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Dynamic adjustments in the Dutch greenhouse sector due to environmental regulations

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Abstract

Horticultural firms are dependent on energy to produce, while policy makers focus on reducing the use of energy and investment in energy-saving technologies. The paper aimed to asses Dutch greenhouse farmers' responses to policies that would affect prices of different energy inputs. The farmer's behaviour is modelled in two steps: firms are assumed to maximize profit at given energy use level, and firms are assumed to minimize the discounted sum of energy costs. The model is estimated using farm survey data spanning the period 2001-2008. Short-run and long-run elasticities with respect to prices and investments in energy-using technology are estimated. The greenhouse sector shows a fast adjustment of energy capital towards its long-run equilibrium. This model provides a framework for assessing policy simulations. Policies will not have much more impact in the long-run compared to the short-run, and incentives to invest would result in an increase of the use of energy-saving technologies.

Keywords: Greenhouse horticulture, Energy, Dynamic duality, Adjustment costs

JEL classification: C51, C61, D92, Q12, Q18, Q48.

1. INTRODUCTION

Horticultural production is one of the most energy-intensive agricultural sectors and plays a role in increasing the concentration of greenhouse gases (GHG) in the environment, and, therefore, contributing to global climate change. The sector's dependence on energy makes the profitability of the firms reliant on energy costs, and policy makers focus on reducing the use of energy by these firms.

This study is applied to Dutch greenhouse firms, whose production relates importantly on the use of natural gas, causing CO_2 emissions. Dutch greenhouse horticulture is responsible for approximately 90% of CO_2 emissions in Dutch agriculture. Because of its size and the intensity of energy use, Dutch greenhouse horticulture has been subject to energy and climate policies on the EU, national and sector level, since at least the 1990s, with measures such as agreements and covenants. On the EU level, environmental concerns have received more attention in the CAP. With cross-compliance in the current Single Payment Scheme, environmental objectives have attracted more attention. An agreement covering all major environmental issues in greenhouse horticulture: energy, pesticides, nutrients and discharges to surface water, specifies targets at sectoral level aimed at reducing energy input per unit of output. Additionally, grants and tax incentives are being used to encourage greenhouse firms to install energy-saving technologies.

A wide range of energy-saving technologies are used in the greenhouse horticulture industry to reduce energy consumption, such as climate computers, condensers, heat buffers and combined heat and power equipment. The latter enables greenhouse producers to make use of economies of scope in producing heating, electricity and carbon dioxide at the same time.

Dutch greenhouse firms can react to policies or taxes by factor substitution between variable inputs or by abatement activities. Abatement activities imply demand for intermediate goods, capital and labour and the accumulation of a stock of abatement capital. Investment choices of greenhouse farmers represent long-term commitments and can be seen as a solution to dynamic optimization problems, in which different constraints, timing options, play an important role (Pietola and Oude Lansink, 2006). The traditional approach, the static optimization framework, is therefore inappropriate for examining the structure of production and investment in agricultural sector, specifically in the greenhouse sector. Environmental issues in the greenhouse sector and the economic impact of related policies has been addressed by some studies, including Oude Lansink and Van der Vlist (1999), Oude Lansink (2003), and Pietola and Oude Lansink (2006). None of them uses the dynamic approach in their analysis. Many studies have been based on a static system of factor demand equations which assumes that producers adjust instantaneously to changes in the market and technological environment in which they operate (Asche et al., 2008). Although this assumption simplifies the analysis, it is well known that farmers do no react instantaneously to changes in prices and other exogenous factors, but take time to adjust (Epstein, 1981). The dual approach is used for examining dynamic adjustment in agriculture by several authors (Howard and Shumway (1988); Epstein and Denny (1983); Lopez (1985); Vasavada and Chambers (1986); Vasavade and Ball (1988); Weersink (1990); Fernandez-Cornejo et al., (1992); Stefanou et al. (1992), Agbola (2005), Serra et al. (2010).

The aim of the paper is to asses Dutch greenhouse farmers‘ responses to policies that would affect the prices of different categories of energy inputs. The behaviour of the firm is modelled in two stages. In the first stage, firms are assumed to maximize short-term at given quantities of quasi-fixed factors and a given energy use level. The second stage uses a dynamic model of adjustment of the energy capital stock to determine the optimal quantities of gas, electricity and other energy. The possibility of using specialized equipment to produce electricity that is sold to the grid is also taken into account in the second stage. This paper contributes to the literature by a detailed dynamic modelling of the demand for different energy components and allowing for the option of energy production. The model generates a number of policy insights that are useful for the design of future energy and CO_2 emission policy.

The remainder of this paper is organized as follows: The theoretical framework of the model is presented in the following section. Next, the empirical analysis, which contains a discussion of the data, is showed. Results, conclusions and policy implications are in the final sections.

2. THE MODEL

In the first stage, the restricted profit function, firms take energy input as given. This means that firms are assumed to be maximizing profit conditional upon the amount of energy-use. The restricted profit function for a multi-output production technology is:

$$(1) \qquad \pi(P(t);Z(t),\overline{E}) = \max_{(Y,Z)\in T(E)} \sum_{j=1}^{M} \{P_j Y_j; Z(t), \overline{E}(t) \in T\}$$

where the restricted profit function depends upon prices (P) , netputs (Y) and is conditional upon quasi-fixed factors (Z) and quantity of energy-use (E).

This modeling framework assumes weak separability between energy netputs and the variable inputs. It implies that the marginal rate of substitution between netputs is independent of the quantity of other inputs and outputs (Chambers, 1988). Therefore we can aggregate our energy netputs in $E=(e_1,\ldots,e_m)$, which is a vector of allocated energy needed for the outputs, total amount of energy needed is *E*.

In the second stage, we assume that farmers minimize the discounted sum of future energy costs over an infinite horizon, producing at least energy output level, *E*. A greenhouse firm has three main inputs for energy, namely gas, electricity and 'other'. Large Dutch greenhouse firms are also able to produce electricity and sell electricity to the grid as an extra output, and therefore we model the cost minimization framework with two different outputs: electricity sold to the grid and energy quantity, *E*. Adjustment costs are expressed as the reduction in energy output that results from the diversion of resources away from energy production when stocks of quasi-fixed factors are changed.

$$(2) \qquad J(w,r,E,El,K_o,t) = \min \int_0^\infty e^{-it}[w'X + r'K]dt$$

s.t.:

$\dot{K} = I(t) - \delta K(t)$, $K(0) = K_0$, $K(t) > 0$ for all t,

$[E(t), El(t)] = F[X(t), K(t), \dot{K}(t), T]$,

where K is the stock of energy-capital, related to energy-using equipment; X is a vector of the inputs consisting of electricity, gas, other energy, at prices w; El is the electricity output; I is the gross rate of investment in the quasi-fixed input; r is the (constant) rental rate of capital, i is a real discount rate; and δ is the rate of depreciation of the quasi-fixed input energy-using capital. *F* is a production function describing the transformation of energy inputs into outputs. $\dot{K}$ is rate of change of energy capital and is included in the function to reflect internal costs of adjusting quasi-fixed inputs.

The value function is assumed to be real valued, non-negative, twice continuously differentiable, non-decreasing in w and r, decreasing in K, and concave in w (when positive input) and r (Epstein and Denny, 1983). Under those conditions, the Hamilton-Jacobi-Bellman (HJB) equation is:

(3)
$$rJ(w,r,E,El,K,t) = \min\{[w'X + r'K] + J_K(I - \delta K) + \varphi(E - F[(X(t),K(t),\dot{K}(t),t]) + J_t$$

where φ is the Lagrange multiplier associated with the energy production target and can be used to estimate the shadow price of an extra output of energy, by formulating the optimization problem as a sequential decision (see Stefanou (1989)). The HJB is interpreted as the sum of netput costs, rental costs, adjustment costs and the shadow price associated with the amount of energy production. J_K is here the shadow price of the quasi-fixed input. Netput demand equations are obtained by Shephard's Lemma. The conditional demands for the variable netputs and the net investment demand equation are:

(4) $$X^* = rJ_p(w,r,E,El,K,t) - J_{pK}(w,r,E,El,K,t)\dot{K} - J_{pt}(w,r,E,El,K,t)$$

(5)
$$\dot{K} = (i - J_{RK}^{-1}) * K + J_{RK}^{-1}(w,r,E,El,K,t) * [rJ_R(w,r,E,El,K,t) + J_{Rt}(w,r,E,El,K,t)]$$

The subscripts indicate partial differentiation. It will be assumed that C satisfies all regularity conditions (Epstein and Denny, 1983).

3. EMPIRICAL SPECIFICATION AND ESTIMATION

Two different functions are estimated in this paper. For both functions a flexible functional form has to be chosen. Moreover, we assume that individual firms have access to the same production technology, but that firm-specific factors put constraints on the feasible points of the set of production options. This assumption can be incorporated by the fixed effects transformation. By including fixed effects, time-invariant quality differences in inputs between firms are controlled.

For empirical analysis of the restricted profit function, the symmetric normalized quadratic (SNQ) function, which is a flexible functional form, is chosen as an approximation of the true profit function. This form is chosen because the function treats all inputs and outputs identically and does not single out an arbitrary chosen input or output, such as the normalized quadratic function (Diewert and Wales, 1987; Kohli, 1993).

(6)
$$\Pi = \sum_{j=1}^{3}\alpha_j P_j + \tfrac{1}{2}((\sum_{j=1}^{3}\theta_k p_k)^{-1}\sum_{j=1}^{3}\sum_{r=1}^{3}\gamma_{jr}P_j P_r) + \tfrac{1}{2}((\sum_{j=1}^{4}\theta_k p_k)\sum_{n=1}^{4}\sum_{m=1}^{4}\delta_{kh}Z_n Z_m)$$
$$+\sum_{j=1}^{3}\sum_{n=1}^{4}\vartheta_{jk}P_j Z_k + \sum_{j=1}^{3}\rho_j P_j T$$

where Z denotes quasi-fixed inputs: land and capital. The latter excludes energy-using capital, but includes buildings, machinery and other equipment. To simplify the mathematical expression, both output and variable input prices are included in the vector *P*. This means that *P* is a netput vector. θ represents a vector of average shares of netputs in total costs plus revenues, p_k equals the sample mean. In order to identify all parameter, additional restrictions are imposed: $(\sum \gamma_{jr} P_r) = 0$

Netput demand equations for aggregated output, and aggregated materials are obtained by Hotelling's lemma. The netput demand equations are estimated by the iterative 3sls method. This method is chosen because there may appear correlation between the endogenous variables and the exogenous variable energy-quantity.

In applying the dynamic cost-minimization framework, the normalized quadratic (NQ) function is a flexible functional form which satisfy the conditions (Diewert and Wales (1987). With the NQ function, one price is used as numéraire. The firm-specific effect is introduced in the cost minimization framework by including dummies for each firm. Using a normalized quadratic function:

(7)

$$J(w,r,E,El,K,t) = (a_1 a_2 a_3 a_4 a_5 a_6)\begin{bmatrix} w \\ r \\ E \\ El \\ K \\ t \end{bmatrix} + 1/2(wr)\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}\begin{pmatrix} w \\ r \end{pmatrix}$$
$$+1/2((E \quad El \quad K \quad t)\begin{bmatrix} B_{11} & B_{12} & B_{13} & B_{14} \\ B_{21} & B_{22} & B_{23} & B_{24} \\ B_{31} & B_{32} & B_{33} & B_{34} \end{bmatrix}\begin{pmatrix} E \\ El \\ K \\ t \end{pmatrix} + (wr)\begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23}^{-1} & C_{24} \end{bmatrix}\begin{pmatrix} E \\ El \\ K \\ t \end{pmatrix}$$

Prices of gas and 'other energy' are normalized using the price index of electricity input to ensure that the value function is linearly homogeneous in prices. Symmetry is maintained by requiring $A_{12}=A_{21}$,$B_{12}=B_{21}$, $B_{13}=B_{31}$, $B_{14}=B_{41}$, $B_{23}=B_{32}$, $B_{24}=B_{42}$, and $B_{34}=B_{43}$.The intertemporal version of Shephard's Lemma is derived by differentiating the optimized HJB equation (eq. 3) with respect to w and r. We expected, however, that the investment demand equation was different for the firms were investment is negative, zero or positive. Because investment is here used as a censored variable, an ordinary regression analysis could cause selection bias. We counted, therefore, for this selection bias by applying Heckman's procedure via an ordered probit model. Our independent variable is investment which is be ranked as zero (negative and zero investment) or as one (positive investments) (Oude Lansink and Stefanou, 1997). Control variables were normalized energy input prices, energy capital and time. Because our dataset only had 6 negative investments, we used the binary probit model. The estimated parameters of the probit model are used to calculate the inverse Mills ratio (imr), which is then included as an additional explanatory variable in the investment demand equation: $\dot{K}^{+} = \varphi X + \sigma * imr + \varepsilon$. This gives us the following empirical specification:

(8)

$$\dot{K} = (iU - C_{23})K + iC_{23}(a_2 + a_{22}r + a_{12}r + C_{21}E + C_{22}El + C_{24}t) + C_{24}tC_{23} + \delta_x D + \sigma_1 imr$$

where U represents an identity matrix of same dimension as M. This equation is a multivariate accelerators model with an adjustment matrix $\dot{K}^{+} = (iU - C_{23})(K - \dot{K}^{+})$ where $\dot{K}^{+}$ is the steady stock of energy capital; D are the firm-specific dummies. The conditional demands for the other two energy variable netputs and the conditional demand for the numéraire variable netputs are:

(9) $$X^{*} = i(a_1 + a_{11}w + a_{12}r + C_{11}E + C_{12}El) + C_{13}(ik - \dot{K}^{+}) + C_{14}(it - 1) + \delta_x D$$

(10)

$$X_n = i(a_0 + a_3E + a_4El + \frac{1}{2}EB_{11}E + \frac{1}{2}ElB_{22}El - \frac{1}{2}wa_{11}w - \frac{1}{2}ra_2r - a_{12}wr) + a_5(iK - \dot{K}^{+})$$
$$+ EB_{13}(iK - \dot{K}^{+}) + ElB_{23}(iK - \dot{K}^{+}) + KB_{33}(\frac{1}{2}iK - \dot{K}^{+}) + tB_{34}(iK - \dot{K}^{+}) + a_6(it - 1)$$
$$+ EB_{14}(it - 1) + ElB_{24}(it - 1) - KB_{34} + tB_{44}(\frac{1}{2}it - 1) + \delta_x D$$

To obtain parameter values, we simultaneously estimated electricity, gas and other energy demand equations and the energy capital demand equation using three-stage least squares (IT3SLS). This is an appropriate estimation technique because the error terms of the equations may be correlated.

3.1. Data

The greenhouse data used cover the period 2001-2008 and were provided by the Agricultural Economic Research Institute (LEI) from a stratified sample. Firms in the dataset are representative for the Dutch greenhouse sector. This data set contains information on output (measured in €), and inputs of the Dutch greenhouse sector, more specifically on the following inputs: capital stock of buildings, machinery, installations and equipment in general and capital stock related to energy-saving equipment, expenditures on gas, fuel, heat, electricity, pesticides, fertilizers, seeds, plant protection, fertilizers and data on agricultural land and labour.

The data set used for estimation of the restricted profit function includes 896 observations on 211 different farms. For the restricted profit function, we have 2 variable netputs (output and materials) and 5 quasi-fixed inputs. Four fixed inputs are land (ha), capital quantity (include buildings, machinery, installations and equipment), energy-used quantity, and family and operator labour (hours). The total adjusted quality-corrected total labour hours are calculated by dividing the total costs by the wage rate per hour. The quantities of output, materials, and energy are measured in Euro's with corresponding price indices. Törnqvist price indexes were calculated for the aggregation of output (consisting vegetables, pot plants and flowers), and the variable input materials (aggregation of seeds, fertilizer, plant protection). Prices of output are not known at the time decisions are made on the use of variables inputs; using expected output prices are, therefore, preferable above actual output prices. Expected output prices were computed as the first lag of the actual prices. A time trend is added in order to allow for technological change.

Table 1a. Summary statistics of the variables used in the restricted profit function analysis

Variable		N	Mean	Sd.
Output (aggregated)	(€*1000)	896	1110.25	881.29
Capital	(€*1000)	896	495.36	512.13
Energy expenditure	(€*1000)	896	162.37	144.78
Materials expenditure	(€*1000)	896	318.41	367.12
Labour	(hrs)	896	25.04	23.52
Land	Ha	896	2.441	1.74

For the cost function, we have 4 variable netputs (electricity, gas, 'other', and cost of capital) and four quasi-fixed inputs. The four quasi-fixed inputs are energy quantity, electricity output, energy-capital quantity (include machinery, installations and equipment), and time. Implicit quantities of the energy inputs are computed as the ratio of costs and a corresponding price index. Expected prices of energy inputs are used in the estimation as the first lag of the actual prices. A Törnqvist price index was calculated for the aggregate quantity of 'other energy' (consisting of fuels, heat, 'other' and smoke gas). The price of capital is calculated by the depreciation plus the interest rate. The price indexes and the rental price of capital vary over years, but not over the firms, implying that quality differences and differences in the composition of the input between firms are reflected in the implicit quantity.

Table 1b. Summary statistics of the variables used in the energy cost-minimization analysis

Variable		N	Mean	Sd.
Electricity quantity	(*1000)	490	44.30	64.02
Gas quantity	(*1000)	490	191.68	175.69
'Other energy' quantity	(*1000)	490	17.49	51.73
Energy quantity	(*1000)	490	253.47	209.86
Electricity output	(*1000)	490	58.32	165.19
Energy capital	(€*1000)	490	428.63	470.59
Rental rate of capital	(%)	490	0.10	0.0094

4. RESULTS

The model was estimated over the period 2001-2008. Eight out of twenty-six parameters (30.8%) of the parameters of the restricted profit function, estimated using 3sls, are not significant at the 5% level. This may be caused by non-linearity of the profit function and the fixed effects transformation. Results are analysed by means of elasticities. According to the behaviour of our data, the assumption that Dutch greenhouse firms are profit maximisers holds, which reflects in the positive semi-definite Hessian matrix.

Table 2. Short-run elasticities restricted profit function (estimated standard error between brackets)

	Output	Materials	Land	Capital	Energy	Labour	Technological change
Q. of output	0.237**	-0.237**	0.537	-0.022	0.044*	0.404**	0.009
	(0.049)	*(0.072)*	*(0.410)*	*(0.019)*	*(0.022)*	*(0.032)*	*(0.006)*
Q. of materials	0.866**	-0.866**	0.651	0.139**	-0.643**	0.625**	0.069
	(0.263)	*(0.181)*	*(1.394)*	*(0.036)*	*(0.042)*	*(0.023)*	*(0.057)*

* Significant at 5% level
** Significant at 1% level

The elasticities in table 2 show that the supply of output increases with respect to an increase in its own price. When the price of materials increases, the quantity of output decreases. The relation between the output supply and fixed inputs (land, capital, energy quantity and labour) is, as expected, positive for almost all inputs. A non-expected result is the negative sign of the quantity of output with respect to the quantity of capital. If capital increases with one unit, the quantity of output decreases. The elasticity is, however, not significant at a 5% or 10% level. If capital increases with one unit, quantity of materials increases as well. This may be caused by more investments in machinery. A substitutions effect shows between energy quantity and the quantity of materials. If the quantity of energy increases, the quantity of materials decreases. For both netputs, the fixed input land has a positive sign, however, both elasticities are not significant. The influence of technological change on supply of output is 0.9% per year. The variable inputs increase with 6.9%per year because of technological change.

For the dynamic cost minimization framework, we estimated the model in two steps. In the first step, the order probit model is estimated. The ordered probit model is estimated with 896 observations on 211 different firms. The negative and zero investment observations are deleted from the analysis in the second step, because at zero observation no optimal value is achieved and we wanted to describe adjustment behaviour of dynamic adjustments. The final step is done with 490 observations on 178 firms.

The cost-minimization model estimates 745 parameters due to the firm-specific dummies. The Hessian matrix of the cost function shows that the function is concave in factor prices. Thus, the estimated cost-minimization function fulfils all conditions of the (dual) underlying technology. The implication of the parameter estimates for input demands can be summarized by calculating the price elasticities of demand. Short-run price elasticities (table 3) are defined as the elasticities obtained when the quantity of energy-capital is held constant and long-run elasticities are defined as the responses when the energy-capital has fully adjusted to its long-run equilibrium level. The elasticities were calculated at the sample mean.

Table 3. Short-run elasticities of energy cost-minimization function (standard error between brackets)

	Gas	Other Energy	Electricity	Energy quantity	Electricity output	Energy Capital	Technological change
Q. gas	-0.553**	0.0529	0.500**	0.863**	0.050**	-0.000**	0.0077
	(0.143)	*(0.097)*	*(0.085)*	*(0.088)*	*(0.009)*	*(0.00)*	*(0.011)*
Q. other energy	0.768	-3.916*	3.148	2.079**	-0.354**	0.001**	0.169
	(1.563)	*(1.523)*	*(2.63)*	*(0.710)*	*(0.073)*	*(0.000)*	*(0.11)*
Q. electricity	3.722**	-0.104	-3.618**	1.459	-0.006	0.349**	-0.181**
	(0.452)	*(0.289)*	*(0.345)*	*(0.759)*	*(0.105)*	*(0.000)*	*(0.057)*

* Significant at 5% level
** Significant at 1% level

All own-price elasticities of the energy inputs are negative, which is in line with our expectations. If we would like to increase the energy production with one unit, the quantities of the variable inputs increase as well. If quantity of electricity output increases with one unit, only the quantity of gas increases while the two other inputs decrease. Electricity and the aggregate input 'other energy' are complements from each other; an increase of the price of electricity results in increase of the quantity of 'other energy'. The opposite effect holds if the price of 'other energy' increases; then the quantity of electricity decreases. Technological progress in the quantity of gas is minimal, while the quantity of 'other energy' increases with 16.9% per year. This may be the case when the prices of gas and electricity increase, the aggregated input act as substation input for them. Remarkable is that the quantity of electricity decreases due to technological change; 18.1% per year. This may be caused by the fact that firms produce more electricity than they use as an input.

In the long run, energy-capital stocks could adjust towards optimal levels. The adjustment rate of capital is 75.5%. This is high, also compared to earlier findings. Only in the study of Chang and Stefanou (1988), who performed a study in the dairy sector, a capital adjustment rate of 81% is found. Long-run elasticities are shown in table 4.

Table 4. Long-run elasticities of energy-cost function

	Gas	Other Energy	Electricity	Energy quantity	Net investment	Electricity output
Q. of gas	-0.552	0.0519	0.500	0.862	0.0065	0.050
Q. of other energy	0.767	-3.915	3.148	2.079	-0.0079	-0.354
Q. of electricity	3.67	-0.057	-3.610	2.50	-0.231*	-0.006

A small number of elasticities change significantly in magnitude when analysed in the long-run. The own-price elasticities are still negative. But for example, if we increase energy quantity with one unit, it leads to a bigger increase in the quantity of electricity. Moreover, electricity responses more heavily on a change in the price of 'other energy' in the long run than in the short run. Gas and other energy are substitutes in the short run and in the long run. If a firm increases its investment, the quantity of electricity will decrease. This may be caused by substitution of the variable inputs electricity to gas.

5. Policy implications

In a policy context, it is important for policy makers to understand the effects of energy policies on the greenhouse sector and relative impact on profit and their costs. The dynamic model specified and estimated here provides a framework for assessing policy simulations. The estimated elasticities are plausible, and can serve as the basis for analysis of effects of input and output price policy on output and input demand, specified to energy input demand sources.

First, the results obtained in this paper suggest a fast rate of adjustment of energy capital towards its long-run equilibrium. Policies have not much more impact in the long-run compared to the short-run, which implies that policy-makers will see result of policies in the short-run.

Second, the Dutch government wants Dutch greenhouse firms to reduce their energy-use and invest in energy-saving technologies and use more sustainable energy sources. From this framework we see that if firms invest in energy-using capital, they will use more volume of gas, but the volumes of electricity and the aggregate group of other energy will decrease. Moreover, an increase in energy production would also result in an increase in the volume of gas, but a decrease in the volumes of the other two inputs. Producing electricity is done via combined heat and power equipment, which mainly uses gas as an input. This is also reflected in these elasticities and in the elasticity with respect to quantity of electricity output: If the quantity of electricity output increases with one unit, only the quantity of gas increases while the two other inputs decrease. These outcomes indicate that greenhouse farmers invest in combined heat and power, which uses mainly gas as an input. These results imply that incentives to invest would stimulate the use of energy-saving technologies by greenhouse firms.

Third, the large elasticities imply that substitution between energy inputs is easy. Policies could be directed towards reducing use of more polluting inputs.

6. CONCLUDING REMARKS

The ensuing discussion about policies aiming at reducing CO_2 emissions by the agricultural sector needs input on the possible effectiveness of proposed policies and their impact on firms' profitability. In this paper we model the response of Dutch greenhouse firms to changing prices of energy inputs. The models account for possible rates of adjustment towards a new equilibrium. This paper has shown how a general non-linear model of a restricted profit function and dynamic energy netput demands of the Dutch greenhouse sector in time period 2001-2008 behaved. The dynamic demand equations can be used to study the effects over time of unexpected changes in factor prices, of a changing output level, and of policies in which future price changes are changed.

According to our findings, Dutch greenhouse firms behave in the sense that they want to maximise their profit. The fixed factor energy quantity act as a substitute for the variable input materials. In the second stage we used a dynamic model of adjustment of the energy capital stock to determine the optimal quantities of gas, electricity and other energy. A small number of energy input elasticities change significantly in magnitude when analysed in the long-run. This implies that results of a policy can be seen in the short-run. Gas and other energy are substitutes in the short run and in the long run. If a firm increases its investment, the quantity of electricity will decrease. This may be caused by substitution of the variable inputs electricity to gas.

A direction for further research is to simulate some ex-ante energy policy scenarios and CO_2 emission policy. According to our results, substitution between energy inputs is uncomplicated. The costs for farmers, when a policy is introduced to reduce a more polluting input, can be estimated. As last, the effects on the energy inputs can be linked to the profitability of the firm, estimated in the first stage of our model.

Of course, these findings are subject to some limitations. Our approach involves several forms of aggregation, each of which might be questioned. In particular, we aggregated outputs (i.e. fruits and vegetables, pot plants and flowers) across firms, we aggregated a variety of diverse inputs under the caption of 'materials' or 'other energy', and we took average of price indices and quantities over each year as the objects of analyses. We believe, however, that our empirical results provide some insight into the structure of aggregate production, the importance of adjustment costs, and the role of energy in (Dutch) greenhouse sector.

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