Crop Substitution on UK Sugar Beet Farms and its Effects on the Environment: A Multi-Product Cost Function Approach

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Abstract

This paper analyzes the effect that the imminent reform of the EU sugar beet regime will have on United Kingdom (UK) sugar beet farms. Specifically, we estimate a multi-product cost function to analyze the effect the changes on the sugar beet price support and quota will have on the crop allocation of sugar beet farms and their aggregate use of inputs. Based on these estimates we discuss the implications that changes in the crop patterns may have on farm environmental variables such as soil loss and groundwater pollution.

Keywords: Multi-product cost function, UK sugar beet production, CAP reform.

I. Introduction

This paper is part of an analysis of the effects that the imminent reform of the EU sugar beet regime will have on United Kingdom (UK) sugar beet farms.

The EU sugar regime has been part of the Common Agricultural Policy (CAP) since 1968, and during this period it has never been fundamentally reformed. Other sectors of the CAP were reformed in 1992, 2000 or 2003, but not sugar; therefore the sugar regime is coming under increasing pressure to promote greater competitiveness and stronger market orientation in line with the reformed CAP.

In September 2003, the European Commission proposed three broad possible ways forward: (1) extend the present regime beyond 2006, cutting quotas as necessary; (2) reduce the EU internal price, with a view to eliminating quotas; (3) completely liberalize the current regime, including tariffs. Furthermore, the most recent proposal made in July 2004 (CEC, 2004) considers a combination of quota and support price reductions.

The environmental effect of the possible reform of the sugar beet regime has been an important part of the debate surrounding the reform proposals. In fact, as part of this debate UK's Department for the Environment Food and Rural Affairs (Defra) undertook a consultation exercise about the impact on biodiversity; land use and soils; and waste and water (Defra, 2002a) and released a report (Defra, 2002b). Also, as part of this exercise, British Sugar, the only processor of sugar beet in the UK also prepared a report about the environmental impacts of growing sugar in the UK.

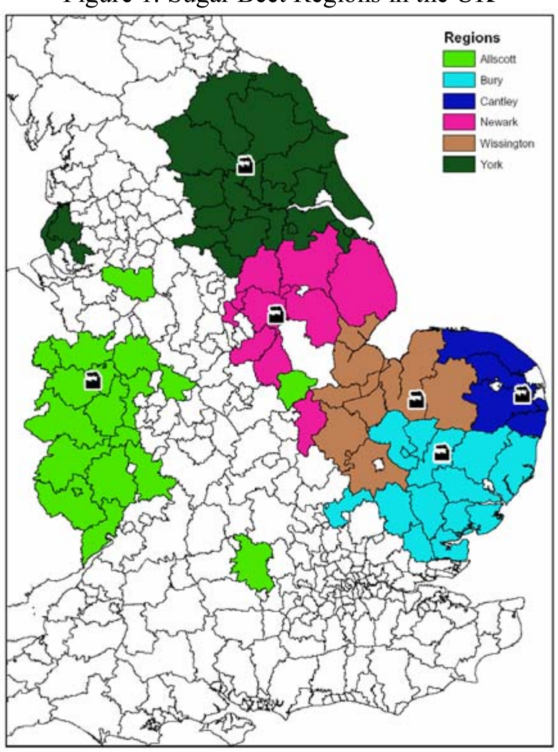
While the aforementioned studies are focused on the environmental impact of sugar beet production, they do not address the environmental impact that changes in land use due to the reform might have on the environment. The contribution of this paper is to estimate the effects that changes in the sugar beet support price and quota level might have on the crop allocation of sugar beet farms and on the aggregate use of inputs, in order to discuss what the possible impacts on farm environmental variables such as soil loss and groundwater pollution are.

We start this paper presenting the data used and the empirical approach followed, which consisted of estimating of a multi-product cost function and use it in order to compute the change in farm outputs and inputs due to three potential reform scenarios: a 25 per cent cut in the UK sugar quota, but no price cut; a fall in the average beet price of 25 per cent and; a fall in the average beet price of 40 per cent. Finally, we discuss the possible environmental effects that these results.

II. Data

The data available for the estimation is an unbalanced panel dataset, which was assembled from surveys collected by the Rural Business Unit, University of Cambridge during the period 1994 – 2002 for the Eastern Region (East Anglia) of the UK, which produces around 60 percent of the UK sugar beet. The surveys provide disaggregated information about gross margins for several important crops of the area, such as winter and spring wheat, winter and spring barley, beans, peas, oilseed rape and potatoes since 1994. This panel is unbalanced due to the fact that not all the farmers remain in the survey permanently as 10 per cent of the sample varies each year. The number of farms in this dataset is 241 and the total number of observations is 1,289. The following map (figure 1) presents all the UK sugar beet regions, which are based on the locations of the British Sugar's factories. This paper is focused on the regions of Bury St. Edmunds (Suffolk), Cantley (Norwich) and Wissington (Norfolk), which are the only regions for which data on costs for different crops was available.

Figure 1. Sugar Beet Regions in the UK



A problem faced with the FBS is that it does not report either the quantity of inputs used or the input prices. Therefore, it was necessary to assume, such as in other works (see Guyomard et al., 1996, Alvarez et al., 2003) that all the farmers faced the same input costs. While this assumption is suitable for the goal of measuring economies of scale, it is not appropriate when the objective is to recover the conditional demands for factors needed for the productivity analysis. For this purpose, we assume that the input prices vary over time and we use the advantage of working with panel dataset to recover the information related to inputs. The information on input prices was collected from Defra database. All the prices were deflated by Defra's crop output prices base year 1995.

In addition, table 1 presents the average crop share for the three sugar beet regions. As shown in the table cereals comprise above 60 percent of the cropping area, reaching in the case of Bury St. Edmund 71.2 percent on average for the period 1994-2002. Sugar beet is incorporated into cereal farms production due to two reasons: first, it is a well remunerated cash crop and second, as part of the agronomic crop rotations, it works cleaning the fields of weeds in between cereal crops.

Table 1: Average Crop Share in Sugar Beet Farms by Region and Year
Percentages based on sample data

Region/Year	Winter Wheat	Spring Wheat	Spring Barley	Winter Barley	Beans	Peas	Oilseed Rape	Potatoes	Sugar Beet
Bury St Edmunds									
1994	47.5	2.4	6.4	15.1	3.3	1.4	1.3	1.8	20.8
1995	50.2	0.2	6.7	15.8	2.8	0.7	2.6	1.6	19.4
1996	49.5	0.1	6.5	17.7	2.3	0.7	2.9	1.7	18.6
1997	47.5	0.2	8.4	17.5	1.9	1.4	4.1	1.4	17.5
1998	48.7	0.2	5.4	16.0	1.8	2.4	5.4	3.1	17.0
1999	50.3	0.0	8.8	11.3	1.6	1.7	5.0	3.7	17.6
2000	56.3	0.8	5.5	8.2	3.8	1.3	4.4	3.8	15.7
2001	48.2	1.9	9.2	7.6	5.0	1.8	5.9	2.7	17.6
2002	53.7	1.0	6.3	9.4	3.9	1.4	4.5	2.7	17.1
Cantley									
1994	26.5	2.1	10.0	28.4	1.1	0.2	1.1	5.1	25.6
1995	31.6	1.2	9.4	26.9	0.5	0.2	0.0	5.0	25.2
1996	32.0	0.5	9.0	27.9	0.2	0.1	0.0	4.8	25.5
1997	26.1	0.7	11.5	31.6	0.7	0.1	0.0	4.9	24.4
1998	27.4	0.7	9.6	32.7	1.0	0.5	0.0	4.4	23.7
1999	25.8	0.8	13.5	28.3	0.9	0.4	0.0	5.6	24.6
2000	34.7	0.2	7.8	29.1	1.0	0.1	2.3	4.8	19.9
2001	28.1	0.0	14.2	28.2	1.0	0.2	4.4	3.4	20.6
2002	38.2	0.4	9.4	21.5	3.5	0.3	3.4	3.4	19.9
Wissington									
1994	44.3	2.4	5.3	12.0	2.2	3.6	3.4	4.9	21.8
1995	48.3	0.5	4.8	13.1	1.8	2.3	2.3	4.9	22.0
1996	47.4	0.3	4.9	15.4	1.7	2.7	2.4	5.0	20.2
1997	44.9	0.3	3.8	16.2	2.2	4.7	4.1	4.5	19.4
1998	48.3	0.4	3.4	13.3	1.7	4.2	5.0	5.2	18.5
1999	50.1	0.7	2.6	9.6	1.8	3.4	4.8	8.4	18.6
2000	53.6	0.4	2.9	8.9	2.0	2.7	5.6	7.2	16.7
2001	49.3	1.4	4.7	7.5	2.5	3.0	6.3	8.1	17.3
2002	53.0	0.6	3.4	8.0	2.3	2.8	4.4	8.5	17.0

Source: Based on University of Cambridge, Farm Business Survey Data for England's Eastern Counties.

III. Estimation

In order to analyze the allocation of crops due to changes in the sugar beet policy we estimated a multi-product variable cost function and used it to compute the crop substitution elasticity due to changes in sugar beet price support and quota.

The use of a multi-product cost function is interesting not only because it can be introduced into mathematical programming problems of land allocation but also because it has been less frequently used in agricultural production problems than, for instance, the multi-product profit function approach (Akridge and Hertel, 1986 applied a multi-product cost function to the analysis of retail fertilizer plants). Furthermore, most of the work done on the estimation of cost functions has been for specialized farms (typically livestock or dairy farms) or using an aggregate measure of output where the farms had several outputs.

Empirical work requires the choice of a functional form. Thus, we estimated a generalized translog multi-product cost function. The reasons for choosing this functional form are based on Caves, Christensen and Tretheway (1980). Namely, this functional form has all the convenient properties of the translog function and, in addition, it allows some of the farm outputs to be equal to zero. This is achieved by expressing the output using a Box-Cox transformation.

The cost function was estimated using a fixed effects model, which allows us to control by the specific farm characteristics that can be associated to soil or other factors that do not change over time. The reason behind this choice is due to Mundlak's (1978) argument that individual characteristics (e.g., managerial ability) may be correlated with the explanatory variables (e.g., level of output) and, therefore treating the farm characteristics as part of the error term, such as in the random effect model, we have regressors that are correlated with the error term.

The specific econometric estimation consists of a two-stage procedure due to the "regression fallacy" problem (Alvarez et al., 2003). Hence, in a first stage, we estimate the output based on inputs and in a second stage we estimate the multi-output cost function using the predicted output from the previous stage. Equation (1) presents the estimated translog production function, where the sub-index i denotes the crop and Y is the output (the sub-index corresponding to the observation has been suppressed for simplicity) X_1 is the log of the quantity used of seeds, X_2 of fertilisers, X_3 of crop protection products, X_4 of hired labour, X_5 of miscellaneous, which includes contracting of harvester and haulage,. The estimates are presented in the annex.

$$(1) \qquad \ln Y_i = \alpha_o + \sum_{j=1}^{5} \alpha_j \ln X_{ij} + \frac{1}{2} \sum_{j=1}^{5} \sum_{h=1}^{5} \beta_{jh} \ln X_{ij} \cdot \ln X_{ih}$$

The cost function (in its variable cost form) to be estimated is given by equation (2), where the sub-index t for "period" has been suppressed:

$$(2) \qquad \ln C_f = \alpha_f + \sum_{j=1}^{5} \alpha_j \ln W_j + \sum_{j=1}^{5} \xi_j \ln W_j \ln Z_f + \tfrac{1}{2} \sum_{j=1}^{5} \sum_{h=1}^{5} \beta_{jh} \ln W_j \ln W_h$$

$$+ \sum_{i=1}^{9} \delta_i f(Q_{if}) + \sum_{i=1}^{9} \varsigma_i f(Q_{if}) \ln Z_f + \sum_{i=1}^{9} \sum_{j=1}^{5} \psi_{ij} f(Q_{if}) \cdot \ln W_j + \tfrac{1}{2} \sum_{i=1}^{9} \sum_{k=1}^{9} \gamma_{ik} f(Q_{if}) \cdot f(Q_{kf}) + \tfrac{1}{2} \vartheta (\ln Z_f)^2$$

Where $\alpha, \beta, \delta, \Psi, \varsigma, \xi, \vartheta$ and γ are the function parameters. C_f is the variable cost function for the farm 'f'. The sub-index related to time has been dropped to simplify the notation. Function (1) considers nine outputs and five inputs and one quasi-fixed input (Z_f). W_1 is the log of the price seed, W_2 for fertilisers, W_3 for crop protection products, W_4 for hired labour, W_5 for miscellaneous, which includes contracting of harvester and haulage, Q_1 is the transformed output of sugar beet, Q_2 for winter wheat, Q_3 for spring wheat, Q_4 for spring barley, Q_5 for winter barley, Q_6 for beans, Q_7 for peas, Q_8 for oilseed rape and Q_9 for potatoes. The only fixed factor considered due to data availability was family labour.

The output in the generalised translog cost function uses $f(Q)$, which is a monotonic function instead of logarithms. Such as in Caves et al. (1980), $f(\bullet)$ is given by the Box-Cox transformation in equation (2), where λ is the Box-Cox parameter. We assumed the same λ for all the crops in order to reduce the estimation burden.

$$(3) \qquad f(Q) = \begin{cases} \dfrac{(Q^{\lambda} - 1)}{\lambda} & \lambda \neq 0 \\ \ln(Q) & \lambda \to 0 \end{cases}$$

Even if according to Caves et al. (1980) the generalised translog is the function with the fewest number of parameters to estimate, this number is still high. In our case with five inputs and nine outputs and a quasi-fixed factor, the total number of slope parameters to estimate (even when imposing symmetry of the cross products and excluding the fixed effect intercepts) is equal to 145 (including the Box-Cox parameter). Due to this fact, we divided the estimation of parameters into three stages.

We first estimated the Box-Cox parameter in view of the fact that, once this parameter was computed, it was possible to transform the production parameters and make the system linear. This was done by means of a grid search procedure to find the value of the Box-Cox parameter that maximised the log likelihood value of the non-linear share equations.

Due to the high number of parameters it was not possible, such as in Caves et al. (1980) to estimate the entire cost function and the input share equations together. Instead, the next step consisted of transforming the outputs, using the estimated Box-Cox parameter and estimating the input share equations using an iterative seemingly unrelated regression equations procedure, imposing symmetry and price homogeneity to be sure that the parameters corresponded to a well-behaved cost function. This estimation was carried out using only the panel dataset.

The next step was to recover the remaining parameters of the cost function, which were associated to the output terms (not associated to input prices) and the fixed effect terms. To estimate these terms we averaged the data by farm (or region in those cases were we only had data for 2002) and estimated the equation as deviations of the means, such as in Hsiao (1993) for the fixed effects model. This estimation stage used the entire sample. Table 1 presents the estimation results and Figure 2 shows a histogram of the individual fixed effect terms (only for Bury St. Edmunds, Cantley and Wissington).

After we estimated all the parameters of the model we computed the estimated input shares, which have to be positive in order to satisfy the concavity conditions and we also checked the Hessian matrix with respect to input prices to be negative semi-definite. We did not impose any condition on the outputs. All but five cases presented negative shares. Similar results were obtained for the Hessian.

Once we estimated the cost function, for each farm "f" we computed the marginal cost functions (MgC_{i-f} being i the output index) for each output and the input use (X_{j-f} being j the output index), which are given by equations (4) and (5):

$$(4)\qquad MgC_{i-f} = Q_i^{\lambda-1}\cdot \exp\left\{ H_f + \sum_{i=1}^{9}\delta_i^* \frac{\left(Q_{if}^{\lambda}-1\right)}{\lambda} + \frac{1}{2}\sum_{i=1}^{9}\sum_{k=1}^{9}\gamma_{ik}\frac{\left(Q_{if}^{\lambda}-1\right)}{\lambda}\cdot\frac{\left(Q_{kf}^{\lambda}-1\right)}{\lambda}\right\}\cdot\left\{\delta_i^* + \frac{1}{2}\sum_{k=1}^{9}\gamma_{ik}\cdot\frac{\left(Q_{kf}^{\lambda}-1\right)}{\lambda}\right\}$$

$$(5)\qquad X_{j-f} = \left(\frac{1}{W_j}\right)\cdot \exp\left\{ H_f + \sum_{i=1}^{9}\delta_i^* f(Q_{if}) + \frac{1}{2}\sum_{i=1}^{9}\sum_{k=1}^{9}\gamma_{ik} f(Q_{if})\cdot f(Q_{kf})\right\}\cdot\left\{\alpha_j^* + \sum_{i=1}^{9}\Psi_{ji}\cdot f(Q_{if})\right\}$$

Where:

$$H_0^W = \sum_{j=1}^{5}\alpha_j \ln W_j$$

$$H_1^W = \frac{1}{2}\sum_{j=1}^{5}\sum_{h=1}^{5}\beta_{jh}\ln W_j \ln W_h$$

$$H_f = \alpha_f + H_0^W + H_1^W$$

$$\delta_i^* = \delta_i + \sum_{j=1}^{5}\Psi_{ij}\ln W_j$$

IV. Simulation of change in crop allocation and input use

To find the values of the output due to changes in the sugar beet policy we solved the following non-linear mathematical problem (shown in 6) using the estimated cost function for each estimated farm (f) constrained by the land availability.

$$(6)\qquad \underset{Q_{if}}{\text{Max}}\quad \pi_f = \sum_{i=1}^{9} P_i Q_{if} - C(W,Q,Z)$$

Where P_i is output i price, Q_i is the i-th output, and $C(W,Q)$ is the estimated variable cost function (i.e., $\exp(\ln C_f)$). Because the cost function is non-linear with a high number of parameters, instead of maximizing equation (6) we obtained the change in farm output by solving the following linear system based on the differentiation of equation (6) and evaluating the Jacobian matrix at the individual farm output values. Thus, for the case of a decrease in the sugar beet quota the change in output is given by the system (7), where the sub-index f has been dropped to simplify:

$$(7) \qquad \left[\eta_1^{i,j}\right]\cdot\left[\frac{dQ_i}{Q_i}\right]=\left[\frac{dQ_1}{Q_1}\right] \qquad j=2,..,9 \quad i=2,..,9$$

Where $\left[\eta_1^{i,j}\right]$ is an 8x8 matrix of elasticities representing the response in crop i due to a change in the sugar beet quota with elements $\eta_1^{i,j}$ defined such as:

$$\eta_1^{i,j}=-\frac{\dfrac{\partial MC_i(\bullet)}{\partial Q_j}}{\dfrac{\partial MC_i(\bullet)}{\partial Q_1}}\cdot\frac{Q_j}{Q_1}$$

$\left[\frac{dQ_i}{Q_i}\right]$ is a column vector 8x1 of changes in the supply of each product in the farm and $\left[\frac{dQ_1}{Q_1}\right]$ is the change in the sugar beet quota.

For the case of a change in the support price we differentiate with respect to all the marginal cost equations including the sugar beet equation and we get the following linear system (8):

$$(8) \qquad \left[\varepsilon_1^i\right]\cdot\left[\frac{dQ_i}{Q_i}\right]=\left[\frac{dP_i}{P_i}\right] \qquad i=1,..,9$$

Where $\left[\varepsilon_1^i\right]$ is a 9x9 matrix of elasticities representing the response in the farm output i due to a change in the sugar beet price with elements ε_1^i defined such as:

$$\varepsilon_{beet}^i=\frac{\partial MC_i(\bullet)}{\partial Q_1}\cdot\frac{Q_1}{P_i}$$

$\left[\frac{dQ_i}{Q_i}\right]$ is a column vector 9x1 of changes in the farm output and $\left[\frac{dP_i}{P_i}\right]$ is a column vector of price changes, which only takes a positive value in the case of the change in the support price for sugar beet.

In the case of a decrease in the price support, before applying (8) we verified whether the marginal cost of producing sugar beet at the current situation was greater than the new support price. If it was greater (i.e., sugar beet was producing a rent) then we assumed that the farmer would continue producing the sugar beet quota, in which case (as we assumed other output prices constant) the crop allocation was unaffected. Otherwise, we used (8) to find the new crop allocation.

Once the relative changes in the output of each crop were computed, the new output Q_{if}^{N} was obtained such as in equation (8), where Q_{if}^{0} is the initial output. We estimated the changes in output and input based on the 2002 information.

$$(9) \qquad Q_{if}^{N} = \left(1 + \frac{dQ_{if}}{Q_{if}}\right) \cdot Q_{if}^{0} \qquad i = 1,..,9$$

It is important to note that, as the change in output given by (9) is not constrained by the land availability, the results were rescaled to the availability of land by a procedure presented in the Annex. While this modified the magnitude of the changes, the procedure preserved the sign predicted by the model.

Table 2 presents the changes in land use (assuming that average yields remain the same) with respect to the baseline. While there are some differences with respect to the change in land use in the three regions, it is clear that the decrease in sugar beet area will be distributed among the remaining eight crops. Furthermore, in Bury St. Edmunds all the scenarios indicate that a mild increase (or in some cases decrease) in cereals and increases concentrated in beans, peas, oilseed rape and potatoes. In Cantley and Wissington the increase is in the area under cereals, principally winter barley. It important to emphasize that these results are based upon the relative performance of the specific crops in 2002 and therefore the apparent substitution will be sensitive to changes in the relative prices.

Under the reduction of quota scenario, if sugar beet production ceases it is likely to be substituted by one of the eight alternative crops - winter and spring wheat, winter and spring barley, beans, peas, oilseed rape and potatoes. This suggests changes in crop rotations to favor winter wheat and winter barley as opposed to other break crops. The replacement of sugar beet with potatoes and field scale vegetables is likely to limited, given existing growers and markets, but this may occur particularly where water for irrigation is available.

In the case of the reductions in sugar beet price, the main replacement crops are likely to be winter wheat followed by winter barley, oil seed rape and spring crops, suggesting changes in crop rotations to favor winter wheat and winter barley as opposed to other break crops. As in the previous scenario the replacement of sugar beet with potatoes and field scale vegetables is likely to be limited.

Our results indicate that at an aggregate level all crops increase in response to the reduction in the sugar beet quota and the reduction in the average price for sugar beet. Of special importance, the results show an increase in the area to be planted with winter wheat, oilseed rape and potatoes, which indicates that these crops are probably going to replace, at least partially, the sugar beet in the crop rotation.

Table 2: Percentage Changes in Land Use by Crop with Respect to Baseline Case (Baseline figures are in Ha)

Scenario and Region	Crops									Total
	Sugar Beet	Winter Wheat	Spring Wheat	Spring Barley	Winter Barley	Beans	Peas	Oilseed Rape	Potatoes	Area
Model Baseline (2002 Situation)										
Bury St Edmunds	1,371.0	4,742.0	77.8	500.0	873.1	322.1	119.8	513.6	197.8	8,717.1
Cantley	890.4	1,722.8	15.5	414.0	953.4	155.9	11.9	151.7	151.4	4,467.1
Wissington	3,353.8	10,449.3	115.7	659.1	1,535.1	461.1	558.2	861.2	1,690.9	19,684.3
Simulation 1: Reduction of quota by 25 percent										
Bury St Edmunds	-25.0	4.6	11.0	-0.1	3.2	11.6	8.0	5.8	6.6	0.0
Cantley	-24.0	3.2	-1.5	11.0	11.8	-2.9	-0.6	0.5	3.4	0.0
Wissington	-26.3	3.3	3.3	-1.9	28.6	1.4	6.1	3.8	1.8	0.0
Simulation 2: Reduction of average price by 25 percent										
Bury St Edmunds	-6.2	1.3	5.2	-2.0	-0.3	5.2	3.8	0.6	3.2	0.0
Cantley	-2.9	0.4	-0.2	1.4	1.5	-0.7	-0.1	0.0	0.4	0.0
Wissington	-16.6	1.9	2.7	-3.8	21.4	0.6	2.4	3.0	0.8	0.0
Simulation 3: Reduction of average price by 40 percent										
Bury St Edmunds	-9.8	1.9	5.8	-1.5	0.7	5.8	4.2	1.8	3.5	0.0
Cantley	-8.1	1.0	-0.5	4.0	4.2	-2.1	-0.2	0.0	1.2	0.0
Wissington	-23.3	2.9	3.0	-2.1	25.9	1.2	5.1	3.5	1.5	0.0

Table 3 represents the changes in the use of inputs by sugar beet producing farms due to the reform. These figures are based on the whole farm model and therefore after cropping changes have occurred. Although, the impacts on input usage depend on the subsequent crop patterns, which vary by region, the decrease in sugar beet production impacts significantly on miscellaneous costs, which encompasses contract harvesting and haulers.

Table 3: Percentage Change in the Use of Inputs with Respect to the Baseline Case

	Inputs				
	Seed	Fertilizer	Crop Protection	Hired Labour	Miscelaneous 1/
Simulation 1: Reduction of quota by 25 percent					
Bury St Edmunds	-1.4	-4.4	-1.4	6.7	-13.5
Cantley	8.7	19.7	10.5	8.3	-11.9
Wissington	-0.6	7.7	12.0	0.0	-38.5
Simulation 2: Reduction of average price by 25 percent					
Bury St Edmunds	-0.5	-3.4	-1.8	1.1	-2.2
Cantley	4.4	8.9	6.0	5.4	-3.4
Wissington	-1.8	2.4	6.3	-2.2	-23.0
Simulation 3: Reduction of average price by 40 percent					
Bury St Edmunds	-0.5	-3.3	-1.4	2.4	-4.5
Cantley	11.9	24.7	16.7	14.8	-10.2
Wissington	-0.9	6.2	10.4	-0.7	-33.8

Notes:
1/ Includes contracting of harvesting machinery and haulage.

The results corresponding to all the scenarios are quite similar. The usage of seed, fertilizer, spray and other variable inputs per hectare of sugar beet grown are expected to decrease to reduce costs although this may not occur in the short term. Over time, less efficient producers will either bring standards of cost control up to those of the higher performing farms or they will cease sugar beet production. Across farms however, there is likely to be an increase in overall levels of fertilisers and pesticides applied when taking into account restructured crop rotations and replacement crops.

V. Crop substitution and effects on the environment

We focus the discussion on the environmental impacts of the sugar beet reform on two topics: the effects on land use and soils and effects on waste and water.

The main land use and soil issues arising from growing sugar beet production relate to soil erosion by mechanical removal during harvesting, wind erosion and water erosion; soil compaction; application of fertilisers, in particular Nitrogen; and the application of pesticides. Note that there is a close link between waste and water impacts and land use and soil issues arising from growing sugar beet i.e., siltation of watercourses and chemical pollution arising from inputs apply equally to both.

The key soil issues relate to the relatively light soils which are well suited and often used for sugar beet growing, the establishment of the crop in the spring - leaving the land uncropped and sometimes uncultivated over the preceding winter, the relatively open nature of the crop especially during the spring/summer period and the harvesting of the crop in late autumn or early winter when wet weather can lead to unsuitable ground conditions for lifting. It is estimated that around 450,000 tons of soil (British Sugar, 2003) are removed from land used for growing sugar beet each year. Soil is removed when beet is harvested and then carted to processing plants. Over recent years considerable effort has been placed by the industry on reducing this quantity for economic and environmental reasons. The UK has reduced its dirt tare by 50 per cent over the past 15 years and now records one of the lowest dirt tares (6.5 per cent) of any sugar beet producing country in the EU. In addition the industry recycles the soil removed back to agricultural and other land. However this still represents significant soil loss from farmland (50 per cent of the soil removed is not returned to agriculture) and individual fields used for sugar beet growing. Note that in addition to soil, around 70,000 tons of stones are removed from land during harvesting, these are then recycled and sold for construction use.

Soil is also lost through wind and water erosion before, during and after sugar beet is grown on land. The quantity of soil lost in this way is less significant overall than the amount lost through removal as beet is lifted at harvest time however such erosion can still be damaging, particularly on light land during the spring time when the crop canopy is more open. Cover crops and improved soil practices, involving less cultivation, have helped reduce wind and water erosion and it is estimated that less than 1 per cent of the sugar beet crop area requires re-drilling each year because of erosion damage (British Sugar, 2002). Relative to other crops, the late harvest of sugar beet can help provide cover through early winter and into January on lighter soils.

Soil compaction is an issue at harvest time, particularly in late winter when heavy machinery is used, often in wet conditions. Rutting and damage to soil structure can occur although in recent years increased industry awareness, resulting in better techniques and improved timing of field operations, together with the introduction of low ground pressure tires on tractors and harvesting machinery have helped reduce this problem.

On the positive side sugar beet can benefit soil organic matter through plant residues (beet tops, leaves, rootlets and root fibers etc) left on the land after harvest and available for subsequent crops and wildlife.

In terms of fertilizers, in general, sugar beet requires lower fertilizer inputs than most other crops in conventional arable rotations, although not as low as spring barley. Nitrogen rates for sugar beet are estimated to be, on average, 57 per cent of the rates applied to winter wheat, oilseed rape and potatoes (CSL, 2004) - around 100-105 kg/ha of Nitrogen for sugar beet compared to around 190 kg/ha for winter wheat and winter oil seed rape and potatoes (Defra, 2002). This low fertilizer requirement relates to sugar beet's deep roots and dense network of root fibers which can extract most available Nitrogen (from preceding crops) from the topsoil for the benefit of the beet and reduce the risk of nitrates leaching during and after the crop. Research over recent years has helped reduce the industry average application of Nitrogen for sugar beet by around 33 per cent. In addition to the cost and environmental benefits lower Nitrogen rates are also considered to result in increased sugar yield per hectare. Current rates of application are regarded to be 'close to optimum' (Defra, 2002a).

With regard to other fertilisers phosphate rates for sugar beet are similar to combinable crops but only about 29 per cent of the rates applied to potatoes; and potash rates for sugar beet were just over twice those applied to other combinable crops but only 45 per cent of the rates applied to potatoes (CSL, 2004b). It should be noted however, that a significant number of growers apply phosphate and potash for more than one crop (i.e. sugar beet and a following cereal crop) when they fertilize their sugar beet crop.

Similar to fertilizer applications, the total amount of pesticides applied to sugar beet has declined significantly in recent years - a reduction of 60 per cent to 5kg/ha by weight of active substance and a reduction of 52 per cent by total volume over the period 1982 to 1998 (Defra, 2002a). This decline has been the result of industry strategy focused on integrated pest management including monitoring, modeling, research and targeted control measures. However whilst the 2002 average for sugar beet of 3.63 kg/ha (weight of active substance) is significantly lower than potatoes (14.58 kg/ha) it is still marginally more than other crops in conventional arable rotations including winter wheat, winter seed rape and spring barley (CSL, 2004b).

In terms of herbicides, the development of more efficient and low dose sprays has led to a 63 per cent reduction herbicide inputs (1982-1998). However compared to other crops, sugar beet is most demanding in terms of herbicide use (CSL, 2004b), almost double the number of applications made to winter wheat, oil seed rape and potatoes. On average 4-5 applications are made to sugar beet in the early stages of crop establishment, in the period from March to June, when weed competition is high.

The quantity of fungicides used on sugar beet is low in comparison to other crops. This has not been reduced in recent years due to the occurrence and need to control powdery mildew. A single fungicide application is becoming standard practice for sugar beet. By comparison, 3 applications are usually made to cereal crops and as many as 7 to potatoes.

It is also worth noting the importance of sugar beet as a break crop in the arable rotation with respect of pests and diseases. Sugar beet hosts pests and diseases different from combinable crops and can therefore result in lower pest and disease levels in the rotation and contribute to lower pesticide applications. This in turn can contribute to increased yields and returns.

A comparison of sugar beet with other crops with respect of various inputs (kg/ha) is shown in the summary matrix in Table 5.1. The mean figures show sugar beet in second highest position after potatoes. Whilst winter wheat and oil seed rape are not dissimilar in mean ranking, they have different input requirements.

Table 4: Ranking Input Use 1/ 2/

Crop	Nitrogen	Phosphate	Potash	Herbicide	Insecticide	Fungicide
Sugar beet	2	3	4	5	4	1
Winter wheat	4	1	2	4	3	4
Oilseed rape	5	4	1	2	2	3
Spring barley	2	3	3	1	1	3
Potatoes	3	5	5	3	4	5

Source: CSL, 2004

Notes:
1/ Original data in Kg./Ha.
2/ Un-weighted ranking order being 1 = lowest and 5 = highest.

Note that taking into account benefits arising from improved soil structure, soil nutrients and pest and disease control, it is estimated that sugar beet has positive yield benefits on subsequent cereal crops, which are estimated to be around 15 percent.

In summary, qualitatively the three scenarios produce similar results. Thus, there is likely to be an immediate reduction in the area cropped with sugar beet and therefore subject to soil removal and susceptible to soil erosion and soil compaction. Soil loss is likely to be reduced and also the stone removal. Soil and stone loss from replacement crops such as winter wheat and winter barley is likely to be very low in comparison to sugar beet. The influence of cross compliance, including the requirement for producers to develop and implement soil management plans should help reduce soil erosion, particularly in the worst cases. However, conversely, the lighter lands which are more vulnerable to erosion are more likely to remain in production as they are best suited to growing sugar beet. Less sugar beet is also likely to mean a depletion of soil organic matter on cropping farms compared to the baseline position.

On land still used for growing sugar beet, reduction in the area under sugar beet are likely to result in less efficient production in the short term. However, in the long term there is likely to be a modest reduction in applications of fertilisers and pesticides, per ton of sugar beet produced, as productivity increases. Note however that growers may be tempted to apply more insurance treatments of pesticides with a smaller but more important crop area, potentially resulting in increased pesticide rates per hectare of sugar beet. Across all arable land in beet growing farms there may also be a small increase in overall levels of fertilisers and pesticides applied due to restructured crop rotations and replacement crops. Winter wheat and winter barley, for example, demand higher rates of Nitrogen, similar rates of phosphates and lower rates of potash. The nutrient benefits of sugar beet residue are likely to being diminished requiring further fertilizer inputs. In the same way the benefits of sugar beet as a break for pest and disease control will be reduced which may require greater use of certain pesticides in cereals, for example. Less sugar beet is also likely to result in higher rates of fungicide but also lower rates of herbicide and insecticide across the farm.

The main waste and water issues arising from growing sugar beet production relate to the potential for: the siltation of watercourses arising from soil erosion; the eutrophication of groundwater and surface water due to the leaching of Nitrogen and Phosphates applied to sugar beet; the contamination of groundwater and surface water from pesticides applied to the crop; and the depletion of scarce water resources as a result of abstraction for irrigation.

Siltation, Nitrogen and Phosphate and pesticides levels are all recognized as water pollutants arising from arable production, including sugar beet. However, the potential for diffuse (as opposed to point source) water pollution arising from growing sugar beet very much depends on a range of factors including physical circumstances (e.g. soil type, topography, proximity to hydrological pathway and watercourses/water bodies; frequency and severity of rainfall etc), land use patterns and management practices.

In general, the reductions in soil erosion and fertilizer and pesticide applications achieved in recent years and highlighted earlier, should contribute to a reduction in diffuse water pollution associated with sugar beet growing. The low fertilizer requirement for sugar beet and following crops reduces the risk of nitrates and other nutrients leaching to ground water and surface water, relative to other crops. However, with the exception of potatoes, higher quantities of pesticides (based on weight of active substance) are used for sugar beet relative to other conventional arable crops which increases the risk of water pollution arising from this source. The extent of the diffuse water pollution problem in the first place and the impact on it of subsequent improvements made to farm management practices and patterns will obviously vary from location to location. Defra (2002a) recognizes that ‘there is a need for greater understanding of the environmental impacts of agro-chemical use. Issues to consider include: the impacts of pesticides and fungicides on water courses and aquatic species; eutrophication of groundwater and surface water as a result of inputs (nitrogen and phosphates); the potential hazards of increased seed treatment; herbicide drift and run-off into adjacent habitats’.

In respect to water use, sugar beet has a relatively low water requirement and makes very efficient use of the water in soil. As a result sugar beet can withstand much drier conditions than other crops without affecting quality or yield significantly. Usually less than 5 per cent of the crop by area will receive irrigation, and then mainly on light soils in August (British Sugar, 2002). The use of irrigation for sugar beet may nonetheless have localized impacts where abstraction in a dry season reduces water flows in sensitive aquatic habitats (although this also applies to field scale vegetable crops which may replace sugar beet in some rotations if producers cease production). These adverse impacts are more likely to occur in areas of light and sandy soils where irrigation demands may be high. In the future no additional surface and groundwater is likely to be available in much of South and East of England and the total available is likely to decline in the future due to climate change. Comparing sugar beet with other crops, note that in 2001, a "wet year", 9,760ha of sugar beet were irrigated using 4,630,000 cu m of water, whereas 4,620ha of cereals were irrigated using 1,470,000 cu m and for main crop potatoes the figures were 69,820 ha and 69,940,000 cu m. This illustrates the relatively small area of sugar beet irrigated compared to potatoes and relatively low irrigation water requirement.

In general in all the scenarios, it is expected that a reduction in the area cropped with sugar beet and consequent reduction in soil erosion are likely to mean a decrease in the siltation of watercourses. The extent of the reduction in siltation will depend on whether sugar beet is no longer grown, the replacement land use or crops and general improvements in soil management. Cross-compliance is likely to mean that the most vulnerable land is targeted for better land use/management i.e. fields with the steepest slopes and land near (sensitive) watercourses. Set-aside or other buffer strips will be used. However, note that the more vulnerable, lighter lands are more likely to remain in production as they are best suited to growing sugar beet.

With regard to the eutrophication of groundwater and surface water due to the leaching of Nitrogen and Phosphates and the contamination of groundwater and surface water from pesticides, whilst there is likely to be a long term reduction in the overall amount of fertilisers and pesticides applied to land still used for growing sugar beet, due to productivity improvements, this is counteracted by an increase in the overall levels of fertilizers and pesticides applied to farms due to restructured crop rotations and replacement crops. So, while there may not be significant changes in the eutrophication and contamination of watercourses, at an aggregate level, as a result of quota cuts, there may be adverse impacts from specific pollutants. These include more nitrates due to the higher crop requirements of winter cereals for nitrogen and more pesticides of the type used for winter cereals (including more fungicides). These changes may have a particularly adverse impact on areas with already high levels of nitrates, for example Nitrate Vulnerable Zones (Brooms Barn Research Station in Defra, 2002-a)

In addition, reductions in the sugar beet area are unlikely to result in any significant change in the use of water resources for irrigation. This is due to the simple fact that those producers who have invested in irrigation infrastructure and abstraction licenses will seek to redeploy water to other crops, including potatoes and field scale vegetables if they cannot grow the same amount of sugar beet as previously. One way or other, water which can be abstracted under license is likely to be used.

Summarizing, the environmental impact of the possible changes in the crop patterns is mixed. Thus, on the one hand, a reduction in soil loss is expected as the main replacement crop, winter wheat, would create lower soil loss than the sugar beet. On the other hand, all the replacement crops require greater use of nitrogen than sugar beet does, which depending on land and water management issues, may have an adverse impact on environment (e.g., nitrogen leaching and eutrophication in the case of nitrogen surplus in soil or soil erosion in the case of low content of nutrients in soil). Furthermore, the reduction in the sugar beet area will reduce the benefits of sugar beet as a break crop for pest and disease control.

VI. Conclusions

This paper analyzed the effect that the imminent reform of the EU sugar beet regime will have on United Kingdom (UK) sugar beet farms. We estimated a multi-product cost function to study the effect the changes on the sugar beet price support and quota will have on the crop allocation of sugar beet farms and their aggregate use of inputs and further discuss the possible environmental impact of the reform in terms of soil loss and groundwater pollution.

With respect to the changes in output, under the reduction of quota scenario, if sugar beet production ceases it is likely to be substituted by one of the eight alternative crops - winter and spring wheat, winter and spring barley, beans, peas, oilseed rape and potatoes, which suggests changes in crop rotations to favor winter wheat and winter barley as opposed to other break crops. In the case of the reductions in sugar beet price, the main replacement crops are likely to be winter wheat followed by winter barley, oil seed rape and spring crops, suggesting changes in crop rotations to favor winter wheat and winter barley as opposed to other break crops.

With regard to input usage, although they depend on the subsequent crop patterns, which vary by region, the decrease in sugar beet production impacts significantly on miscellaneous costs, which encompass contract harvesting and haulers. In addition, usage of seed, fertilizer, spray and other variable inputs per hectare of sugar beet grown are expected to decrease to reduce costs although this may not occur in the short term. Over time, less efficient producers will either bring standards of cost control up to those of the higher performing farms or they will cease sugar beet production. Across farms however, there is likely to be an increase in overall levels of fertilisers and pesticides applied when taking into account restructured crop rotations and replacement crops.

In conclusion, the environmental impact of the possible changes in the crop patterns is mixed. Thus, on the one hand, it is expected a reduction in soil loss as the main replacement crop, winter wheat, would create lower soil loss than the sugar beet. On the other hand, all the replacement crops require greater use of nitrogen than sugar beet does, which depending on land and water management issues, may have an adverse impact on environment. Furthermore, the reduction in the sugar beet area will reduce the benefits of sugar beet as a break crop for pest and disease control.

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VIII. Annex

Table A.1 Translog Production Function Parameters by Crop

	Winter Wheat		Spring Wheat		Winter Barley		Spring Barley		Beans		Peas		Oilseed Rape		Potatoes		Sugar Beet	
Variable	Coeff.	t Stat.	Coeff.	t Stat.	Coeff.	t Stat.	Coeff.	t Stat.	Coeff.	t Stat.	Coeff.	t Stat.	Coeff.	t Stat.	Coeff.	t Stat.	Coeff.	t Stat.
Intercept	2.4903	40.6790	2.7051	24.9610	2.1756	38.6200	2.0887	26.7870	0.8588	4.8077	1.5629	9.7171	2.4571	20.8480	2.9154	23.5060	4.0535	50.3690
X_1	0.1374	14.7480	0.1559	5.0403	0.1817	13.0150	0.2614	8.0999	0.0951	2.2007	0.2771	3.7533	0.0333	1.3114	0.1549	5.5554	0.2157	11.4960
X_2	0.0756	19.3760	0.0134	0.4210	0.1021	11.0700	0.0786	6.8993	0.0225	6.0463	0.0284	5.9928	0.2279	7.7876	0.0768	4.3719	0.0402	4.3001
X_3	0.1844	20.4270	0.0988	6.6160	0.1824	12.0850	0.0783	5.7589	0.1160	4.9667	0.0902	2.6968	0.1323	6.4080	0.3377	10.3780	0.1034	7.2782
X_4	0.0250	8.8587	0.0218	2.7239	0.0475	2.0283			0.1276	7.7759			0.0672	10.2620	0.0134	2.3814	0.0120	3.5937
X_5	0.0147	9.3689	0.0100	2.1516	0.0263	13.7790	0.0187	4.4959	0.0271	4.9501	0.0322	6.0969	0.0236	4.2946	0.0361	3.2001	0.0447	13.6600
X_6	0.4346	49.1200	0.4552	10.4900	0.4721	31.2370	0.4892	19.0730	0.5278	15.3120	0.5708	12.3140	0.2754	7.3473	0.4520	8.3515	0.5273	32.0800
X_1^2	-0.0125	-11.6020	-0.0127	-2.0233	-0.0195	-12.0920	-0.0237	-4.3160	-0.0321	-2.4068	-0.0589	-3.8239	-0.0028	-0.3018	-0.0047	-2.3250	0.0016	0.9311
X_2^2	0.0016	1.7662	-0.0087	-0.9883	0.0059	4.4205	0.0041	2.1753	0.0039	4.6764	0.0015	1.8591	-0.0006	-0.1452	0.0149	6.1386	0.0015	1.4572
X_3^2	-0.0007	-0.9334	0.0130	3.6463	-0.0007	-0.4893	0.0138	8.0064	-0.0029	-0.7960	-0.0036	-0.9499	0.0017	0.2865	-0.0070	-2.8575	-0.0054	-3.7670
X_4^2	0.0011	1.9086	-0.0053	-6.1008	0.0442	2.9063			0.0196	7.3909			-0.0027	-2.3654	0.0005	0.6793	-0.0001	-0.2264
X_5^2	0.0008	3.3072	0.0013	2.0008	0.0018	6.4097	0.0004	0.6903	0.0018	1.6610	0.0013	1.4001	0.0023	2.4444	0.0043	3.5049	0.0044	13.9530
X_6^2	0.0254	30.3020	0.0237	5.4461	0.0216	14.0000	0.0307	9.8860	0.0335	5.0748	0.0592	6.8200	0.0088	1.9194	0.0439	13.9060	0.0148	7.8259
X_1X_2	-0.0106	-15.2220	-0.0083	-1.4401	-0.0152	-13.9000	-0.0032	-0.8416	-0.0075	-1.6488	-0.0130	-2.4069	0.0010	0.2380	-0.0126	-5.7116	-0.0065	-5.2753
X_1X_3	-0.0050	-8.5826	-0.0187	-2.8241	-0.0133	-12.6890	-0.0153	-3.4073	0.0212	1.5956	0.0401	2.7871	0.0029	0.6027	0.0035	1.8487	-0.0111	-8.9250
X_1X_4	0.0035	5.9585	0.0050	1.9577	0.0030	0.4567			-0.0050	-1.2961			0.0065	4.0433	0.0006	0.6393	0.0010	1.1497
X_1X_5	-0.0009	-2.3652	0.0058	2.7627	-0.0008	-0.9605	0.0038	1.4630	0.0185	3.8363	0.0273	5.4681	0.0049	1.4040	0.0046	3.7206	-0.0018	-2.0708
X_1X_6	0.0072	12.4640	-0.0025	-0.5597	0.0021	2.3448	-0.0006	-0.2092	0.0065	1.1343	0.0037	0.5097	0.0124	3.0743	0.0033	1.1237	0.0002	0.1957
X_2X_3	-0.0063	-10.9670	-0.0020	-0.3114	-0.0009	-0.8903	0.0055	0.9744	0.0008	0.1423	-0.0015	-0.2513	-0.0218	-8.5242	-0.0076	-2.9465	0.0021	0.8475
X_2X_4	0.0018	6.2298	0.0004	0.1406	-0.0150	-3.9560			-0.0018	-4.7720			-0.0107	-5.2014	0.0035	3.1813	0.0018	2.9338
X_2X_5	0.0012	2.8474	-0.0019	-0.5385	0.0005	0.6115	0.0037	1.9633	0.0006	0.8369	0.0008	0.9898	0.0014	0.8494	-0.0049	-4.5531	0.0008	0.9872
X_2X_6	0.0050	8.8327	0.0024	0.5523	0.0053	6.1250	-0.0104	-2.8669	0.0037	1.0593	0.0069	1.9184	0.0186	6.5970	-0.0201	-5.1844	0.0052	3.2098
X_3X_4	0.0024	4.8567	-0.0048	-3.3602	-0.0200	-4.8019			-0.0028	-1.5834			-0.0041	-2.2694	0.0023	2.1880	0.0010	1.4835
X_3X_5	-0.0001	-0.4611	0.0005	0.2807	-0.0001	-0.1621	-0.0066	-5.0919	-0.0076	-1.8360	-0.0068	-1.6328	-0.0078	-3.1015	0.0064	3.3071	0.0014	2.6008
X_3X_6	0.0119	25.6350	-0.0006	-0.1076	0.0087	10.5490	0.0020	0.7059	-0.0388	-5.2608	-0.0365	-4.6579	-0.0046	-1.7319	-0.0088	-2.4903	0.0027	2.3309
X_4X_5	0.0000	-0.1098	-0.0013	-2.7531	-0.0029	-1.5144			-0.0024	-4.3558			-0.0011	-2.4610	0.0003	0.7337	-0.0004	-1.5179
X_4X_6	-0.0099	-22.5500	-0.0245	-8.5978	-0.0012	-0.6803			-0.0150	-5.3789			-0.0114	-4.7268	-0.0119	-7.7819	-0.0071	-10.4340
X_5X_6	-0.0021	-13.8660	-0.0062	-3.0710	-0.0019	-3.5838	-0.0037	-2.4904	-0.0165	-4.8171	-0.0186	-6.3696	-0.0009	-0.7359	-0.0158	-3.6668	-0.0050	-11.6620
Adj. R^2	0.98		0.88		0.97		0.93		0.83		0.83		0.92		0.95		0.95	
Obs.	1210		91		721		511		285		239		231		399		1289	

Table A.2 Multi-product Cost Function Parameters

Dependent Variable: Log(Variable Cost)
Log-Likelihood - factor demands block : 7,845.19
Log-Likelihood - only output block: 1,138.76

Variable	Coefficient	t -stat.	Variable	Coefficient	t -stat.
Box-Cox λ	0.338000	Grid Search	W_5*Q_1	0.002728	8.440
W_1	0.220338	44.584	W_5*Q_2	-0.004042	-13.180
W_2	0.192743	33.990	W_5*Q_3	0.003755	7.390
W_3	0.343697	48.870	W_5*Q_4	0.000527	1.617
W_4	0.047666	2.200	W_5*Q_5	-0.002556	-8.975
W_5	0.195556	23.009	W_5*Q_6	0.000622	1.376
W_1*W_1	-0.017090	-0.741	W_5*Q_7	0.001616	3.905
W_1*W_2	0.004160	0.259	W_5*Q_8	-0.000167	-0.389
W_1*W_3	0.028968	1.447	W_5*Q_9	-0.002482	-15.712
W_1*W_4	-0.033366	-1.125	Q_1	0.009944	15.765
W_1*W_5	0.017328	0.629	Q_2	0.005453	14.344
W_2*W_1	0.004160	0.259	Q_3	0.001770	5.493
W_2*W_2	0.166006	8.568	Q_4	0.001039	4.768
W_2*W_3	-0.072119	-4.539	Q_5	0.002810	9.331
W_2*W_4	-0.029935	-1.131	Q_6	0.001472	5.347
W_2*W_5	-0.068111	-2.646	Q_7	0.001405	4.146
W_3*W_1	0.028968	1.447	Q_8	0.001670	6.452
W_3*W_2	-0.072119	-4.539	Q_9	0.008434	20.749
W_3*W_3	0.091094	3.613	Q_1*Q_1	0.000086	6.379
W_3*W_4	0.059153	1.767	Q_1*Q_2	0.000063	10.876
W_3*W_5	-0.107096	-3.530	Q_1*Q_3	0.000018	3.402
W_4*W_1	-0.033366	-0.024	Q_1*Q_4	0.000020	4.796
W_4*W_2	-0.029935	-2.949	Q_1*Q_5	0.000007	1.153
W_4*W_3	0.059153	2.792	Q_1*Q_6	0.000030	4.844
W_4*W_4	-0.188132	-3.395	Q_1*Q_7	0.000017	2.203
W_4*W_5	0.192281	3.611	Q_1*Q_8	-0.000028	-4.643
W_5*W_1	0.017328	0.629	Q_1*Q_9	0.000025	3.559
W_5*W_2	-0.068111	-2.646	Q_2*Q_2	0.000368	15.631
W_5*W_3	-0.107096	-3.530	Q_2*Q_3	0.000007	0.613
W_5*W_4	0.192281	2.373	Q_2*Q_4	-0.000035	-2.812
W_5*W_5	-0.034402	-0.460	Q_2*Q_5	-0.000010	-0.904
W_1*Q_1	-0.000139	-0.768	Q_2*Q_6	0.000022	2.486
W_1*Q_2	-0.000815	-4.746	Q_2*Q_7	0.000035	3.456
W_1*Q_3	-0.000458	-1.612	Q_2*Q_8	0.000074	8.708
W_1*Q_4	-0.000053	-0.288	Q_2*Q_9	0.000031	2.605
W_1*Q_5	0.000432	2.710	Q_3*Q_3	0.000223	4.433
W_1*Q_6	-0.000166	-0.655	Q_3*Q_4	-0.000138	-3.417
W_1*Q_7	0.000885	3.824	Q_3*Q_5	0.000092	2.577
W_1*Q_8	-0.001349	-5.626	Q_3*Q_6	0.000173	3.068
W_1*Q_9	0.001661	18.796	Q_3*Q_7	0.000127	1.376
W_2*Q_1	-0.000344	-1.586	Q_3*Q_8	-0.000131	-1.738

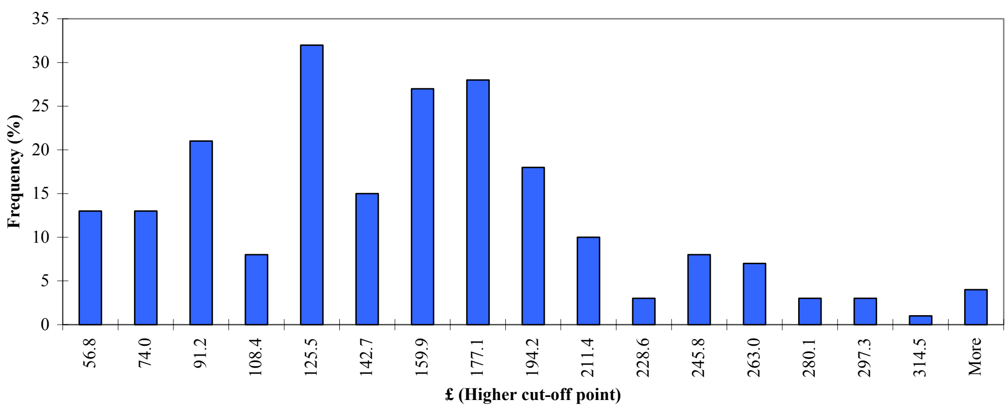
Continues

Continues

W_2*Q_2	0.001880	9.140	Q_3*Q_9	-0.000002	-0.061
W_2*Q_3	-0.001484	-4.355	Q_4*Q_4	0.000189	5.068
W_2*Q_4	0.001003	4.582	Q_4*Q_5	-0.000006	-0.346
W_2*Q_5	0.001967	10.305	Q_4*Q_6	-0.000014	-0.335
W_2*Q_6	-0.000144	-0.475	Q_4*Q_7	-0.000138	-2.980
W_2*Q_7	-0.001864	-6.716	Q_4*Q_8	-0.000154	-4.257
W_2*Q_8	0.000686	2.387	Q_4*Q_9	0.000075	3.515
W_2*Q_9	-0.001699	-16.025	Q_5*Q_5	0.000326	10.176
W_3*Q_1	-0.001968	-7.298	Q_5*Q_6	-0.000067	-2.719
W_3*Q_2	0.003132	12.239	Q_5*Q_7	-0.000041	-1.306
W_3*Q_3	-0.000694	-1.637	Q_5*Q_8	-0.000066	-2.829
W_3*Q_4	-0.000767	-2.819	Q_5*Q_9	-0.000086	-3.601
W_3*Q_5	0.000445	1.872	Q_6*Q_6	0.000021	0.308
W_3*Q_6	0.000103	0.272	Q_6*Q_7	0.000084	1.126
W_3*Q_7	0.000580	1.678	Q_6*Q_8	-0.000041	-0.773
W_3*Q_8	0.000084	0.235	Q_6*Q_9	-0.000167	-4.027
W_3*Q_9	-0.000914	-6.932	Q_7*Q_7	0.000052	1.434
W_4*Q_1	-0.000258	-1.381	Q_7*Q_8	-0.000086	-1.061
W_4*Q_2	0.000019	0.107	Q_7*Q_9	-0.000057	-1.758
W_4*Q_3	-0.001415	-4.815	Q_8*Q_8	0.000685	12.454
W_4*Q_4	-0.000566	-3.008	Q_8*Q_9	-0.000107	-2.695
W_4*Q_5	0.000546	3.318	Q_9*Q_9	0.000243	6.440
W_4*Q_6	-0.000293	-1.124			
W_4*Q_7	-0.001040	-4.353			
W_4*Q_8	-0.000104	-0.420			
W_4*Q_9	0.003111	34.113			

Notes:
1/ Variables are in logs or transformed by the Box-Cox transformation.
2/ Standard deviation was computed using the heteroskedasticity-consistent covariance matrix.

Histogram of Farm Fixed Effects



Procedure used to constrain the change in the area of the other crops equal to the reduction in the area under sugar beet

Since it was not possible to constrain the parameters of the cost function to produce a change in the area of the other crops equal to the reduction in the area under sugar beet, we rescaled the results obtained from the model so the reduction in the area dedicated to sugar beet was absorbed according to the directions indicated by the model. We performed this change in scale by considering the information about the cropping area by region and by simulation scenario.

The starting point was the condition that the decrease in the sugar beet area in the region j (ΔA_j^{Beet}) with respect to the base case had to be distributed by considering the changes in the other crops. Mathematically this is equal to (A.1):

$$(A.1) \quad -\Delta A_j^{Beet} = \sum_{i=2}^{9} \Delta A_j^i$$

The scaling weight for the region j is then equal to (A.2):

$$(A.2) \quad \gamma_j = \frac{-\Delta A_j^{Beet}}{\sum_{i=2}^{9} \left(A_j^{U,i} - A_j^{0,i} \right)}$$

Where $A_j^{U,i}$ is the (unadjusted) area in region j for crop i predicted by the model after simulating the change in policy, and $A_j^{0,i}$ is the area in the baseline case for crop i. Therefore, for region j the following condition has to hold (A.3):

$$(A.3) \quad \sum_{i=2}^{9} \Delta A_j^{F,i} = \gamma_j \cdot \sum_{i=2}^{9} \Delta A_j^{U,i}$$

Where $\Delta A_j^{F,i} = A_j^{F,i} - A_j^{0,i}$ is the change in the area of the crop i after we scaled the unadjusted results. In addition, it should be noted that $\sum_{i=2}^{9} \Delta A_j^{F,i} = \gamma_j \cdot (-\Delta A_j^{Beet})$. Operating (3) we can arrive to condition (A.4):

$$(A.4) \quad \sum_{i=2}^{9} A_j^{F,i} = \gamma_j \cdot \sum_{i=2}^{9} A_j^{U,i} + \left(1 - \gamma_j\right) \cdot \sum_{i=2}^{9} A_j^{0,i}$$

Our goal is to find a set of $A_j^{F,i}$ that satisfies (A.4). There are several ways to do this; however, an appealing solution is one that conserves the sign of the change in area predicted by the model. Hence, we choose the following solution to (A.4) that says that the final area is a linear combination of the baseline solution and the unadjusted solution. This is (A.5):

$$(A.5) \quad A_j^{F,i} = \gamma_j \cdot A_j^{U,i} + \left(1 - \gamma_j\right) \cdot A_j^{0,i}$$

It should be noted that (A.5) is also satisfied for the output, assuming that there are no changes in yields. This is easy to see after multiplying (A.5) by y_j^i (crop i yield in region j) (A.6).

$$(A.6) \quad Q_j^{F,i} = A_j^{F,i} \cdot y_j^i = \gamma_j \cdot A_j^{U,i} \cdot y_j^i + (1-\gamma_j) \cdot A_j^{0,i} \cdot y_j^i = \gamma_j \cdot Q_j^{U,i} + (1-\gamma_j) \cdot Q_j^{0,i}$$

Finally, with respect to the change in area, dividing (A.6) by the baseline area we get (A.7):

$$(A.7) \quad \frac{A_j^{F,i}}{A_j^{0,i}} = \gamma_j \cdot \frac{A_j^{U,i}}{A_j^{0,i}} + (1-\gamma_j)$$

Which can be simplified as (A.8):

$$\left(1 + \frac{\Delta A_j^{F,i}}{A_j^{0,i}}\right) = \gamma_j \cdot \left(1 + \frac{\Delta A_j^{U,i}}{A_j^{0,i}}\right) + (1-\gamma_j)$$

$$(A.8) \quad \frac{\Delta A_j^{F,i}}{A_j^{0,i}} = \gamma_j \cdot \frac{\Delta A_j^{U,i}}{A_j^{0,i}}$$