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Combining dynamic economic analysis and environmental impact modelling: Addressing uncertainty and complexity of agricultural development

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Abstract

In this study, the impacts of different agricultural policies on agricultural production and nutrient leaching from agricultural land are evaluated using the economic DREMFIA agricultural sector model and the field-scale nutrient transport model ICECREAM. DREMFIA simulates competitive markets of agricultural products and includes an evolutionary scheme of technology diffusion which explicitly considers farm investments, evolving farm size structure and technological change. The technology diffusion model allows self-enforcing patterns of technical change driven by the spread of information and farmers' knowledge related to different technological alternatives. Hence, the long-term changes in agriculture due to policy changes may be essentially larger than those predicted by traditional static equilibrium models. Larger potential for changes in production provides a larger perspective for evaluation of environmental impacts. The modelled variables in ICECREAM are nitrogen and phosphorus losses in surface run-off and percolation. The considered environmental effect is eutrophication of surface waters. In this paper, the modelling strategy will be presented and highlighted using two case-study catchments with varying environmental conditions and land use.
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1. Introduction

Water quality has been a part of agricultural policy debate in Finland because agricultural activities are responsible for a significant part of nutrient load. At the same time, agriculture is under rapid structural change due to economic pressures. In this paper, we therefore combine analyses of long-term economic viability of agriculture, nutrient leaching and water quality. There are only few such studies, although it is obvious that agricultural policies probably have environmental effects which include impacts on nutrient leaching and water quality by influencing production intensity and/or production allocation between geographical areas.

We have approached this issue through modelling, using a strategy that integrates a national-level multi-regional agricultural sector model (Lehtonen, 2001, 2004) with a region-specific field-scale nutrient leaching model (Tattari et al., 2001). The chosen approach is challenging, because the agricultural production economy both at national and regional level has to be combined with sets of factors that influence water quality.

A similar, but not identical integrated agri-environmental modelling approach was used by Shou et al. (2000). They used a sector-level economic model in calculating economically rational changes in variable factors of production as a response to changing policy. The resulting prices and quantities of inputs and outputs were then utilised in different farm

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level economic models and in nutrient leaching models in order to calculate nutrient loads and their abatement costs for different soil types. The approach was seen convenient in combining the strengths of detailed bottom-up-based environmental analysis with the opportunities of aggregate top-down-based policy descriptions and economic modelling of agricultural production. However, the econometric sector level model used was not considered appropriate in evaluating effects of relatively large changes in prices or policy. The farm-level models based on statistical databases were static in the sense that no long-term adjustment mechanisms, like technology-inducing effects of price changes, or potential for cost-saving in the longer run, were modelled.

The Dynamic Regional Sector Model of Finnish Agriculture simulates economically rational production decisions, and is used to evaluate the likely impact of agricultural policy change on agricultural production. In this model, the most important production lines and production areas are connected through prices and resources—most importantly, agricultural land. Changes in agricultural policy influence relative profitability between agricultural products. Rational economic behaviour gradually drives use of inputs and production to the products and areas in which the production is relatively most profitable. Concerning variable factors of production, all this is a common feature in many agricultural sector models.

What is not a common feature in agricultural sector models is that agricultural investments are modelled explicitly in DREMFIA. Investments in new production techniques have wide ranging consequences in the medium- and long-term by affecting technical and structural change in agriculture and accumulation of knowledge and skills of farmers. Such effects of agricultural policy changes have been little analysed in economic literature. For example, the proceedings of 65th European Association of Agricultural Economists (EAAE) seminar in 2000 (Heckelei et al., 2001) include few explicit examples of modelling agricultural investment and technical change on sector level, or applying such schemes in policy analysis. Also the impact analyses of the Mid-Term Review (MTR) proposals of the European Commission[1] do not report effects on investments and technical change. The primary focus of the impact analyses seems to be short- or medium-term (up to 2009) impacts on agricultural production and income at the EU level. No structural or technical change is assumed in those analyses where production resources are assumed as given.

When evaluating environmental effects of agricultural policies, both regional and dynamic aspects are relevant. The regional dimension is vital in any deeper analysis of environmental effects which are often regionally specific and varying. Dynamics is important because of technical and structural change, and because of re-allocation of production between regions over time.

Two catchments, which vary in their location and characteristics but represent two rather typical agricultural production regions in Finland, have been selected for this study. Production in both areas is influenced by production in other areas in Finland because of the balance between total supply and demand. Our purpose is to show how integration of dynamic economic and environmental modelling can be carried out in practice, and to discuss some of the challenges.

2. Methods

2.1. The sector model

DREMFIA is a dynamic recursive model and includes 17 production regions. The model provides effects of various agricultural policies on land use, animal production, farm investments and farmers' income. The model consists of two major parts: (1) a technology diffusion model which determines sector level investments in different production technologies, and (2) an optimisation routine which simulates annual production decisions (within the limits of fixed factors) and price changes, i.e., supply and demand reactions, by maximising producer and consumer surpluses subject to regional product balance and resource (land and capital) constraints (cf. Fig. A1 in Appendix A).

In the DREMFIA model, annual land use and production decisions from 1995 to 2020 are simulated by an optimisation model which maximises producer and consumer surplus subject to regional product balance and resource (land) constraints. Products and intermediate products may be transported between the regions. The optimisation model is a typical spatial price equilibrium model (see e.g. Cox and Chavas, 2001), except that no explicit supply functions are specified (i.e., supply is a primal specification). Furthermore, foreign trade activities are included in DREMFIA. The Armington assumption (Armington, 1969), which is a common feature in international agricultural trade models but less common in one-country sector models, is used. Imported and domestic products are imperfect substitutes, i.e., endogenous prices of domestic and imported products are dependent. There are 18 different processed milk products and their regional processing activities in the model.

Four main areas are included in the model: Southern Finland, Central Finland, Ostrobothnia (the western part of Finland), and Northern Finland. Production in these areas is further divided into sub-regions on the basis of the support areas. In total, there are 17 different production regions. This allows a regionally disaggregated description of policy measures and production technology. The final and intermediate products move between the main areas at certain transportation costs.

Technical change and investments, which imply evolution of farm size distribution, are modelled as a process of technology diffusion. Investments are dependent on economic conditions such as interest rates, prices, support, production quotas and other policy measures and regulations imposed on farmers. The model of technology diffusion follows the main lines of Soete and Turner (1984).

Two crucial aspects about diffusion and adaptation behaviour are included: first, the profitability of a new technique, and second, the risk and uncertainty involved in adopting a new technique. The information about and likelihood of adoption of a new technique will increase as its use becomes widespread.

To cover the first aspect, the likelihood of adoption of a new technique ($f_{\beta\alpha}$) is made proportional to the fractional rate of profit increase in moving from technique α to technique β, i.e., $f_{\beta\alpha}$ is proportional to $(r_\beta - r_\alpha)/r_\alpha$, where r_α is the rate of return for technique α and r_β is the rate of return for technique β. The second aspect is modelled by letting $f_{\beta\alpha}$ be proportional to the ratio of the capital stock in β technique (K_β) to the total capital stock K (in a certain agricultural production line), i.e., K_β/K. The total investments to α technique, after simplification, is where

$$I_\alpha = \sigma(Q_\alpha - wL_\alpha) + \eta(r_\alpha - r)K_\alpha \tag{1}$$

σ is the savings rate (proportion of economic surplus re-invested in agriculture), η is the farmers' propensity to invest in alternative techniques, Q_α is

[1] http://europa.eu.int/comm/agriculture/publi/reports/mtrimpact/rep_en.pdf, http://europa.eu.int/comm/agriculture/publi/reports/reformimpact/rep_en.pdf

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