INVESTIGATING THE ECONOMIC AND WATER QUALITY EFFECTS OF THE 2003 CAP REFORM ON ARABLE CROPPING SYSTEMS: A SCOTTISH CASE STUDY

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Abstract

The 2003 Common Agricultural Policy Reform aimed to promote the socio-economic and environmental sustainability of agricultural systems. An important question is how far the Reform has indeed encouraged farmers to contribute to achieving broad economic and environmental goals. The economic and water resource effects of the Reform have been explored for the case study area of the Lunan catchment, which is typical of Scottish arable cropping areas. Land use data analysis, bio-physical modelling and bio-economic modelling were used in combination to identify the effects of a range of scenarios. The results indicate only small changes in the cropping pattern and associated economic and water quality indicators as a result of the Reform, with the main changes in farmers' decision making being explained by crop price changes.

Keywords: Common Agricultural Policy, bio-economic modelling, water, land use, Scotland.

JEL: Q10, Q18, Q25.

Introduction

The 2003 Common Agricultural Policy (CAP) Reform aims to increase the prominence given to the sustainability of agricultural systems in both socio-economic and environmental terms. An important question is whether the Reform is indeed an improvement in terms of effectively driving farmers towards the achievement of broad economic and environmental goals. The effects of the Reform on economic decision making and associated viability of farms can be explored by analysing data on current farmers’ decisions and related economic indicators. However, the comparison of such figures before and after the implementation of a policy, is complicated because they represent the combined effects of all the changes that took place during that period, such as the change of the policy, the changes in prices of inputs and outputs, structural changes, etc. As it is unlikely that the individual effects of each of these factors can be identified, Mathematical Programming Modelling provides an attractive alternative for policy assessment.

Mathematical programming models (MPMs) have been widely used for agricultural economics policy analysis. An optimisation-based MPM selects the optimal allocation of farm resources to a large number of alternative agricultural activities, through the optimisation of an objective function subject to technical, agronomic, economic and policy constraints. For each of the policy scenarios modelled, the parameters or constraints representing the scenario are altered, invoking changes in land use and the economic and environmental outcomes of the optimisation. The comparison of those outcomes to a base scenario facilitates the ex-ante impact assessment of policies and consequently their design. Even though MPMs are predominantly used for ex-ante policy assessment, their use for ex-post assessment is particularly useful as the impact of different factors affecting agricultural production can be studied separately. Using MPMs for ex-post analysis and comparing the results with the actual effects of policies, can be also fruitful for testing the reliability of models, an aspect that is of increasing importance for the quality assurance of models and their performance for ex-ante assessment of future policies.

The environmental effects of the Reform are not easy to predict. This is because first, they are the result of the interaction of changes in farmers’ production decisions with biophysical factors such as soil type and climate and second, they are subject to significant time lags between the cause and effect of the environmental problems. Water is a major environmental asset that is directly impacted by agricultural production. The effects of the reform on farmers’ production and management decisions through the decoupling of payments, the imposition of cross-compliance measures, and the potential agri-environmental measures of the Rural Development Programs can have a direct impact on water resources. An investigation of the effects of the reform on water resources is essential, if there is to be a reconciliation of the economic and environmental objectives of the CAP. The effects of farmers' decisions on water resources can be estimated with biophysical agronomic simulation models (BSMs). BSMs deal with the effects of weather, soil types, inputs, management practices, and their interactions on agricultural productivity and yields, while also providing information on specific environmental attributes of different agricultural activities. Effectively these models consist of a set of non-linear mathematical equations describing the complex biophysical processes that take place within the agricultural system. If constructed appropriately, they provide a reliable way to estimate production and pollution functions, overcoming the scarcity of consistent data and allowing both the combined and separate assessment of varying levels, timing, type and application methods of fertilisers and irrigation water, crop rotations, and alternative tillage techniques.

Against this background, the overall aims of the paper are to explore the economic and water resource effects of the 2003 CAP Reform on arable cropping systems in Scotland and to present and to evaluate the methodology with special reference to agricultural and environmental policy assessment. The analysis uses the case study area of the Lunan catchment, a representative catchment of Eastern Scotland. The effects of the CAP Reform will be first assessed by analysing land use figures for the farms of the catchment. Secondly, the results of a bio-economic modelling exercise, integrating the outcomes of a BSM into a MPM, will be presented and discussed. Results are expected to be more widely applicable to the Atlantic North Environmental zone of Europe (Metzger et al., 2005), as the factors used in that stratification are the climatic factors that result in particular farming systems being adopted and that are used as inputs for BSMs. Mathematical Programming component of the Farm Systems Simulator (FSSIM-MP) (van Ittersum *et al.*, 2008; Louhichi *et al.*, 2007) has been used for modelling farmers' decision making. NDICEA (van der Burgt, 2004; van der Burgt *et al.*, 2006), a nitrogen planner BSM, has been used for the estimation of nitrate leaching associated with the agricultural activities. Finally, conclusions will be drawn on the appropriateness of these data analysis and modelling methodologies for assisting decision-making for the establishment of future agricultural and water policies.

CAP Policies in Scotland

The aim of the CAP Reform is to promote sustainable, market-focused agricultural systems throughout Europe (Scottish Executive, 2008). Under Agenda 2000, the payments to farmers were coupled to their production. The compensation rate per hectare was estimated by multiplying the regional yield by the compensation rate for each crop category. In Scotland, for areas out with the less favoured areas, the payment was equal to 264.71 (£/ha) for protein crops and 230.02 (£/ha) for cereals, linseeds, flax, hemp, oilseeds and set-aside. Producers were obliged to set-aside 10% of the total claimable area in order to receive the payments. The policy was subject to criticisms of distorting the markets and directing farmers towards a subsidy rather than a market oriented behaviour. The response to these criticisms was the 2003 CAP Reform. In Scotland the Reform was brought into effect in 2005. The model chosen was the historic Single Payment Scheme (SPS) under which each farmer was granted entitlements per hectare relating to the reference amounts and the reference areas that gave rise to the direct payments in the reference period 2000-2003. The standard entitlements corresponded to arable and grassland, while the set-aside entitlements corresponded to land that was put to set-aside. The value of the entitlements was equal to the reference amount divided by the reference area. The reference amount was calculated on the basis of average claims made during the reference period. The total number of entitlements equates to the average reference area, adjusted for the overshoot of the base area and the national reserve. The overshoot corresponded to 3.13% reduction of payments in average over the three years (Scottish Executive, 2005a). The national reserve, which aimed to help producers that would be seriously disadvantaged by the Reform, was equal to 3% of all entitlement allocations.

For an entitlement to be activated it had to be matched with an eligible hectare of agricultural land, i.e. arable or forage area for the standard entitlements and land managed under the set-aside rules for set-aside entitlements. The only payments that remain coupled are the protein crop premium (€55.57/ha) and the energy crops premium (€45/ha). In Scotland, both compulsory and voluntary modulation are being used for the funding of Pillar II payments. The rates in 2008 are 8% for the voluntary modulation, and 5% for the compulsory one. For farmers to receive their full payment, they have to conform to a number of Statutory Management Requirements (SMRs) and to minimum standards of Good Agricultural and Environmental Conditions (GAEC), as defined by the individual Member States. In Scotland there are currently 15 SMRs and 18 GEAC measures (Scottish Executive, 2005b). One of the SMRs is the Protection of Water in Nitrate Vulnerable Zones (NVZs). Farmers with land in NVZs must follow the rules of the Action Programme for Nitrate Vulnerable Zones (Scotland) Regulations 2003, as set out in the Guidelines for Farmers in Nitrate Vulnerable Zones (2003). The measures can be broadly classified as a) restrictions on the quantity of N applied; b) restrictions on the timing of N applications; c) manure storage requirements; d) record-keeping requirements; and e) other restrictions on N application.

Methodology

The catchment which is located on the East Coast of Scotland in the Angus region, is representative of intensive arable cropping in Scotland (SEPA, 2007), as it consists of intensively arable agriculture with cereal crops, potato and root crop cultivation (SEPA). The area includes three rivers (Lunan Water, Gighty Water, Viny Water) divided into five water bodies. The Lunan Water Catchment is one of the two priority catchments monitored under the Diffuse Agricultural Pollution Action Plan of the Scottish Environment Protection Agency (SEPA), as it is at risk of not meeting the environmental objectives of the Water Framework Directive (SEPA, 2007). It is a partly groundwater fed catchment, draining an area of 134km² (SEPA). The whole catchment falls within a designated river nutrient sensitive area and a nitrate vulnerable zone (*ibid*).

First, June Census Data (JCD) (Scottish Executive) were analysed to quantify the changes in land use after the Reform. The data set consists of information on cropping areas of different crops for the individual farms in the area, for the years 2000-2007[1]. The JCD use the UK Farm Classification System (DEFRA), to classify the individual farms by type. This typology was also used in our analysis. The JCD were used for the estimation of land use per crop during 2000-2007 for 1) the whole case study area, 2) the average general cropping farm, and 3) the average cereal farm. To compare figures before and after the CAP Reform, two reference periods have been chosen: 1) average values of 2001, 2002, and 2003 representing the Agenda 2000 period and 2) average of 2006 and 2007, representing the 2003 CAP Reform. The intermediate years have not been used for the comparison, as they constitute the transition period from the one policy to the other.

Secondly, these land use data were multiplied by nitrogen input and nitrogen leaching coefficients, to explore the effect of changes on nitrate leaching. Two different levels of fertilisation per crop were considered, labelled as "medium" and "intensive". As no data were available for the actual fertiliser inputs, it was assumed, after discussion with experienced agronomists, that "medium" fertilisation was equivalent to the RB209 (MAFF, 2000) recommendations for the relevant soil types[2]. For the "intensive" techniques, these fertiliser recommendations were increased by 20%. The NDICEA model was used to estimate the nitrogen leaching coefficients. NDICEA is a process-based simulation model which requires relatively easily obtainable data on initial states, parameters and driving variables (van der Burgt et al., 2006). It simulates soil water dynamics, nitrogen mineralization and inorganic nitrogen dynamics in relation to weather conditions and the crop demand for the top soil and subsoil over the course of a rotation on a weekly time-step.

NDICEA was run for the main crops included in our analysis, for the two main soil types in the catchment and the two fertilisation scenarios. Data on the spatial distribution and characteristics of the soil series within the area were made available from the Scottish Soils Knowledge and Information Base of the Macaulay Institute. The soil series were linked to the soil categories of "light", "medium", and "heavy" by means of expert consultation using soil texture as intermediary variable. Heavy soil types represented a very small percentage of the catchment, so they have not been included in our analysis. Weather data for the period 1984-1998 were obtained from the meteorological station at Mylnefield, Dundee which is outside the catchment but which an initial analysis showed was representative of its weather. Due to time limitations, the average weather of the 15 years series was used for all the simulations and rotational effects were ignored. Each of the crop scenarios consisted of the simulation of two crops at a time, with the first crop always being spring barley. Sowing, harvest and fertilisation dates were obtained by means of expert consultation. The Farm Management Handbook (FMH) (Chadwick, 2002) yield estimates were used. For most crops, this provides three levels of yields, representing the lowest, medium and highest ranges of production. It

[1] The catchment is situated within an area of 12 agricultural parishes which extend beyond the boundaries of the catchment. As no information on the spatial distribution of the farms is available, and the areas outside the catchment are similar to those within, the JCD of all the farms within the 12 parishes have been analysed.

[2] The values were also compared to those of the FMH and the British Survey of Fertiliser Practice (DEFRA, 2004).

has been assumed that the medium yield range corresponds to medium soils, and the average yield for the lowest and medium ranges corresponds to light soils. Yield estimates were increased by 10% for intensive fertilisation. Fertilisation and yield data were also validated by experts. In this paper, only the results of the intensive fertilisation scenario will be presented, using the average coefficients of the two soil types.

Finally, the average general cropping and average cereal farms were modelled by means of bio-economic modelling. Bio-economic modelling is a specific type of mathematical programming modelling that facilitates the integration of socio-economic and agro-ecological information by linking BSMs to MPMs. While the MPM describes farmers' production and management decisions, the BSM describes the relevant production and environmental processes. It is thus used to establish agronomic and environmental pollution relationships, which serve as an input to the MPM. The bio-economic MPM that was used for modelling farmers' decision making is FSSIM-MP, developed under the EU FP6 Project SEAMLESS. The model is based on profit maximisation and risk aversion and includes a detailed specification of the agricultural activities in terms of rotations, soil types, and management techniques. The non-linear objective function represents expected income and risk aversion towards price and yield variations (Louhichi *et al.*, 2007; van Ittersum *et al.*, 2007):

$$Max\ U = Z - \varphi\sigma$$

Where: **U**: Utility, **φ**: the risk aversion coefficient, **σ**: the standard deviation of income according to states of nature and market defined under two different sources of instability: yield (due to climatic conditions) and price, **Z**: expected income

$$Z = \sum_{c,prd} Price_{c,prd}\, Sales_{c,prd} - \sum_{r,s,t,p,sys} Costs_{r,s,t,p,sys} \frac{X_{r,s,t,sys}}{N_r} + \sum_{r,s,t,sys,c} Prme_c \frac{X_{r,s,t,sys}}{N_r} - PMPterm - \sum twage\ .Tlabour$$

Where: **c**: crop, **prd**: product type, **r**: crop rotations, **s**: soil types, **t**: production techniques, **p**:period, **sys**: production system, $\mathbf{Price_{c,prd}}$: price of crop products, $\mathbf{Sales_{c,prd}}$: total sales of each crop, $\mathbf{Costs_{r,s,t,p.sys}}$: variable cost per crop within agricultural activity, $\mathbf{X_{r,s,t,sys}}$: level of selected activity, $\mathbf{N_r}$: number of years of each crop rotation, $\mathbf{Prme_c}$: compensation payment for each crop, **PMPterm**: the Positive Mathematical Programming term, **Twage**: labour cost, **Tlabour**: average number of hours rented labour[3].

[3] This is the model formulation for the model version used in research, as adapted from the references.

The model is calibrated using the risk approach, and subsequently complemented by an extension of the PMP approach (Howitt, 1995)[4]. FSSIM-MP follows a joint production approach using discrete production/pollution functions for the incorporation of yield and environmental information, as opposed to the incorporation of continuous production and pollution functions or of cost functions as a proxy for environmental damages. Effectively, the agricultural activities are defined as vectors of technical/environmental coefficients describing the inputs, the outputs and the environmental effects (Ruben *et al*., 1998). The model has a high technical specification and the definition of the agricultural activities is multi-dimensional, allowing their specification as discrete and independent options, whether they refer to different crop or livestock activities, to different technologies for the same activity, or to variations of the same technology.

The agricultural activities are defined as a combination of a rotation, crop, soil type and technique. The two different soil categories and fertilisation scenarios that were used for NDICEA were also used for the bio-economic modelling. Forty-nine rotations were composed based on advice given by experts. This resulted in input-output matrixes of around 1600 rows, which required data modelling modules to feed the information into FSSIM-MP, using MS Access and the MDB2GMS utility. The fertilisation and yield data that were used for the NDICEA simulations, also served as an input to FSSIM-MP. The variable costs were estimated using the FMH estimates, after subtracting the FMH fertiliser cost estimates and adding the quotient of fertiliser input by fertiliser price. The FMH was also used for labour requirements per crop category. The nitrate leaching coefficients were the result of the NDICEA simulations. To calculate family labour availability, the JCD items relating to the work of the occupier or spouse were multiplied by their hourly equivalent, assuming full time labour to be 1900 hours per year. The percentage distribution of each soil category within the area was calculated and then attributed to the average cereal and general cropping farm, where their average size was calculated using the JCD. Although this is a rather crude assumption, lack of additional information on the spatial distribution of farms within the parishes, offered no alternative. Finally, the JCD were used for the calculation of the average land use pattern of each of the two farm types that were used for model calibration.

The scenarios of JCD Analysis and FSSIM-MP modelling to be discussed are shown below:

[4] PMP is a methodology that adds quadratic cost terms to the objective function, ensuring that the model outcomes in the base run calibrate exactly to the observed production levels (Janssen & van Ittersum, 2007).

Table 1 - Scenarios (Modelling and Part of JCD Analysis)

	Baseyear Agenda 2000 (2001-2003)	Agenda 2000 - NVZ Regulations	Average 2006-2007[5]	CAP Reform	Price Changes	Price Changes 2
Source of Scenario Outcomes	JCD used also for FSSIM-MP calibration	FSSIM-MP modelling	JCD analysis	FSSIM-MP modelling		
Exogenous Assumption[6]	2001-2003 prices			2001-2003 prices	2006-2007 prices	
EU CAP	Agenda 2000		2003 CAP Reform			
Measures		NVZ: £5K fine if average N use >170kg/ha		Cross-compliance NVZ: 60% cut of premiums if average N application >170kg/ha		

Results

The results of the JCD analysis are outlined in Tables 2 and 3 and Figures 1 and 2. Table 2 shows the average percentage of the number of farms and agricultural area occupied for each farm type for the periods 2001-2003 and 2006-2007, and the change in these percentages between the two periods. The main changes are a slight decrease in the number and areas of general cropping farms and a minor increase in the area of mixed farms. There is also a slight increase in the area of the cereal farms which is associated with a decrease in their number.

Table 2 - Number of Farms and Area per Farm Type as a percentage of the total

	Cereals	General cropping	Horticulture	Pigs-Poultry	Cattle-Sheep (Lowland)	Mixed	Other
Farm numbers							
2001-2003	12.5	45.1	2.3	3.0	4.3	4.8	28.1
2006-2007	10.7	40.4	2.7	3.5	6.7	6.2	29.7
Change	-1.8	-4.6	0.5	0.5	2.3	1.4	1.7
Area							
2001-2003	8.4	81.2	0.2	0.8	0.5	5.7	2.9
2006-2007	10.4	75.6	0.4	0.4	0.5	9.6	2.4
Change	2.0	-5.6	0.2	-0.3	0.1	3.9	-0.6

[5] This is not a modelling scenario but part of the results of the JCD Analysis. For ease of comparison it is labeled as a scenario.
[6] Prices shown in Table.

Figure 1 illustrates total land use per crop and Table 3 the average percentage of total land use for the periods 2002-2003 and 2006-2007, and the change in percentage between the two periods. The land use changes for the average general cropping farm are very similar to those of total land use, due to the large number of such farms in the sample. The largest changes are a decrease in the area of barley and seed potatoes and an increase in the area of wheat, main crop potatoes and vegetables.

Figure 1 - Total Land Use

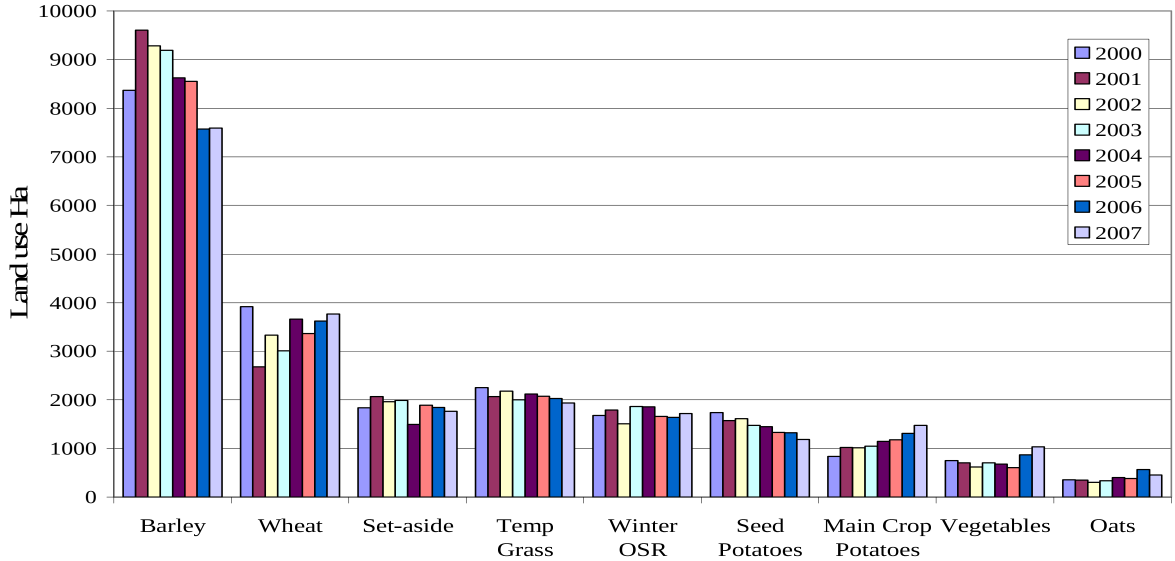


Table 3 - Percentage of Land Use per Crop – All Farms

	Barley	Wheat	Set-aside	Temp Grass	Winter OSR	Seed Potato	M. Potato	Vegetables	Oats
2001-2003	35.67	11.46	7.65	7.93	6.56	5.93	3.92	2.59	1.26
2006-2007	29.55	14.41	7.04	7.73	6.55	4.90	5.44	3.71	2.00
Change	-6.12	2.95	-0.61	-0.20	-0.01	-1.04	1.52	1.12	0.74

Regarding the average cereal farm (Figure 2), fluctuations in the levels of barley and temporary grass accompanied by fluctuations in the opposite direction of wheat, oilseed rape and potatoes, seem to be more pronounced after 2003. The most significant change is, as for the general cropping farms, a decrease in the area of barley followed by an increase in the area of wheat. The areas of winter oilseed rape and oats also rose, while set-aside and temporary grass declined.

The nitrogen inputs and nitrogen leaching coefficients used in our analysis are shown in Table 4. The nitrate leaching differs by less than 5% between the two soil types, because the fertilisation levels take the soil type into account. Even though spring crops have much lower input that the equivalent winter crops, the average leaching (kg/ha/year) is higher, since land is left bare for longer periods of time. Figure 3 illustrates, the average nitrogen use and nitrogen leaching per hectare for the average cereal and average general cropping farms. Even though the cereal farm has higher inputs compared to the general cropping farm, their nitrogen leaching curves overlap showing how their leaching effects are essentially very similar, due to nitrogen uptake by nitrogen intensive crops being higher. This is also the reason that nitrogen leaching remains unaltered throughout 2000-2007, despite some land use changes, and slight increases in the fertilisation levels mainly for the cereal farm.

Figure 2 - Land Use - Average Cereal Farm

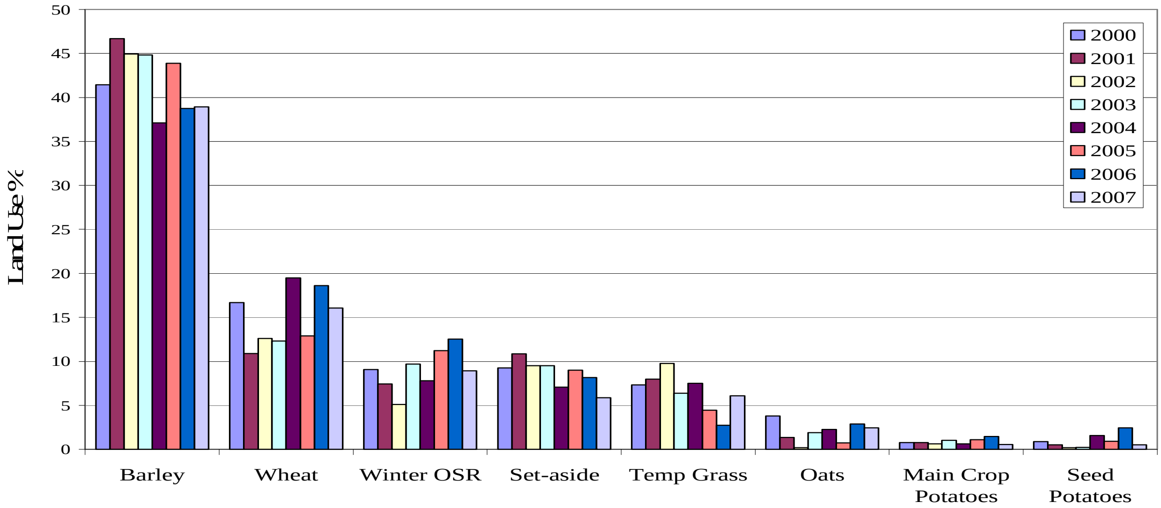


Table 4 - Nitrogen Inputs and Nitrate Leaching Coefficients per Soil Type

	Nitrogen Input			Nitrate Leaching		
	Medium	**Light**	**Average**	**Medium**	**Light**	**Average**
Spring Barley	144	120	132	84	82	83
Winter Barley	216	192	204	85	84	84.5
Winter Wheat	240	192	216	77	72	74.5
Winter Oilseed Rape	198	220	209	66	76	71
Spring Oats	144	120	132	81	79	80
Winter Oats	156	144	150	64	66	65
Maincrop Potatoes	216	216	216	79	78	78.5
Seed Potatoes	114	114	114	87	85	86
Spring Beans	0	0	0	58	58	58
Winter Beans	0	0	0	55	56	55.5
Vining Peas	0	0	0	69	67	68
Carrots	72	132	102	73	89	81

Figures 4 and 5 show the percentages of total land occupied per crop under each of the scenarios, for the average general cropping and cereal farms, respectively. The "Agenda 2000" (Baseyear) and "Average 2006-2007" are the actual percentages of crop levels as an average of the years 2001-2003 and 2006-2007 respectively, estimated through the JCD. The former has also been used as the Baseyear for model calibration. The scenario of “Agenda 2000-NVZ regulations” was not analysed as the average nitrogen use of the farms was below 170kg/ha and therefore the quota had no effect on the results. The Price Changes 2 scenario was only analysed for the cereal farm, as again the quota was inactive for the general cropping farm. The rest of the scenarios correspond to scenarios modelled with FSSIM-MP. The prices used for modelling are shown below:

Figure 3 - Nitrogen Use and Nitrate Leaching for the Cereal and General Cropping Farm Types

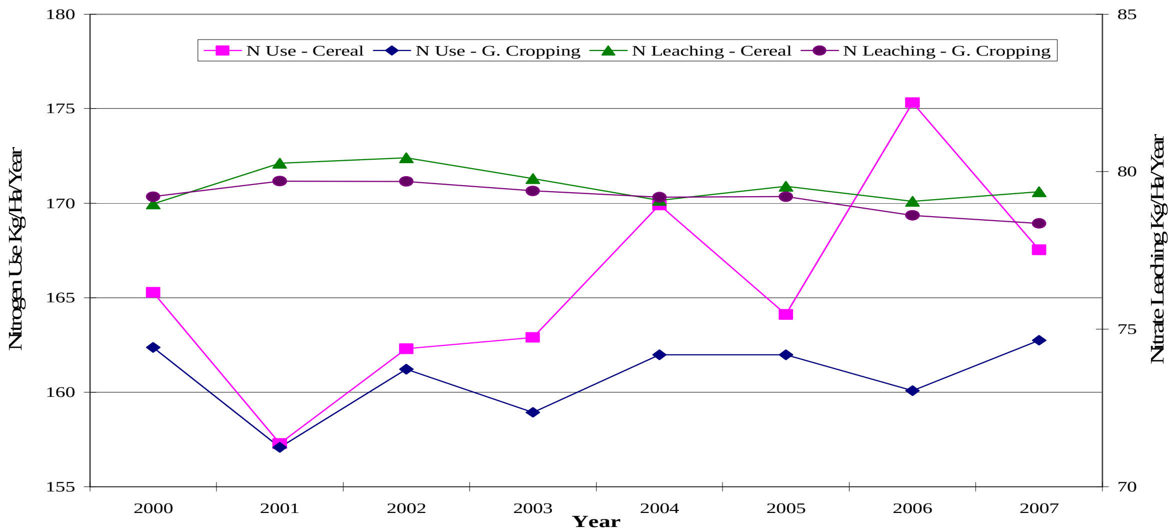


Table 5 - Crop Prices Used for the Bio-economic Modelling Simulations

	Barley	Wheat	Winter OSR	Oats	M. Crop Potatoes	Seed Potatoes	Beans	Peas	Carrots
2001-2003	68	75	148	70	97	140	72	230	220
2006-2007	70	80	160	65	140	130	79	230	240

Under the CAP Reform scenario, the areas of barley and winter oilseed rape in the general cropping farm decrease, while the areas of seed potatoes and wheat increase. Minor increases were also observed in the areas of oats, maincrop potatoes and vegetables. The Price Changes scenario indicates decreases in the areas of barley, seed potatoes and vegetables and increases in the areas of wheat, main crop potatoes, winter oilseed rape and oats.

For the average cereal farm, under the scenario of CAP Reform there are some slight increases in area for all crops which are replacing set-aside land[7]. The Price Changes scenario indicated considerable reductions in the levels of barley, which was mainly replaced by winter wheat and winter oilseed rape. Maincrop potatoes also slightly increased, and oats and seed potatoes decreased slightly. When the nitrogen input quota constraint is not active, the changes in relation to barley, wheat and winter oilseed rape are more pronounced.

Figure 4 - Modelling Results and Current Levels - Average General Cropping Farm

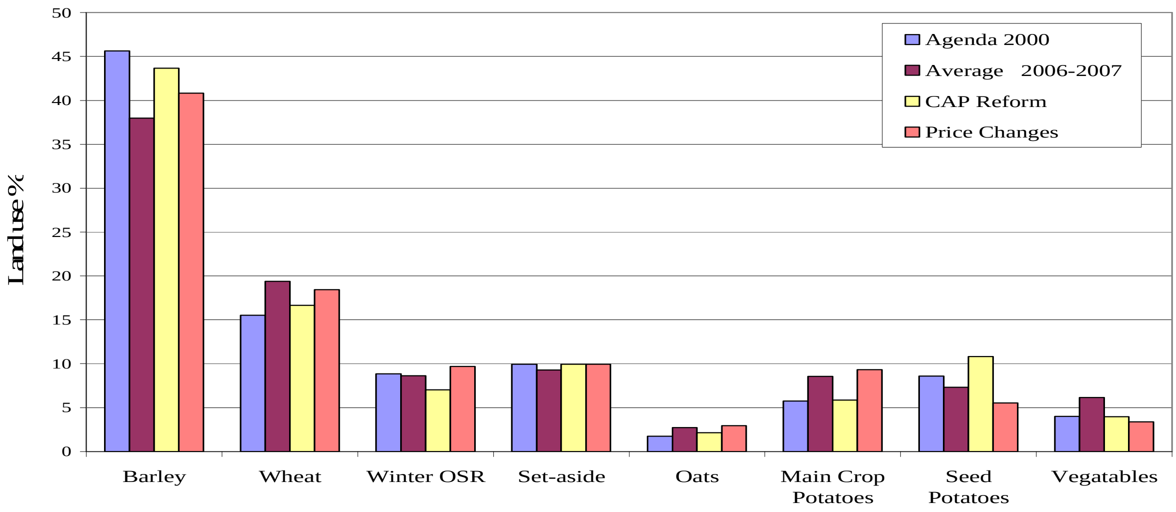
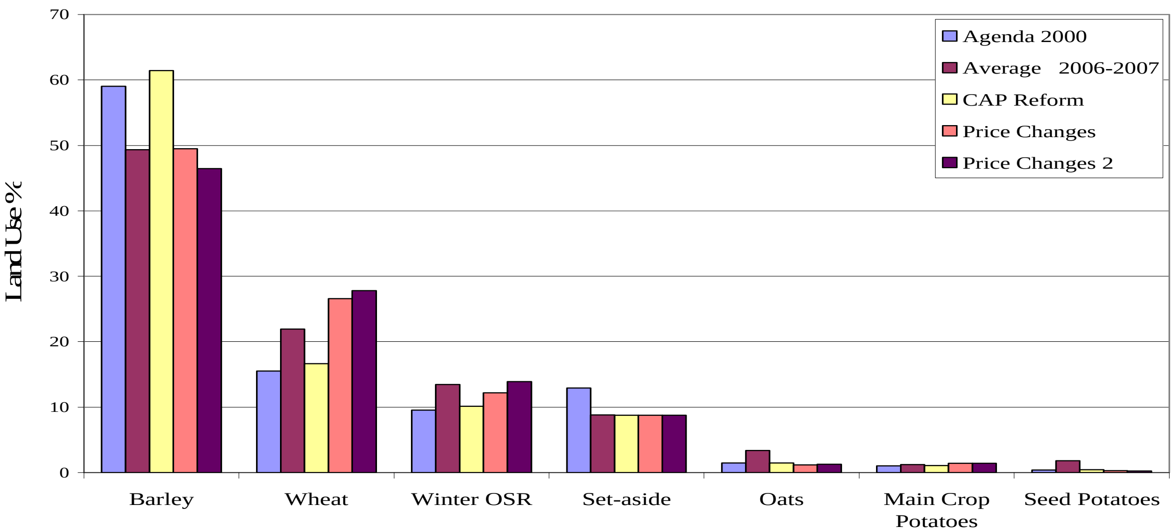


Figure 5 - Modelling Results and Current Levels - Average Cereal Farm



A summary of the main economic and environmental results of the modelling scenarios are shown in Tables 6 and 7. Regarding the General Cropping farm, the income of

[7] Set-aside land was kept to the actual level using a model constraint.

the farm is slightly reduced under the CAP Reform scenario. In contrast, when changes in the prices are taken into account it increases considerably. The premium share of income is lower in the Price Changes scenario. The average nitrogen use is below the nitrogen quota for all scenarios. Neither nitrogen use nor leaching differ significantly between the scenarios. The cereal farm appears to have lower income per hectare than the general cropping farm, while the premiums as a share of total income are much higher. Income does not decline significantly after the CAP Reform scenario. The highest income is achieved under the Price Changes 2 scenario. Under this scenario, however, the nitrogen use surpasses the quota, even though nitrate leaching does not increase.

Table 6 - Economic and Environmental Results – Average General Cropping Farm

	Agenda 2000	CAP Reform	Price Changes
Utility (£)	66677	66136	84530
Farm income (£)	81530	81182	101610
Income per ha (£/ha)	635	632	792
Premiums (£)	21722	20793	20793
Premium share of income (%)	27	26	20
Nitrogen use (kg/ha)	152	151	159
Nitrate leaching (kg/ha)	72	72	71

Table 7 - Economic and Environmental Results – Average Cereal Farm

	Agenda 2000	CAP Reform	Price Changes	Price Changes 2
Utility (£)	15405	15010	17164	17364
Farm income (£)	21866	21821	24246	24858
Income per ha (£/ha)	463	462	514	527
Premiums (£)	9003	8482	8482	8482
Premium share of income (%)	41	39	35	34
Nitrogen use (kg/ha)	162	170	170	180
Nitrate leaching (kg/ha)	70	73	72	71

Discussion and Conclusions

The analysis of both the JCD analysis and modelling results show only small changes in the cropping pattern of the two farm types. The most significant changes are decreases in the area of barley and increases in the area of wheat. This is explained by the higher relative price increases of winter wheat, and its higher yield compared to spring barley. The same applies to the increase of maincrop potatoes in both farm types in all modelling scenarios. The decrease of seed potatoes in the case of the general cropping farm could be attributed to the reduced price, as also demonstrated by the modelling scenario of Price Changes. The price change of oilseed rape also showed an increase to its production in both Price Changes scenarios and in the data analysis of the cereal farm. Even though vegetables increase, this is only captured by the CAP Reform and not the Price Changes scenario, as their price changes were not sufficient to invoke upward effects.

The effects of the CAP Reform scenario for the cereal farm showed an increase in the area of all crops after a reduction of set-aside. While this is in line with the data analysis for most crops, it is not the case for barley. This is due to barley being an important crop in terms of Scottish rotations. This effect is reversed with the introduction of the new prices, that match to a great extend the actual changes shown by the JCD analysis. In the case of the general cropping farm, the CAP Reform scenario captures the direction of changes for most crops. However, these are further augmented and much closer to the changes shown in the data analysis after the introduction of the new prices. Overall, a shift towards higher yielding and therefore more profitable crops can be observed, partly as a result of the CAP Reform, but mainly due to changes in crop prices.

Farm incomes do not decline significantly after the introduction of the Reform. Indeed, significantly higher incomes are achieved after the introduction of new crop prices. These effects could however be augmented if modulation is also taken into account. As would be expected, the premiums as a share of income decline under all scenarios. The cereal farm appears to have lower income per hectare and to be more dependant on premiums than the general cropping farm, as the premium's share of total income is much higher. It also seems to be more reactive to price changes, as demonstrated by higher crop fluctuations of the yearly JCD analysis and by stronger model predictions in relation to the main crops.

The average nitrogen use is below the nitrogen quota for all scenarios, except for the Price Changes 2 scenario of the cereal farm. It is however very close to the 170 kg/ha limit and this might be constraining farmers' flexibility in relation to high input crops. Overall nitrogen use and nitrate leaching do not differ considerably between the scenarios for each of the two farm types. The Price Changes 2 cereal farm scenario provides the highest income for this type of farm. Under this scenario, nitrogen use exceeds the quota, even though nitrate leaching does not seem to increase. As a consequence cereal farmers appear to be more constrained in their decisions as some of the most profitable cereals require high fertilisation. While this constraint leads to reduced profits, it does not seem to change the resulting nitrate leaching levels, due to nitrogen uptake of nitrogen intensive crops being higher. This is also why nitrogen leaching remains unaltered through 2000-2007, despite the land use changes, illustrated both by the JCD analysis and modelling. This suggests that the assumption that increased nitrogen fertilisation levels inevitably leads to increased leaching is a misconception, and that measures of more restrictive input quotas will yield no major improvements. On the other hand, measures of target fertilisation in relation to soils and crop might be more efficient.

Bio-economic modelling facilitates the comprehensive representation of the agricultural system in economic and bio-physical terms. It therefore provides a consistent framework for simultaneously analysing both economic and environmental impacts of farmers' decision-making. The methodological framework of combining analyses of actual data on land use with bio-economic modelling offers significant advantages. Specifying the driving forces of land use changes is not easy, as they are the result of various interacting factors such as policy changes, price changes, structural changes, etc. A key conclusion of this work is that in spite of a lack of detailed input data, bio-economic modelling can help in explaining the drivers of changes demonstrated by modelling results and actual data analysis. The structure of the models lends itself to further sensitivity analysis and an exploration of the boundaries of resilience of farming systems. Although the comparison of model predictions with actual data constitutes a form of model testing and increases confidence in the model outcomes, not all potential modelling scenarios have been tested and it does not imply blind acceptance of model predictions. Rather, the outcomes should be considered as hypotheses that become the input to further discussions with experts and policy makers.

The present research represents a pilot study for testing the methodology. The work will be developed further to take account of further factors and to include a richer representation of farms. The research would benefit from a longer JCD data series, a more detailed farm classification taking into account farm size and differentiated soil type land endowments, inclusion of fixed costs, consideration of rotational effects, more refined weather scenarios, and a comparison of simulated and actual nitrate losses. Further research will include the examination of more measures to counter water pollution, such as target fertilisation, and the exploration of the effects of the Reform on livestock and mixed farming systems.

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