Understanding impacts of environment-related payments on farm level production and economy through integrated spatial modelling

Urban, Daniel; Shrestha, S; Barnes, AP; O'Donoghue, Cathal; Ryan, Mary

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Technical brief

Understanding impacts of environment-related payments on farm level production and economy through integrated spatial modelling

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Daniel Urban[1,2], Shailesh Shrestha[1], Andrew Barnes[1], Cathal O'Donoghue[2], Mary Ryan[3]

1. *REER, Scottish Rural College, Edinburgh, UK*
2. *National University of Ireland, Galway, Ireland*
3. *RERC, Teagasc, Galway, Ireland*

Abstract

The EU Water Framework Directives (WFD) sets to achieve a 'good' surface water quality status, while the practical means to achieve this target is in hands of the individual member states though application of Agri-Environmental Schemes and their specific protective measures. In its EU withdrawal agreement, the United Kingdom has decided to retain the European water regulatory framework. In Scotland, almost 30% of watercourses are expected to be of lower than 'good' ecological status in 2021, and thus require attention of policymakers. Scotland's River Basin Management Plans (RBMPs) set out a range of actions to address the issues with regional water quality. The farmers' capacity to meet its obligations are, in turn, supported by the adoption of the Agri-Environment Climate Scheme (AECS). Nitrogen is one of the main water pollutants emitted by agricultural practices of farms, and thus it is of crucial importance to determine the most cost-effective ways to reduce nitrogen pollution bellow the target levels. This study aims to adapt the SMILE spatial microsimulation model to run farm-level scenario analysis of a set of specific measures aimed at reducing disperse nitrogen loads. The scenario results are compared against a baseline simulation, that represents the current state of all the farms. The resulting net change in total nitrogen emitted, and the change in farm gross margins is used to calculate the individual marginal abatement costs of the farms with a specific geographic reference on the level of electoral districts. The context, in which the abatement costs vary does not only change the absolute values of the costs, but also their relative ranks, and thus the appropriateness of given measures under the circumstances. In order to describe the main determinants of variation in abatement costs, they are analysed in context of geographically varying environmental conditions, water quality metrics and farm characteristics, followed by an analysis of variation within and between electoral districts. These assessments will then drive a discussion on appropriateness of specifically targeted policies, in contrast of undifferentiated, one-size-fits-all schemes. Furthermore, the targeting of policies will also be assessed based on the results of spatial analysis of variation to determine, whether policies targeted on farm specific characteristics, or those targeted geographically, would achieve the targets with higher efficiency. The empirically surveyed farmers' attitudes to given measures, and thus the likelihood to adopt them with also be included in the final analysis of scenario results.

Contents

Research Question:

What are the most cost-efficient measures for reduction of agricultural N pollution in context of individual farms' geographies, economies and environmental attributes?

Approach:

This study adopts the SMILE (Spatial Microsimulation for Irish Local Economy) framework. In its most basic form, it creates a statistical match of two datasets containing partial information to produce a single, data-rich database of individual farms with unique geographical reference, used for spatial analysis of assessed measures. Using this micro-dataset, scenario analysis is employed to run alternative policy simulations to determine the absolute and relative cost-efficiency of individual Nitrogen-reducing measures through induced behavioural change on individual farms. Furthermore, variation in marginal abatement costs is assessed, which in turn is used for categorization of farms through their response to the measures based on their typology, geography, environment and economies.

Policy Context

EU Agricultural Policy

The Common Agricultural Policy (CAP) of European Union provides the underlying frameworks and funding for the majority of regional planning and development with main focus on agriculture and food production.

Since establishment in 1957, as a part of the treaty of Rome, the CAP has undergone a series of structural reforms. The most prominent ones being the 1992 MacSharry reforms, that moved from price support mechanisms towards more compensatory mechanisms for agricultural sector. The Fischler reforms of 2003 then represented a major shift from coupled distorting production payments to farm support schemes, that were not connected to specific agricultural production (decoupling).

The CAP support schemes, as described under the 2013 reforms are divided into two major blocks: Pillar I and Pillar II schemes. Pillar I, representing the major bulk of funding, encompasses the Single area payment scheme, which is an income support payment for all the eligible farms in the EU. However, the more relevant systems are a part of the Pillar II payments, that focus on *"restructuring, environmental protection and territorial-based rural development programmes"*.

This system primarily includes schemes such as the LEADER programme, which is a network of local development companies, and in context of Scotland the Agri-Environment Climate Scheme (AECS) or the Less Favoured area scheme (LFA).

UK Agriculture act 2020

The UK's new Agriculture Act has been called "one of the most significant pieces of legislation for farmers in England for over 70 years". It could directly affect the livelihoods of 460,000 people and determine the future of the 70% of UK land area (17.4 million hectares) currently under agricultural management. The bill outlines the UK's approach to farming after it left the European Union, replacing the Common Agricultural Policy (CAP) that the UK has been part of since 1973 (UK government, 2021).

Over the next seven years, farmers will move from the CAP regulations to a new system of environmental land management contracts. These will detail the terms and conditions under which farmers and land managers will receive funding. Subsidies are expected to be paid out from taxpayer funds at the same rate as the EU – about £3 billion a year – to enable landowners to deliver the public goods set out in the UK government's 25 Year Environment Plan and the Clean Growth Strategy.

Businesses receiving up to £30,000 in BPS will face a reduction of up to 5%, with those receiving £150,000 or more seeing a reduction of 25% in 2021.

Environmental Land Management system (ELMs)

In England, farmers will be paid to produce 'public goods' such as environmental or animal welfare improvements. The new Environmental Land Management system (ELMs), also referred to as Environmental Land Management scheme, began its test and trial period in 2019, with pilots planned to run from 2021. Defra's ambition is for 1,250 businesses to enter the ELMs pilot scheme in 2021, building to 15,000 by the end of the pilots in 2024.The ELMs will replace BPS and Countryside Stewardship funding and its rollout is planned from 2025-2027.

According to a National Audit Office report published in June 2019, Defra aims to have enrolled 82,500 farmers and land managers by 2028.Payments could also be available for farmers to invest in new technologies and methods that boost productivity, and there will be pilots for schemes to boost animal welfare. Direct payments will be separated from the requirement to farm the land and several years' worth could be paid in a single lump sum, which will give farmers money to invest in their business, diversify or even retire from farming.

Scottish Agriculture (Retained EU Law and Data) Act 2020

In the specific case of Scotland, most of the EU environmental and agricultural law has been transferred to a post-Brexit regulatory framework as a 'retained EU law'. Under this legislation, the Scottish ministers have the power to simplify or improve the EU common agricultural policies and collect agricultural data. This act then ensures CAP legislative continuity and farmers' support. This also applies to the EU Water Framework Directive and it's reflection into the Scottish River Basin Management Plans and Ang-Environment Climate Scheme (Scottish Government, 2021).

Methods

Data Requirements

The fact, that regional differences are often exhibited on various demographic, economic and environmental variables in a complex, correlated dynamics, the aggregate national or regional data is not enough to capture the true mechanisms under certain phenomena, which is necessary to understand, in order to successfully simulate and predict changes in the systems due to anticipated policy shifts. In a similar manner, surveys, that contain detailed indicators on researched issues don't possess necessary generality for large-scale application. Since large datasets, containing detailed census data on household or individual levels are rare, a methodology, which connects the national census data with local survey results to synthesize a required dataset is necessary.

Available methods

The microsimulation techniques, that provide such technology, began to be developed in 1980s, and gained prominence during the following decades. Unlike the macro, or meso scale models such as input-output or equilibrium/partial equilibrium models, the microsimulation models work on the level of individuals, or individual households. This kind of resolution is necessary in order to determine which specific demographic and geographical groups are going to be primarily affected by given policies. The latter is a focus of spatial microsimulation.

The basic idea behind microsimulation is to either estimate new combinations of variables from large scale datasets, such as census, or reweight small-scale surveys, to make them representative of the entire populations. Static models, that is the simpler and cheaper option, use a cross-sectional database at a single point of time, while the more complex dynamic models include lifecycle transitions from base year onwards with higher level of endogenic determination of variables.

Examples of static aspatial microsimulation models include TAXMOD (Atkinson and Sutherland, 1988) or STINMOD (Lambert, 1994), that analyse tax and fiscal changes at the household level. Dynamic aspatial models include DYNOMOD (Antcliff, 1993) and DESTINIE (Bonnet and Mahieu, 2000).

Spatial microsimulation

The origins of spatial microsimulation date back to 1957, when Hägerstrand employed micro-analytical framework to study migration in Sweden. Wilson and Pownall (1976) continued on this work and included individual lists, instead of matrices and employed further complexity with higher requirement of computational capacity.

Later, in their SYNTHESIS model, Birkin and Clarke (1988) used Iterative proportional fitting to generate income for individuals. On a national level, the SVERIGE model aims to analyze spatial consequences of policies in Sweden. Similarly, The Australian Centre for Social and Economic Modelling employs the SpatialMSM and HouseMOD models to look at rent issues and housing stress.

The Leeds school of microsimulation later applied further models to assess morbidity levels and regional GP performances, or with their SimLeeds model identified local commuting patterns.

At a very fine spatial scale, Birkin et al. (2019) introduced the MOSES model for the whole of UK to produce robust population forecasts.

SMILE

The Simulation Model for Irish local Economy was developed to assess the socio-economic impacts of policy or economic changes (O'Donoghue et al.,2013). The core algorithm of SMILE uses a process known as quota sampling, which was chosen over other appropriate methodologies due to its efficiency and simplicity.

In an early version of the model, an IPF methodology was used to create spatial microdata, based on which conditional probabilities were calculated. Afterwards, a set of synthetic individuals was produced using a Monte Carlo simulation.

Alternative deterministic process to IPF is the Deterministic Reweighting, which reweights the survey population or household dataset which will best fit the individual or household characteristics known at the small-area level by matching them against the census variables. This was used by Edwards and Clarke (2009) in the SimObesity model.

Alternative to the deterministic models, that set the relationship between the survey and census datasets in an absolute manner, the probabilistic assessment process works with a probability of matching individuals with the defining variables. Heuristic combinatorial optimisation methods, such as simulated annealing, hill climbing or genetic algorithms reweight existing microdata samples to fit small area population statistics using probabilistic approaches. Simulated annealing selects a configuration of micro units, such as households or farm from a micro dataset calibrated to totals in districts taken from small area census data, such that the structure of the simulated tables is as similar as possible to the tables of the original small area census.

The 2013 version of SMILE uses the Quota Sampling methodology, developed by Farrell et al. (2012) based upon Simulated Annealing. It is a probabilistic reweighting methodology, where survey data are reweighted according to key constraining totals, or quotas for each local area. It then randomly orders the micro data and then samples until the quotas are filled. The data used in the modelling come from The Living in Ireland Survey, whole 2000 version included 13,067 individuals across 3,467 households. The census information comes from the Small Area Population Statistics on the level of electoral districts. Household are classified based on their Geo-directory. The constraint variables, such as education, age and employment status, have been chosen based on their R^2 values, that come from regression with household disposable income.

The modelling itself is conducted in 3 stage: The first one is sampling of underrepresented households. This is followed by sampling of all households, and finally controlled broadening of constraints, as defined by the simulated annealing procedure.

The spatial microsimulation is complete, when the selection of individuals from the micro dataset can reproduce the SAPS tables for the number of individuals by household size, education level, age/sex, farm ownership with less than 5% difference between the original SAPS tables and those generated from the micro dataset selection. The final step then merges the rest of the variables from the micro dataset to the simulated dataset, by merging together the individual and household identifiers common to both the micro dataset and the simulated dataset.

Practical use

The firstly mentioned example was a model developed by a cooperation between Teagasc and University of Leeds (Balllas et al.,2005) for the purpose of spatial analysis of various economic development policies in Ireland. This model builds a dataset by matched the data from the Irish Census on Agriculture with the National Farm Survey. The resulting analysis compared the historically paid SAP CAP payments with a flat-rate payment scenario, to produce a spatial account of the impact of this policy change, in terms of farm income. This could act as a policy guideline for the future of CAP payments for the 2013-2020 budget period.

The second case study assesses the environmental effectiveness of Agri-environmental schemes under the Irish Rural Environment Protection Scheme (REPS) (O'Donoghue et al.,2013). This model matched the National Farm Survey with the REPS Participation statistics and using a logit model finds out, which areas (with what attributes) are most likely to be affected/protected by the Agri-Environmental Schemes. It also determined, what kind (and where) farmers are most likely to participate. The results found, that more marginal land, with lower productivity, tends to be affected by the REPS schemes more. This might be because farmers in the marginal regions are more dependent on this kind of schemes, and economically would make more of their land by being under a protection scheme, rather than more intensive agricultural use.

Another relevant case assesses the impact of a methane tax on regional emissions, in order to comply with the targets, set in the National Climate Change Strategy. Similarly to the first case, the SMILE model was applied to the National Farm Survey and the Census of Agriculture. Using a proxy measure for individual methane emissions, this study created a regional account (on ED level) of both the methane tax levy and agricultural methane emissions. The results of the study found, that farms, that participate in REPS schemes are more efficient in methane emission reduction. Therefore the authors propose a system of redistribution of methane tax revenues to the farms, that participate in REPS in order to incentivise this favourable behaviour (O'Donoghue et al.,2013).

Data

To produce a synthetic farm-level dataset for spatial microsimulation, two major databases are statistically matched:

Farm Business Survey for Scotland, *2018*

This document provides an overview of the methodology behind the Farm Business Survey (FBS) for Scotland along with descriptions of the main income estimates produced from the data collected from this survey. It describes the quality of the information collected in this survey and the headline measure of income, namely Farm Business Income (FBI) and provides information about the relevance of the FBS and why the information is required.

Farm Business Income (FBI) – the total income available to all unpaid labour (farmers and spouses, non-principal partners and directors and their spouses and family workers) and on their capital invested in the farm business, including land and buildings. Income from diversified activities are included in overall FBI.

FBI Data

Data Providers Estimates of farm income in Scotland (including Farm Business Income (FBI), which is the headline measure produced by the Scottish Government) come from the Farm Business Survey (FBS) for Scotland, which is based on a sample of approximately 500 farms. Annual data collection for the FBS is carried out by SAC Consulting (SACC) on behalf of the Scottish Government (SG). SACC recruits a sample of farms and collects data directly from them through farm visits and detailed examination of each business's books and paperwork. When complete, the processed data is anonymised and passed to the Scottish Government for analysis and publication. Currently, around 500 fully reconciled farm accounts are compiled each year, constructed from the information supplied by co-operating farmers, meaning the quality of information collected is very high. SACC collects detailed financial and economic information (and some physical information, such as crop areas and stock numbers) for the farm business on outputs, inputs, income and balance sheets.

The FBS results are obtained from a sample of farms that are stratified by farm type and economic size. The survey does not currently include farms predominantly engaged in horticulture, poultry, egg production or pig production. The coverage of the survey is restricted to those farms which have considerable economic activity (at least 25,000 Euros of output, equivalent to £21,315) and are not considered as spare time farms.

Policy

The primary use of FBS data is to inform policy decisions and to help monitor and evaluate current policies, especially their impact on different agricultural sectors. The data is also used to model the impact of potential future policy options. Furthermore, FBS results also contribute to the compilation of Total Income from Farming (TIFF) estimates, especially as the source of input costs, which are forecast forward a year to account for the lag in survey results. The prominent profile of FBS in policy issues relates to the nature of the information collected and the scarcity of alternative sources.

Research

Another important use of the survey is for academic research. The full dataset can be made available in an anonymous form and under strict confidentiality conditions for a number of research projects. The survey covers farm businesses with a Standard Labour Requirement of 0.5 and above and covers most main farm types in Scotland, excluding horticulture, specialist pig and specialist poultry producers. Around 10,802 holdings are represented at present.

Sampling

The sampling strategy of the FBS is based on a stratified simple random sample and is effectively designed as a panel survey with little change in the membership of the sample between years. The sampling frame for the survey is the Scottish Agricultural Census, according to the specific requirements of the FBS sample in regards to farm type and standard output (SO) size. Around 10,802 holdings are represented by the FBS at present. An important feature of the survey is the measurement of changes in farm incomes and in incomes from diversified activities for particular types of farm for at least two years. To achieve this, it is necessary to maintain farms in the sample surveyed over a number of years. Once recruited, the farm may stay in the sample for an unlimited time period. The involvement of farms in the FBS is entirely voluntary. If farms drop out of the survey, replacements are selected depending on which farm types, economic output and district of Scotland are required to achieve a sample which is representative of the population of farms in Scotland. Replacement farms are then selected at random from within these groups.

Weighting

To account for potentially unrepresentative nature of the sample a new calibration weighting method was applied for this publication, making the weighted averages more representative of the population. Data has been reweighted back six years (2012-13). Comparisons between weighted data prior to this time should not be made because the weighting methodologies are different. 7 Weightings are based on the June Census distribution of agricultural holdings in Scotland and are published broken down by eight farm types and three farm tenures.

June Agricultural Census 2019

In Scotland the registered details of the 51,292 agricultural holdings are used to maintain a holding-level dataset of agriculture for statistical purposes. This provides a virtually complete coverage of agricultural activity in Scotland.

The outputs from the census on livestock and crops are also used as key inputs to the Total Income from Farming (TIFF) model, which is used to estimate the value of agricultural productivity in Scotland.

Data Collection

The June Agricultural Census is conducted annually by the Scottish Government's Rural and Environmental Science Analytical Services division (RESAS). Data are requested from all holdings who submitted a Single Application Form (SAF) in the previous year, together with some other large businesses that would not be eligible for support payments. A sample of holdings which didn't submit a SAF or who didn't return a form last year were also sent a census form.
Data for the June census is collected from three sources:
Land data were extracted from the Single Application Form (SAF) database for around 22,700 holdings that are claiming under the Basic Payment Scheme (BPS). Holdings that submitted a SAF in 2019 were also sent a cut-down census form (21,400 farms) to collect the additional data on livestock and labour. From the remaining holdings that did not complete a SAF in 2019, 10,300 (potentially including holdings that submitted a SAF for the first time in 2019) were sent a full census form covering land, livestock and labour.

Data cover

Land-use data was received for holdings covering 84 per cent of the total agricultural area, either from returned full census forms or the SAF.
Cattle data was received for 100 per cent of holdings with cattle, from the CTS.
Other data was received for holdings covering 66 per cent of the total agricultural area, from returned census forms.

Proposed Measures (Scenarios)

Default (base) scenario

Represents the business as usual- corresponds to the original FBS values. All the subsequent scenarios are compared against the base.

Change Fertiliser amount (-10%)

The total amount of applied inorganic fertiliser decreases by the factor of 0.9, with an assumption resulting linear decrease in rates of growth. The reduced growth of grass as an input into the livestock enterprise is covered by a corresponding increase in purchase of bulk feed

Change Fertiliser amount (-20%)

The same steps as previous, while the value of coefficient, adjusting the total amount of fertiliser application on each farm is 0.8

Reduce Stocking Rate by 20%

The total numbers of all the livestock on the farm (beef cattle, dairy, sheep) is reduced by a factor of 0.8.

Change Feed mix to reduce N

Purchasing of bulk feed for livestock with lower nitrogen content will lead to lower nitrogen discharge through defecation, and thus decrease the total farm nitrogen loads

Fencing-off streams

1.5m buffer zone with Intensification of production

In case a farm has a stream on its land, that livestock has access to, in this measure the farmers will build fences to prevent defecation directly into the stream. This measure will reduce both the amount of nitrogen directly deposited into the stream, and also the total level of leaching form the land. The reduction of the utilised area in this case leads to relative intensification of production, with the same output, animal numbers, crops and fertilisers applied, but on smaller extent of land, thus increasing the livestock stocking density.

1.5m buffer zone with constant production

The fences are built in a same was as the previous scenario, but this time the output per unit of land (ha) stays the same. This assumes linear reduction of inputs, crops and livestock numbers.

Slurry Efficiency

Switch season of slurry application from summer to spring

The total amount or method of application of slurry does not change, but the application pattern follows the advice of good agricultural practices and distributes slurry during the period shortly before the spring growth spurt, and thus maximises the nitrogen retention by the crops/grass and minimises the seasonal leaching loads, that would otherwise contribute to water pollution.

Change application method from Splash Plate to Trailing shoe

Trailing Shoe method of application ensures allows more slurry to access the roots of the vegetation, and thus reduces the total amount of fertiliser necessary to achieve the same rate of fertilisation and growth. In this scenario, the season of application stays the same.

Change both season and method of application

This scenario combines both reduction of the total amount due to higher application efficiency and higher fertiliser retention by the crops due to higher seasonal uptake.

Increase Breeding Index-decrease number of Dairy Livestock Units

Breeding technology allows higher output of milk per dairy cow, and thus replacing the herd with cows with higher milk output per livestock unit will allow the farm to actually maintain a smaller herd with relatively lower nitrogen discharge, and thus decrease of total leachable nitrogen.

Expected results and future steps

The resulting variation in marginal abatement cost of the aforementioned measures will be assessed in the context of the absolute difference in the amounts of Nitrogen abated and net change of farm gross margins. The geographical, environmental an economic context, in which the observed variation occurs will be driving the next steps in analysis. If the spatial analysis shows significant variation in abatement costs across different regions of Scotland, then further attention will be paid to the specific drivers and sensitivity of individual farms to measures and environmental risk and potential water quality deterioration. The most sensitive farms, in regards of their location or production patterns will then be the selected of deeper assessment for the purpose of efficient policy targeting. In practical terms that means that the characteristic farms in the most sensitive areas in regards of the water quality status with the most risky production patterns will be the primary focus of policy targeted at promotion of the most cost-effective nitrogen-reducing measures. In further steps this assessment will be followed by statistical tests of spatial within and between variation of farms grouped by their parish geographical reference, followed by mapping of the spatial variation of the abatement cost of the measures across Scotland. These results will then provide a base for discussion on the most efficient targeting of policies aimed at reduction of diffuse nitrogen pollution.

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