	0.00	(0.04)	0.12	(0.08)	-0.22**	(0.07)	0.18*	(0.09)
LLANDxTREND	-0.02**	(0.01)	0.02	(0.02)	-0.05**	(0.06)	-0.02*	(0.02)

Technical efficiency model								
CONSTANT	-7.22**	(0.72)	-4.58**	(0.81)	8.37**	(0.40)	-0.82**	(0.37)
AGE	-0.08**	(0.01)	0.01**	(0.01)	-0.02**	(0.02)	0.01**	(0.01)
FAMFIRM	0.77*	(0.01)	0.68**	(0.17)	-3.07**	(0.05)	0.40*	(0.22)
AMANAGER	-0.41**	(0.03)	-0.34	(0.08)	0.93	(0.01)	-0.16**	(0.07)
TREND	-0.14**	(0.02)	-0.01	(0.03)	0.03**	(0.03)	-0.01	(0.01)
EIA PROGRAM	-0.86**	(0.24)	-1.59**	(0.41)	-1.48**	(0.04)	-0.41	(0.25)
$S^2 = S_v^2 + S_u^2$	0.85**	(0.10)	0.37**	(0.05)	1.37**	(0.06)	0.04**	(0.01)
S_u^2 / S^2	0.94**	(0.01)	0.91**	(0.02)	0.97**	(0.02)	0.43**	(0.12)
Log-likelihood	-268		-52		-37		+209	
Number of observations	1511		554		404		553	
Number of cross-sections	401		148		105		148	
Number of time periods	9		9		9		9	
LR statistic	260 (7)		220 (7)		42 (7)		42 (7)	

Notes: *, ** significant at 5% and 1%, respectively

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[i] These authors also point out that the Porter hypothesis is not in line with the the neoclassical theory of the firm and that it is controversial in the sense that it implies the paradox that firms should adopt environmental policy voluntarily and unilaterally since it is in their self-interest to do so. See also Palmer et al. (1995), and Jaffe et al. (1995).

[ii] Gabel and Sinclair-Desgagné (1995) also observe that the advantage in both variants may become disadvantages if the importing countries do not introduce similar regulations.

[iii] For an excellent review of the developments of the field we refer to the recent book by Kumbhakar and Knox Lovell (2000), from which we heavily draw in the present section.

[iv] The translog specification is an alternative specification. It is considered in Appendix A.

[v] In total 77 firms did and they are removed from the sample, reducing the sample by 312 observations. The sample used in the empirical application therefore contains 1727 observations for 417 firms, as mentioned earlier.

[vi] PROG1 is 0 before 1993, and 1 for 1993 and thereafter.

[vii] PROG2 is 0 before 1997, and 1 for 1997 and thereafter.

[viii] We removed 266 observations for the 109 firms for which the necessary information is lacking.

[ix] The likelihood ration test statistic equals $-2(\ln L_0 - \ln L_1)$ where L_0 is the value of the log likelihood of the restricted model and L_1 the log likelihood of the unrestricted model. The LR has an asymptotic Chi-square distribution with degrees of freedom equal to the number of restrictions on the parameters if the null hypothesis is true.

[x] The change in sign may relate to the heterogeneity in the technical production system.

[xi] A Likelihood Ratio test showed that PROG1 and PROG2 do not increase the log-likelihood significantly. As a result we did not include these variables in the final specification.

[xii] Note that the parameter of TREND in the production frontier model does not give the full impact on output because it appears in the technical efficiency model also.

[xiii] Some flower varieties can either be produced in 'low temperature regimes' using a capital- extensive and energy-extensive production system, or in 'higher temperature regimes' using a capital-intensive and energy-intensive production system.

[xiv] The importance of time horizon in explaining investments in Dutch horticulture can be found also in Goncharova et al., 2004.

[xv] FRONTIER 4.1 models the log-likelihood in terms of probability heights rather than probabilities possibly resulting in positive log-likelihood values.