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Modelling the interactions between regional farming structure, nitrogen losses and environmental regulation

K. Happe [a], N.J. Hutchings [b,*], T. Dalgaard [b], K. Kellerman [a]

[a] Leibniz Institute of Agricultural Development in Central and Eastern Europe, Halle, Germany
[b] Department of Agroecology and Environment, Faculty of Agricultural Sciences, University of Aarhus, Denmark

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ABSTRACT

Changes in the structure of agriculture are known to affect emissions of environmental pollutants from agriculture. Such changes are often driven by structural changes in agricultural production, so structural changes are likely to have indirect effects on emissions. In a pilot study, we consider how linking two complementary simulation models might be used to explore these effects. The agent-based AgriPoliS model was used to simulate the structural dynamics of agricultural production. The results from AgriPoliS were passed via a number of intermediate models to the Farm-N model, which was used to estimate the nitrogen surplus and losses from each farm for each year.

The modelling complex was exercised by simulating the effects of two plausible policy scenarios for each of 14 years. The initial sizes and types of farms were based on statistics from a region in Denmark and the farms were randomly distributed within this region. The reference scenario (REF) implemented the current area-based Common Agricultural Policy payments for Denmark. The 1 LU scenario applied the additional constraint that a minimum area of 1 ha land had to be available for the application of the manure produced by one livestock unit.

Substantial changes in the structure of agricultural production were shown for both scenarios. The effect on the regional nitrogen surpluses was predicted to differ between scenarios and the contribution of the different farm types to change with time. Predicted ammonia emission changed with time and differed between the scenarios, whereas the Danish fertiliser and manure legislation meant that nitrate leaching remained fairly stable.

The implementation of additional environmental legislation significantly changed the trajectory of structural adjustment processes. Results emphasize the complex interplay between structural changes, losses of nitrogen, and environmental regulation.

It is concluded that the effects of structural change on environmental emissions can be usefully explored by linking agent-based models of farmers' investment decisions with other models describing nutrient losses from the farm and that such modelling can play a useful role in designing effective environmental policies for agriculture. However, the approach demands the availability or collection of many region-specific data and this could create a barrier to its use.

1. Introduction

Changes in the structure of agriculture (e.g. farm size and specialisation) are likely to affect agricultural practices and production. For example, small farms often manage manure as a solid, whereas large farms often manage it as slurry (Danish Ministry of Food Agriculture and Fisheries, 2006). Since agricultural practices have a direct effect on the environmental pollution from agriculture, changes in the structure of agriculture might be expected to have an indirect effect on this pollution.

Structural change is a complex and dynamic process involving adjustment reactions by farms to farm-external (e.g., policies, the development in other sectors of the economy, credit availability, regional conditions) and farm-internal (e.g., objectives, production costs, endowment with land, labour, and capital, presence of a farm successor, managerial ability of the farm operator) driving factors. From an economic point of view, the result is an ongoing re-allocation of resources among farm units, and between the agricultural sector and other sectors of the economy in response to different pressures (OECD, 1994; Blandford and Hill, 2006). Likewise emissions from agriculture, too, are the effect of many interacting processes (Vatn et al., 2006).

Policy is one important factor affecting structural adjustment reactions (Blandford, 2006). The magnitude and scale of structural

* Corresponding author. Tel.: +49 (0)345 9491455.
E-mail addresses: mail@kathrin-happe.de (K. Happe), nick.hutchings@agrsci.dk (N.J. Hutchings).

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adjustment can be substantial, with some farms being driven to exit the industry. However, when some farms exit the industry, others receive additional opportunities, e.g. via increasing their acreage. In this way, adjustments by one farm may affect other farms. In addition, the voluntary or obligatory adoption of technologies that lead to lower emissions affects the costs of production, and so the production structure is potentially affected by the response to environmental issues. To illustrate the link between structural changes and emissions: in connection with the IPPC Directive (CEC, 1996), Danish regulators have fixed a maximum cost of just over 1 € per finishing pig produced for the ammonia abatement technologies to be considered Best Available Technology. Since the cost per animal produced of implementing abatement technologies declines as the number of livestock produced increases, this results in a demand for the use of technologies with higher ammonia reduction efficiencies as livestock holding increases (Danish Ministry of Environment, 2010).

In order to estimate the effect of structural change on emission levels from agriculture, it is important to understand the factors that determine changes in production and production practices. Economic–ecological modelling can assist in this task. Several models have attempted to combine the analysis of economic and environmental impacts to assist decision-making, policy assessment, developing or improving methodologies, or do all of these (Janssen and van Ittersum, 2007). There are many examples of models combining an economic and ecological analysis of policy impacts on the emission of agricultural pollutants. Most studies pose the question of the impact of different management practices on pollution outcomes. Examples of studies exist for nutrient leaching (e.g. Semaan et al., 2007; Lehtonen et al., 2007), greenhouse gas emissions (e.g. Leip et al., 2008; Neufeldt et al., 2006; Neufeldt and Schäfer, 2008), all nitrogen losses (Velthof et al., 2009), sustainability (e.g. van Calker et al., 2004), or interactions and feedbacks between the ecological and economic system (e.g. Vatn et al., 2006). At the level of the individual farm, the farming system or farm type level, mathematical programming approaches are typically employed (e.g. Annetts and Audsley, 2002; van Calker et al., 2004; Semaan et al., 2007). A review of models is provided by Janssen and van Ittersum (2007). Other studies derive results at the regional level, either by using an aggregation procedure from individual farms or farming systems to the region scale (e.g. Neufeldt and Schäfer, 2008; Uthes et al., 2011; Vatn et al., 2006), or by directly employing a regional or sectoral modelling approach (e.g. Lehtonen et al., 2007; Leip et al., 2008). Other impact assessment methods at the regional scale are reviewed by Payraudeau and van der Werf (2005). Regional models, farm type or farming systems models tend to disguise the variability and diversity of farms by analysing representative farm types or farming systems (Fezzi et al., 2008).

While having the potential to be very detailed with regard to defining management practices and determining emission levels, model-based analyses are comparatively static in the sense that medium and long-run adjustment reactions such as the re-allocation of labour and capital, farm exit, or investments are considered only in a stylised way, if at all. Hence, despite the wide range of models, the interaction between structural changes in the agricultural sector and emissions has received little attention. How does a change in the composition and specialisation of farms affect emissions of agricultural pollutants from farming? One reason for this is the complexity of structural change due to many driving factors, many different actors, and interactions between actors and the environment. Another reason is the lack of appropriate methods to explicitly model the process of structural change as a result of individual farms' decision-making and interactions.

This paper presents a pilot study of the potential of linking models of farmers' investment decisions with other models describing nutrient losses from the farm to the environment, to analyse the dynamic interactions between farm structure changes, changes in production practices, environmental regulation, and agricultural pollution. The objective of the study was to assess the potential advantages that would result from such an approach and identify the significant barriers that might confront anyone wishing to use it.

2. Methods

The method used for this exploration was to attempt to link an existing farm-based economic model of structural change with another existing model of the losses of nitrogen (N) from individual farms. The AgriPoliS model was used to simulate the structural dynamics of agricultural production in a region for two plausible policy scenarios, for each of 14 years. The initial sizes and types of farms were based on statistics from a region in Denmark and the farms were randomly distributed within this region. Using the results from AgriPoliS, the Farm-N model was used to estimate the N emissions from each farm for each year and scenario.

2.1. Models

2.1.1. AgriPoliS

AgriPoliS is a spatial and dynamic agent-based model that simulates regional structural change in agriculture based on economic considerations. Full details of the relationships and mechanisms used in the model can be found in (Kellermann et al., 2008; Happe et al., 2004, 2006 http://www.agripolis.de/documentation/agripolis_v2-1.pdf, while examples of its application can be found in Happe et al. (2008, 2009), Piorr et al. (2009) and in http://www.agripolis.de/documentation/adaptation_v1.pdf. The model integrates key components of regional agricultural structures: heterogeneous farm enterprises of different types, space, markets for products and production factors. It rests on the assumption that the agricultural system is a complex adaptive system in which individual agents, the farms, are the key decision-making units. A specific feature of agent-based models is that outcomes at higher levels of scale, such as the region or the sector, are the results of the actions and interactions of individual agents. In pursuit of a goal (e.g. to maximise income), each farm uses physical, monetary and human resources to produce a set of goods, and thereby causing changes to itself and to the social and physical environment. Individual farms make their own decisions and interact with each other.

AgriPoliS represents the structure of an agricultural region by considering the number of farms, number of animals and the distribution of farms according their specialisation, their size and type. Farms are embedded in the general technical, economic and political environment, within which they interact, co-operate, and exchange information with other agents that have possibly conflicting aims. Individual farms' actions lead to certain phenomena such as structural change at the regional scale.

At each time step, each farm agent takes production and investment decisions. The guiding behavioural assumption behind farms' actions is to optimise labour, production and investment decisions given their resource endowments (capital, land, family labour). Here, the focus is on economic consideration. This is why we assume that farms agents act autonomously to maximise total household income, an assumption made in many economic models. The optimal mix of activities at the farm level is determined by a recursive mixed integer programming model, that allows farms to choose between different production alternatives, to invest in new animal housing and equipment, hire labour forces, take out short-term loans, offer family labour forces off-farm and save money. Decisions are based on expectations about income in the following year. In this way, the individual farms adapt differently