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Ozone Pollution and Farm Profits in England and Wales

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Abstract

Tropospheric ozone is an air pollutant known to adversely affect crop yields across Europe. Experimental work is underway to quantify yield effects at ambient ozone levels for a number of crops. In this paper, we undertake direct, farm-level evaluation of the impact of ozone by estimating a multi-output profit function using a panel dataset of cereal farms in England and Wales. A system of equations, comprising the profit function, input and output share equations is estimated using a fixed-effects seemingly unrelated regression technique, with ozone as a quasi-fixed input. Estimated parameters are used to calculate tropospheric ozone-related profit and output supply elasticities. The main findings from the profit function show that a 10% increase in average ozone levels would decrease variable profits by 1.3% and wheat output supply by 1%. These results are of a significantly lower magnitude, but qualitatively consistent with findings from similar studies carried out in North America.

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Ozone Pollution and Farm Profits in England and Wales

I. Introduction

Concern over environmental degradation worldwide has triggered the setting up of a number of fora and commissions to look into ways of assessing the extent of damage, with a view to devising new environmental standards and/or modifying existing ones. Over the last decade there has been much associated research activity in Europe, looking into a wide range of pollutants, their impacts and their respective standards. One such important pollutant is tropospheric (ground-level or low-level) ozone.

Tropospheric ozone (TO) is produced by the interaction of solar radiation with the oxides of nitrogen (NO_x) and Volatile Organic Compounds (VOCs, such as methane and carbon monoxide). Although the precursor NO_x and VOC gases are also produced by natural processes, combustion in industrial production and motor vehicle operation have contributed significantly to elevated ozone concentrations in Europe. Such levels can potentially affect human health, crops and materials. Research on these effects is being conducted under the aegis of the United Nations Economic Commission for Europe's (UNECE) Working Group on Effects (WGE). One of these research avenues concerns the externality of TO on crop production.

European research in this area has concentrated on establishing dose-response relationships for various crops using experimental methods, and establishing and refining critical levels beyond which crop yields are affected. Rather than use ambient (mean) ozone concentrations, the so-called ‘Level 1’ approach adopted by European researchers was based on the ‘AOT40’ concept, *i.e.*, the cumulative ozone exposure over 40 parts per billion, over a fixed growing season. Based on critical levels derived from a ‘Level I’ concept, it seems that 91% of the arable acreage in the UK is exposed to potentially harmful ozone concentrations (PORG, 1997).

Recognising that dose-response can be modified by several factors such as pests, rainfall, etc, ‘Level II’ research efforts are underway to fine-tune critical levels, taking these factors into consideration (Karlsson, *et. al*, 2003). But given the multitude of factors that interplay, much more work needs to be done yet to come up with a reliable ‘Level II’ index. Even when sophisticated Level II indices are ultimately developed, they may not be able to capture the true farm-level impact of ozone. Farmers have a variety of mitigatory options available to them, and not all crops are equally susceptible to high TO levels[1]. Consequently, farmers may react to changes in the level of TO by changing land allocated to crop production, changing the levels of other inputs, by altering the output mix, etc. Such mitigatory behaviour is the result of economic decision-making, and is not taken into account even in the most sophisticated physical experiments or by a ‘level II’ index. Biological experiments usually fix the levels of all other inputs at levels where their marginal products are zero, so that the productivity effect of the variable under investigation, such as the ozone level, is not confounded with the effects of these other inputs. By doing so, however, the actual productivity

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[1] Wheat, potatoes and sugarbeet are key UK crops that are more likely to suffer following high ozone concentrations.

effects likely to obtain in the 'real world' where other inputs are not so constrained, are mis-estimated[2].

This study attempts to overcome this shortcoming inherent in using biological dose-response models to estimate the economic impacts of ozone. It does so by intersecting panel datasets on pollution and farm variables, and directly estimating the effect of ozone on profits and supply based on a profit function approach.

The previous literature on the farm-level economic effects of ozone on can be divided into two strands:

(i) The larger strand feeds biological dose-response experimental data into mathematical programming models. The models are then run to optimise farm profits at varying levels of ozone exposure. A number of empirical studies were carried out in the US in the mid-80's using such an approach (see Heck *et. al.* (1984) for a review).

(ii) A much smaller strand uses observations on ozone, and farm inputs, outputs, costs and profits, to directly estimate the effects of ozone on farm-level outcomes using dual methods. This includes Garcia *et al.* (1986) for the US and Young and Aidun (1993) for Canada. Our research belongs to this latter strand.

This study offers the following advantages and innovations compared to previous work:

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[2] We are grateful to a referee for point this out.

(a) To our best knowledge, it is the first application of dual methods to investigate farm-level effects of ozone using European data.

(b) It benefits from employing the AOT40 cumulative exposure index, which is considered by European researchers to be a better predictor of the impacts of ozone on vegetation than seasonal mean measures that have been used by studies conducted in North America.

(c) In contrast to previous work, we control for farm-specific effects in isolating the effects of ozone on profits and supply. As is well known, farm level outcomes are often strongly influenced by unobserved heterogeneity, and controlling for such heterogeneity is important for accurate estimation

(d) By employing a multi-output approach, we allow for a more realistic representation of how ozone affects farm outcomes in comparison to single-output representations.

The paper is organised as follows. Section II introduces the duality concept, sections III and IV outline the econometric methods and data, section V presents the analysis of the results and section VI concludes.

II. Multi-output dual profit function

Producers are characterised as maximising short-run profits with respect to variable inputs, given stress brought about by external factors, including ozone. In our particular case, if there is an observed depression in yields, it is expected that profit-maximising farmers will adjust their practices (Garcia, *et. al.*, 1986). In the short-run, they can alter their variable input mix to mitigate the effect.

This will affect variable input costs, and ultimately profits. In the short to medium term, farmers can alter both their input and output mixes and choose to farm a crop that is less susceptible to ozone. This behaviour can be represented by a dual profit function. For any output-input combination (y, x), the profit function is defined as:

$$\pi(\mathbf{p},\mathbf{w},\mathbf{k}) = \max[\mathbf{p}'\mathbf{y} - \mathbf{w}'\mathbf{x}] \tag{1}$$

where **w** and **x** are vectors of factor prices and factor demands, **p** are the output prices, and **y** are the output quantities respectively. **k** represents fixed and quasi-fixed inputs. If the profit function satisfies certain regularity conditions, it is dual to the production function and its parameters contain enough information to describe the farmer's short-run production behaviour. The profit function should be: decreasing in **w**, increasing in **p**, convex in all prices and be linearly homogeneous in all prices (McFadden, 1978; Chambers, 1988). These regularity conditions are testable.

Differentiating the profit function (1) with respect to **p** gives the output supply functions:

$$\frac{\partial\pi(\mathbf{p},\mathbf{w})}{\partial\mathbf{p}} = \mathbf{y}(\mathbf{p},\mathbf{w}) \tag{2}$$

Differentiating the profit function with respect to **w** results in the input demand functions:

$$\frac{\partial \pi(\mathbf{p},\mathbf{w})}{\partial \mathbf{w}} = -\mathbf{x}(\mathbf{p},\mathbf{w}) \tag{3}$$

(2) and (3) are uniquely defined as profit maximising output and input quantities and they are the behavioural relationships that underpin the dual analysis of production decisions. The empirical strategy involves the simultaneous estimation of the profit function, the output and input share equations as a system.

III. Methods

The translog specification[3]

The multioutput translog profit function to be estimated can be written as:

$$\ln \pi_{it}(\boldsymbol{p},\boldsymbol{k}) = \beta_0 + \sum\nolimits_{r=1}^{7} \beta_r \ln p_{itr} + \alpha \ln \boldsymbol{k}_{it} + \frac{1}{2}\sum\nolimits_{r=1}^{7}\sum\nolimits_{d=1}^{7} \delta_{rd} \ln p_{itr} \ln p_{itd}$$
$$+\frac{1}{2}\theta \ln k_{it}^{2} + \sum\nolimits_{r=1}^{7} \gamma_r \ln p_{itr} \ln k_{it} + \mu_{pf\,it} \qquad i=1.....\mathrm{N},\ t=1.....\mathrm{T} \tag{4}$$

where p_1, p_2 are wheat and barley prices, p_3, p_4, p_5, p_6, p_7 are seed price, fertiliser price, crop protection inputs price, paid labour and land rent respectively, and k is tropospheric ozone. Since agricultural output and input price markets are competitive, exogeneity of prices is a reasonable assumption as made in several profit function studies of European Agriculture. Seed, fertiliser,

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[3] The translog specification is used as it is a interpretable as a second-order approximation to an arbitrary function at a given point. 'Flexible' functional forms such as the translog have become the forms of choice in applied production analysis.

crop protection inputs, paid labour and land are considered as variable inputs, and tropospheric ozone is considered a quasi-fixed input. $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\delta}$, $\boldsymbol{\theta}$, $\boldsymbol{\gamma}$ are parameters to be estimated. $\mu_{pf\,it}$ is the error term for the profit function. The subscripts i and t index farms and years respectively. By differentiating the profit function with respect to output and input prices, we obtain the following set of output supply and input demand equations.

$$\frac{\partial \ln \pi}{\partial \ln p_r} = S_r = \beta_r + \frac{1}{2}\sum_{r=1}^{7} \ln p_{itr} + \ln k_{it} + \mu_{r\,it} \qquad (5)$$

where S_r = the share of netput r in total profit, it is positive for outputs (r=1, 2) and negative for inputs (r=3…..7). $\mu_{r\,it}$ is the error term for the respective share equations.

If the profit function satisfies the conditions of monotonicity, convexity, symmetry and homogeneity, it is dual of the transformation function and its estimated parameters contain sufficient information to describe the farm's production technology at profit maximising points in the production possibility set. Symmetry of the profit function is imposed by using nested cross-equation restrictions and appropriately constraining relevant coefficients in the profit function and the share equations. Linear homogeneity implies that profit will remain unchanged if all variable inputs and outputs prices increase by the same proportion. Linear homogeneity is routinely imposed prior to profit function estimation in the literature. We impose homogeneity by using an input price as a *numéraire* to normalise the profit and price variables, as in common practice (*eg.* Sidhu and Baanante (1985); Kheralla and Govindan (1999)). This has the added benefit of reducing the number of variables to be estimated. Later, symmetry is tested conditional upon homogeneity.

The WITHIN-SURE model

The multi-output profit function system is estimated using a fixed effects model on a panel dataset. This allows the control of unobserved farm and farmer characteristics that do not change over time. Fixed effects are chosen over random effects because of extensive evidence in the agricultural context that individual characteristics (e.g., managerial ability) may be correlated with the explanatory variables (e.g., level of output) and treating them as uncorrelated may lead to bias. The error terms in the system (4) and (5) can thus be described as follows:

$$\mu_{d\ it} = \eta_{d\ i} + u_{s\ it} \quad (d = pf, 1\ldots7) \qquad (6)$$

where $\eta_{d\ i}$ is the farm(er)-specific effect, and the $u_{d\ it}$ is iid error for equation d.

The Within-SURE method involves first subtracting farm means from all variables in equations sets (4) and (5), thereby removing the farm-specific effects $\underline{\eta}_{s\ i}$. Subsequent to removal of means, Seemingly Unrelated Regression (SUR) methods (Zellner, 1962) are applied to the de-meaned equations.

Ozone-related elasticities

The ultimate objective of this paper is to estimate the impact of changes in tropospheric ozone concentration on variable profits and on the supplies of cereal output. Such information can be obtained by considering the elasticities of variable profits and profit-maximising output-supply with respect to changes in ozone concentration. The elasticity of variable profits with respect to ozone can be computed as:

$$\varepsilon_{\pi,k} = \alpha + \frac{1}{2}\theta \ln k_{it} + \sum_{d=1}^{7} \gamma_d \ln p_{itd} \qquad (7)$$

and the elasticity of supply of output v with respect to ozone can be estimated using:

$$\tau_{v,k} = \alpha + \theta \ln k_{it} + \sum_{r=1}^{7} \gamma_r \ln p_{itr} + \frac{\gamma_v}{S_v}\,, \qquad (8)$$

where v indexes the outputs and S_v is the output share. θ and γ_v are estimated parameters.

IV. Data

Cereals

The data used for estimation come from a series of economics studies on cereals undertaken in the UK from 1993 to 1998. The survey was conducted by the Land Economy Department of the University of Cambridge on behalf of the Department of Environment, Food and Rural Affairs, U.K. Wheat and barley constitute the major cereals in the region. Farms having complete production data on winter wheat and barley and that are present in all six years were included in the sample. This constituted a balanced farm level panel dataset of

66 cereal farms, resulting in 396 observations. The prices for wheat and barley were determined by dividing the total respective enterprise revenues by the quantity of the outputs. The total revenue also included revenue received from the sale of straw and set-aside payment. Farm level prices for seeds and fertiliser were calculated by dividing expenditures by respective quantities. In the present context the different seed varieties and different types of fertiliser were aggregated, to ultimately derive a price for seed and a price for fertiliser. Variable profits, output and input prices were respectively deflated using input and output specific price indices for agricultural production, obtained from DEFRA However, as far as crop protection inputs were concerned, only expenditure data were gathered. Hence the price index for crop protection input, constructed by DEFRA under the 'Agriculture in the UK' data series (DEFRA, 2002) was used. The DEFRA national average agricultural wage rates also enter the model as an explanatory variable. Land rental rates were computed by dividing expenditure on land rent by area and expressed as £ per ha. Variable profits and prices were then normalised by the price of crop protection input to impose homogeneity.

Tropospheric ozone

Ozone data were obtained from the UK national air quality information archive, which covers 50 monitoring stations spread across the UK. The reported data are in parts per billion per day. They were downloaded for each day from the 1st day of May till the last day of July of each year covered in the study. This choice is based on previous experimental research, which reveals that the winter wheat crop in the UK is more susceptible to ozone damage during this particular window (Ollerenshaw and Lyons, 1999). The AOT40 is computed as:

$$\sum_{i=1}^{n}(x_i - 40)\ \ for\ \ x_i > 40\ in\ ppb.h \tag{9}$$

where x_i is the hourly TO concentration in parts per billion and n is the number of hours for which $x_i > 40$. According to Lefohn *et al.* (1988), using a cumulative exposure index results in a better predictor of the impacts of ozone on vegetation as compared to seasonal mean measures of the type that were used in Garcia *et al.* (1986) and Young and Aidun (1993). The spatial locations of the monitoring stations and the ozone data were input in a Geographical Information System (GIS) so that ozone levels for farms could be estimated through interpolation. Summary statistics are presented in Table 1.

[Table 1 approximately here]

V. Results

Pre-testing for output price separability and input non-jointness

The fixed effects model is tested for output price separability and input non-jointness. A log-likelihood test is used to check whether restrictions imposed on the system hold. This is a χ^2 test, with the number of restrictions being the degrees of freedom. The null hypotheses are that separability and input non-jointness assumptions hold. The test statistics for the hypotheses are presented in Table 2.

[Table 2 approximately here]

The hypothesis of separability in output prices is rejected at 5% level. The existence of price and quantity indexes that satisfy the adding-up property, and therefore the scope for aggregating wheat and barley as a single output, is rejected. It is therefore theoretically and empirically more appropriate to use a multi-output specification to evaluate wheat and barley profits. The hypothesis that the technology is non-joint in inputs is also rejected at the 5% level. This further suggests that the wheat and barley enterprises are closely synergistic, and any attempt to model either wheat or barley in isolation would have been inappropriate.

Estimates and Diagnostics

We used the Lagrange multiplier (LM) test of Breusch and Pagan to check the hypothesis of a diagonal residual correlation matrix. We obtained a χ^2 value of 407.4, which was significant at the 1% level and therefore reject the null hypothesis of a diagonal residual correlation matrix. The use of SURE over an OLS is consequently warranted. An F test was also carried out to test whether all slopes coefficients were simultaneously zero. This hypothesis was also rejected at the 1% level.

Results from the Within-SURE estimation of the system of equations comprising the multi-output profit function and the share equations are shown in Table 3.

[Table 3 approximately here]

The number of significant parameters at 1%, 5% and 10% significance levels are 23, 24 and 25 out of 30 estimated parameters. Thus most parameters in the model appear to be reasonably precisely estimated. Symmetry restrictions are tested conditional on imposed homogeneity. The results are shown in Table 4.

[Table 4 approximately here]

The results from the likelihood test are encouraging. At the 5% level the property of symmetry conditional on homogeneity is not rejected. Therefore, the parameters of the model in its most restricted form are used to compute the share values and the elasticities.

We next turn to checking monotonicity and convexity in prices. As Table 5 shows, monotonicity is satisfied as the fitted output and input shares are respectively positive and negative. Convexity in prices is satisfied when own-price elasticities are confirmed to have the correct signs. Elasticities evaluated at sample means values are presented in Table 6. As the table confirms, all own-price elasticities display the correct sign. The main theoretically implied restrictions are seen to be satisfied, therefore the estimated profit function is dual to the transformation function and its parameters contain sufficient information to describe the farm's production technology at profit maximising points. We therefore turn to computing ozone elasticities with reasonable confidence in model performance.

[Table 5 approximately here]

[Table 6 approximately here]

Ozone elasticities and their implications

The major aim of this study has been to estimate variable profit and cereal supply elasticities with respect to ozone using equations (7) and (8). Computed elasticities are reported in Table 7. At the sample mean AOT40 of 3090 ppb.h, the estimated elasticity of profits with respect to ozone is –0.134. This elasticity conforms to prior expectations and suggests that a 10% increase in the ozone index above its mean value would correspond to a 1.3% decrease in variable farm profits. The elasticity is significant at the 10% level.

[Table 7 approximately here]

There are no European farm-level studies with which to compare our results. The closest comparable studies are those of Young and Aidun (1993) and Garcia *et al.* (1986). Young and Aidun (1993) estimated an elasticity of –2, which is fifteen times the magnitude of the present estimate. This disparity could be explained by numerous factors. The Alberta study by Young and Aidun modelled ozone effects on profits from a single enterprise, wheat. In our case, involving farms jointly cropping wheat and barley, there are likely more avenues available for farmers to mitigate the effects of ozone on overall profits. In this regard, our results appear more comparable to Garcia *et al.* (1986) and Mjelde *et al.* (1984), who computed profit elasticities of –0.476 and -0.408 respectively, especially given that these studies also modelled a multi-output scenario (wheat, soybeans and corn[4]).

Also, Young and Aidun (1993) used ppb as ozone units and this could have resulted in an overestimation of the ozone effect. Experimental research in Europe has clearly demonstrated that there is a threshold effect to the effect of ozone pollution on crop production, as captured by the AOT40 index we have used. The current sample had a broader spatial coverage, with wider ozone exposures. This could have attenuated the average deleterious effect of ozone that could have occurred with a more geographically localised sample. The levels of TO experienced in Alberta were also of higher magnitude that those experienced in England and Wales from 1993 to 1998. Given that the effect of ozone on crop output is likely to be increasing in ozone levels, wheat production and therefore profits may have been relatively more affected in Alberta as compared to England and Wales. There is also the possibility that the wheat varieties cropped in Alberta could have been more susceptible than those under cultivation in England and Wales.

Possibly, the key reason for the significant difference in magnitudes is that we account for heterogeneity via the use of panel methods. A significant body of research now shows that economic outcomes across farms are strongly influenced by unobserved heterogeneity, including farmer efficiency, soil quality and topography effects, etc. Lack of control for such effects has the potential to significantly bias the estimated effects of variables such as ozone.

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[4] Note however that these studies did not estimate multi-output profit functions and instead aggregated data from multiple crops into scalar indices.

Even though the present estimate is lower than those obtained by Young and Aidun (1993) and Garcia *et al.* (1986) an elasticity of -0.134 can still be of economic significance. The effect is inelastic, but when evaluated at average variable profits, it corresponds to a loss of £ 1465 for a 10% increase in the mean AOT40 index, for an average farm in the sample. Fluctuations significantly larger than 10% are common both across space in a given year, and across years. For example, in 1995, England and Wales suffered a strong TO episode and many counties experienced AOT40 values greater than 4635 ppb.h. This represented a 50% increase in the average sample concentration. Extrapolating the profit elasticity with respect to TO to this average ozone value would suggest a 6.7% reduction in the average variable profits. This equates to a £ 7325 reduction in variable profits for an average cereal producer in the year 1995. Thus the losses can be significant even though the estimated magnitude is smaller than previous studies have indicated.

The wheat supply elasticity with respect to TO is –0.1006 and is significant at the 10% level. The negative sign on the elasticity is validated by biological science studies (Buse *et al.,* 2000), which show that wheat is susceptible to high ozone levels. A supply elasticity of -0.1006 implies that a 10% increase in the average ozone index depresses wheat supply by 1.006%. Young and Aidun (1993) obtained an output elasticity of supply of -0.73 on wheat farms in Alberta. The same explanations discussed for the difference in profit elasticity magnitudes across studies apply here. Somewhat surprisingly, barley supply elasticity is larger, at -1.25. Barley is less sensitive to TO than wheat, and hence the *a-priori* expectation would have been that the effect on wheat supply would be more pronounced. However, a variety of adjustments at the margin are likely to take place in response to ozone exposure over time. This includes changes in variable input applications, changes in land cropped, and changes in the output mix, as producers compensate for ozone-induced losses (Garcia, *et. al*., 1986).

VI. Conclusion

This study sought to identify the economic impact on and adjustments in the behaviour of cereal producers due to changing TO concentrations. Previous economic evaluations of the impacts of ozone in European settings have largely relied on extrapolations from experimental data. However, farmers have an array of behavioural economic responses available to mitigate the effects of ozone, and so such extrapolations can result in overstatement of economic impact. In this paper, we have instead directly relied on farm level data and estimation of a set of behavioural economic equations to investigate the impact of ozone in England and Wales. We have also tried to improve estimation precision compared to the existing literature in this area from North America, by using a more relevant pollution index, and by controlling for heterogeneity.

Our results have confirmed a statistically significant impact of ozone on farm profits and wheat and barley supply in England and Wales. However, the effect is relatively small compared both to what is implied by experimental evidence, and also compared to estimates from North America. Despite the small magnitude of the elasticity, elevated ozone levels can still cause moderate losses on cereal farms.

The main message from this research is that great caution is warranted in freely extrapolating from experimental data to carry out economic impact assessment. Experimental evidence is extremely valuable in several ways, but there can be a significant gulf between experimental and economic outcomes. Farmers as economic agents can and will carry out mitigatory actions to cope with external shocks to productivity, thereby cushioning the impact of the shock. Even the estimates that we have derived cannot be extrapolated to a regional or national scale. At an aggregate level, depending on the elasticities of cereal supply and demand, it is even possible that control of ozone may result in little or no economic gains, despite what is suggested by experimental evidence.

Testing of farm-level outcomes of data using other European data may be a fruitful topic for further research. Ozone levels become elevated with temperature, and hence Southern Europe may be a particularly appropriate setting for such work.

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Table 1. Summary statistics for the variables used in the estimation after conditioning for outliers, negative and non-zero profits.

Variable	Unit	Mean	Minimum	Maximum
Variable profits	£	109327.9	6793.12	598379.80
P_{wheat}	£/t	133.7	97.08	203.73
P_{barley}	£/t	142.7	92.21	204.14
P_{seed}	£/t	244.4	35.30	950.23
$P_{fertiliser}$	£/t	109.6	70.72	429.19
$P_{crop\ protection\ input}$	£/t	173.12	158.10	179.91
P_{land}	£/ha	129.6	90.39	215.23
P_{labour}	£/hour	4.82	4.62	5.08
AOT40	ppb.h	3090.08	405.75	7235.50

Table 2. Tests for separability and input non-jointness

Hypotheses	Number of restrictions	Likelihood ratio statistic	Significance of χ^2
Separability	4	11.45	9.49**
Input non-jointness	1	3.013	2.70**
Separability and input non-jointness	5	8.72	8.06^{+}

Notes: ** χ^2 at 5%, $^{+}$ χ^2 at 15%

Table 3. Parameter estimates for the fixed effects model

	Coefficient	Std. Error	t-Statistic
P_{wheat}	0.551336***	0.011569	47.65673
P_{barley}	0.827126***	0.031144	26.55851
P_{seed}	-0.044557***	0.003767	-11.828
$P_{fertiliser}$	-0.091751***	0.006901	-13.29474
P_{labour}	0.05488***	0.014452	3.797455
P_{rent}	-0.207915***	0.009066	-22.93264
Ozone	1.015608***	0.096557	10.51825
P_{wheat}* P_{wheat}	0.920322***	0.034907	26.36503
P_{barley}*P_{seed}	0.028964***	0.003276	8.839945
P_{barley}* $P_{fertiliser}$	0.043336***	0.005982	7.243952
P_{barley}*P_{labour}	0.090885***	0.012486	7.278989
P_{barley}*P_{land}	0.00677	0.007879	0.859315
P_{barley}*P_{barley}	0.341548***	0.027381	12.47385
P_{seed}*P_{seed}	-0.098645***	0.011466	-8.603178
P_{seed}*$P_{fertiliser}$	0.040317***	0.009829	4.102512
P_{seed}*P_{labour}	0.050722	0.031379	1.616401
P_{seed}*P_{land}	0.062232***	0.017061	3.647541
$P_{fertiliser}$*$P_{fertiliser}$	-0.110577***	0.018143	-6.094903
$P_{fertiliser}$*P_{labour}	0.08301*	0.037594	2.20806
$P_{fertiliser}$*P_{land}	0.052379**	0.021443	2.442662
P_{labour}*P_{labour}	-0.230905	0.177207	-1.303023
P_{labour}*P_{land}	0.459642***	0.070313	6.537115
P_{land}*P_{land}	-0.313523***	0.047606	-6.585762
Ozone*Ozone	0.587347	0.468568	1.253493
P_{wheat}*Ozone	0.035966	0.043975	0.817883
P_{barley}*Ozone	-0.441487***	0.065576	-6.732401
P_{seed}*Ozone	0.087238***	0.007992	10.91552
$P_{fertiliser}$*Ozone	0.143689***	0.014182	10.13169
P_{labour}*Ozone	0.173158***	0.02958	5.853968
P_{land}*Ozone	0.233109***	0.019897	11.71555
Adjusted R^2	0.57		

Notes: *** significant at 1%, ** significant at 5%, * significant at 10%

Table 4. Log-likelihood ratios

Null hypothesis	D.F	Log-likelihood ratio	Critical value of $\chi^2_{0.05}$
Symmetry conditional on homogeneity	30	0.00779	43.77

Table 5. Share values

	Actual shares	Fitted shares
Wheat	1.102	1.077
Barley	0.518	0.432
Seed	-0.088	-0.0779
Fertiliser	-0.154	-0.1417
Crop protection inputs	-0.0968	-0.0238
Labour	-0.0501	-0.0499
Land	-0.2311	-0.2157

Table 6. Estimated price and cross price elasticities

Price and cross price elasticities							
	Price						
	Wheat	Barley	Seed	Fertiliser	Crop protection	Labour	Land
Quantity							
Wheat	***0.9207**** (0.488)	0.0859 (0.0759)	0.9739^{++} (0.654)	0.5441 (0.499)	-3.0026** (1.364)	0.1587 (0.354)	0.3193* (0.169)
Barley	-0.036 (0.0331)	***0.7557***$^{+}$ (0.568)	0.2053 (0.369)	0.1323 (0.189)	0.4215 (0.562)	-1.795 (4.401)	0.3166 (0.845)
Seed	-0.0695 (0.0985)	-0.0346 (0.0543)	***-0.213**** (0.123)	-0.3409 (0.446)	1.517 (2.025)	0.5995** (0.268)	0.2595 (0.367)
Fertiliser	-0.120 (0.215)	-0.039*** (0.015)	0.6092 (0.498)	***-0.337***** (0.169)	0.7219^{++} (0.487)	-1.028*** (0.369)	0.1949 (0.265)
Crop protection	0.019 (0.0235)	-0.806*** (0.236)	-0.4947* (0.264)	0.0568 (0.0481)	***-1.698***$^{+}$ (1.221)	2.6618 (2.351)	0.2627 (0.415)
Labour	0.0013 (0.0147)	0.1861 (0.663)	-0.3687 (0.441)	-0.354^{+} (0.264)	1.5187*** (0.569)	***-2.66***** (1.357)	1.679 (2.025)
Land	-0.712*** (0.239)	-0.146*** (0.015)	-0.712** (0.368)	0.2992** (0.152)	0.5222 (0.41)	3.262 (2.985)	***-2.513*** (2.651)

Notes: Elasticities are computed at the mean of the actual profit shares
Standard errors are in parentheses
*** significant at 1%, ** significant at 5%, * significant at 10%, $^{++}$ significant at 15%, $^{+}$ significant at 20%

Table 7. Ozone related elasticities

	Ozone
Profits	-0.134*
	(0.0811)
Wheat	-0.1006*
	(0.0621)
Barley	-1.2539*
	(0.7015)

Notes: Elasticities are computed at the mean of the actual profit shares
Standard errors are in parentheses
*** significant at 1%, ** significant at 5%, * significant at 10%