Evaluating greening farm policy:

a structural model of agri-environmental subsidies

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Abstract

A quarter of the European Union utilized agricultural area is enrolled in agri-environmental programs. Despite the prevalence of the programs and increasing demand for environmental quality in the European Union, ex-post assessments of program benefits are rare. This study uses a structural econometric model to evaluate impacts of agri-environmental support through the Finnish Agri-Environmental Program. The program's primary goal has been to reduce agriculturally-produced nutrient pollution, and it is considered the primary solution to Finland's substantive surface water quality problem. We quantify the effects of agri-environmental payments on farmers' decisions on the allocation of land to grain production and grassland and on the intensity of fertilizer use over the period 1996-2005, drawing on a representative sample of individual grain farms. Identification of the effect of agri-environmental payments on production decisions is based on variation in payment rates across regions and over time. We then combine the predicted fertilizer use and land allocation with environmental production functions to quantify the impact of agri-environmental payments on nutrient loading. Finally, we assess the monetary value of reduced nutrient pollution drawing on a valuation study evaluating the benefits of reducing nutrient loading from Finland to the Baltic Sea. Results suggest that agri-environmental subsidies reduced the damage from nutrient loading from grain production by 11 to 12 percent. The benefits in terms of reduced nutrient pollution are approximately on par with the costs of program payments.

Keywords: agri-environmental programs, Common Agricultural Policy, farm subsidies, policy evaluation, nutrient pollution, eutrophication, panel data, cost-benefit analysis.

1. Introduction

The European Union (EU) agri-environmental regulation, introduced as part of the 1992 reform of the Common Agricultural Policy (CAP), mandated the member states to submit national agri-environmental programs. The programs are supposed to encourage farmers to produce non-market benefits of agriculture and to reduce agriculturally-produced pollution. While the policy changes reflected the increasing demand for environmental quality, other driving factors were the need to reduce EU agricultural overproduction, and demands from the World Trade Organization for a reduction in trade-distorting measures (Hanley and Oglethorpe 1999, Buller, Wilson and Höll 2000b, Baylis et al. 2011). The design of the national programs was left up to the member states. By 1997, more than 130 different programs had been approved (Buller 2000). By 2002, 25% of the European Union (EU15) utilized agricultural area was enrolled in the agri-environmental programs (AEPs) and annual EU budget spending on the AEPs was on the order of 2 000 million euros (CEC 2005).

At the level of the individual farmer participation in the AEPs is voluntary. Incentives are provided through program payments, but the requirements for participating farms tend to be quite general in nature. Payments are conditioned on environmentally benign practices - such as farm-scale environmental planning and monitoring, maintaining biodiversity, and farmer training - rather than on measurable outcomes. Participating farms thus have significant flexibility in choosing actions to address the environmental impacts of agricultural production, and the administrative burden remains moderate. Differing from prominent conservation programs in the United States, such as the Conservation Reserve Program, the EU AEPs generally aim at supporting environmentally friendly production practices on working lands, rather than land retirement.

Little is known about whether participation in the EU AEPs actually improves farms' environmental performance. While the evaluation of the AEPs is mandatory for the member states, rigorous empirical studies on program impacts are rare.[1] To our knowledge Pufahl and Weiss (2009) and

[1] There is substantial ecological literature which investigates AEP impacts. While not an exhaustive list, examples on European programs include Ekholm et al. (2007) on Finland, Marggraf (2003) on German constituent states, and Primdahl et al. (2003) on nine EU Member States and Switzerland. The ecological literature focuses on trends in environmental indicators or the effect that the stated goals, in terms of changes in agricultural practices, would have on the environment. However, a multitude of factors influences farming practices, of which agri-environmental policy

Chabé-Ferret and Subervie (2012) are the only econometric analyses explicitly addressing the effects of EU AEPs on observed farm production decisions. Di Falco and Rensburg (2008) also touch on AEPs in their analysis of factors that influence the behavior of commonage farmers, in that they evaluate the impact of agri-environmental support on cooperation and conservation.

The limited knowledge on EU AEP impacts is significant for two reasons. First, from an environmental policy perspective, it is important to study whether the agri-environmental programs actually fulfill their promise as environmental policy measures and reduce the environmental damage from agriculture, or enhance the positive effects thereof, over and above what would have happened otherwise. Second, from a trade policy perspective, the willingness to compensate farmers for non-market production activities has led to considerable contention against and between the EU and the US in the stalling Doha Round of trade liberalization talks (CRS 2007, Baylis et al. 2011). Closer to the beginning of the Doha Round, the OECD noted: "A key policy concern is to distinguish between agri-environmental measures that actually address market failures by internalizing environmental externalities or ensuring the provision of public goods associated with agriculture, from policies that appear to be merely labeled "green" and used as a means of disguised protection" (OECD 2003).

To help shed light on these issues, the present paper analyzes Finland's interpretation of the EU agri-environmental mandate, the Finnish Agri-Environmental Program (FAEP). The program is nationwide and the only AEP in Finland. Its main focus is on reducing nutrient runoff from agricultural land and it is considered the primary solution to Finland's substantive agriculturally-produced surface water pollution problem. The FAEP is among the most extensive within the EU, with 90% of all Finland's farms and 92% of the arable area participating in the program (Aakkula et al. 2010).[2] Finnish authorities refer to the high participation rate as a measure of program effectiveness. However, participation rates relate to promised rather than realized changes in management practices; they may merely reflect payment rates that are attractive relative to the

is only one. It is therefore difficult to disentangle the effect of an AEP from other factors such as input and output prices and other agricultural support policies.

[2] Accounts of AEPs in several EU countries may be found for example in Whitby (1996) and Buller et al. (2000). The member states and regional authorities have significant liberty in designing specific AEPs. Some of the programs apply to a large area (often the total utilized agricultural area of the country), which is the case in Finland. Others target either a specific zone or specific types of farming. Baylis et al. (2011) and Baylis et al. (2004) provide comparisons of EU and US AEPs.

costs of meeting program requirements, and thus have a weak relation to actual environmental improvements (see e.g. Hanley and Oglethorpe 1999). Albeit developed in the context of corporate environmental management and therefore not directly applicable to mostly family-operated farm enterprises, the considerable literature on voluntary environmental programs certainly raises questions about whether loosely defined, voluntary AEPs are likely to have environmental benefits (see e.g. Koehler 2007 for a recent review and Darnall and Sides 2008 for a meta-analysis).

To evaluate how crop producers respond to the FAEP, we analyze a data set on individual grain farms in Finland over the period 1996-2005. We estimate a normalized quadratic profit function and the corresponding input demands and land allocation with output and input prices, total land and compensatory payments (agri-environmental and other subsidies) as explanatory variables. We exploit variation in compensatory payment rates across support regions and over time to identify the impact of the payments on production decisions. We are particularly interested in identifying the impact of FAEP payments on the use of nutrient inputs and the allocation of land to grain production and set-aside (grassland). These variables are key determinants of agriculturally-produced surface water pollution. To assess the impact of the FAEP payments on agriculturally-based water pollution on our sample, we use the estimated input demand and land allocation functions to predict farms' fertilizer intensity and land allocation under two scenarios, a "factual" one where program payments are set to their historical values, and a counterfactual one where agri-environmental payments are set to zero. We then combine the predicted fertilizer intensity and land allocation with environmental production functions to predict nutrient runoff. Comparison of the outcomes under the "factual" baseline and the counterfactual allows identifying the effect of the agri-environmental payments. Finally, relying on a valuation study measuring the willingness to pay for reducing nutrient loads from Finland to the Baltic Sea, we compute the monetary value of FAEP environmental benefits on our sample and compare them to the agri-environmental payments.

Pufahl and Weiss (2009) evaluate the effect of German AEPs on farms' input use, including land allocation and agrichemicals, and output produced. The authors use panel data and apply a difference-in-difference propensity score matching approach. The analysis reveals that AEP participation increases both the area in cultivation and grassland, and decreases the use of agrichemicals. Chabé-Ferret and Subervie (2012) estimate the additional and windfall effects of five agri-environmental schemes in France. The authors analyze a sample of individual farms, with data recorded prior to and five years after the onset of the schemes, also applying difference-in-difference matching. They then incorporate the estimated additional and windfall effects into a cost-benefit framework and find that the schemes promoting crop diversity and cover crops have had modest success, whereas the schemes subsidizing grass buffer strips and organic farming may well be socially efficient in light of a tentative cost-benefit analysis. Di Falco and Rensburg (2008) analyze the behavior of farmers operating on land held under common property in Ireland. The authors use a recursive bivariate probit model and include AEP payments as a variable predicting farmers' cooperation and conservation effort. They find that AEP payments enhance cooperation and conservation. Finally, the benefits that AEPs are designed to deliver have received significant attention in the United Kingdom. Hanley, Whitby and Simpson (1999) summarize the results from a number of studies estimating the monetary value of AEP environmental benefits. While these studies do not address the question of whether environmental benefits are delivered in reality, they provide interesting information that could be used in conjunction with econometric models of program impacts, in order to evaluate the social welfare impacts of AEPs in a cost-benefit framework.

The US also has numerous agri-environmental programs which pay farmers for retiring environmentally sensitive agricultural land (such as the Conservation Reserve Program and the Wetlands Reserve Program) or for adopting environmentally friendly production practices (such as the Environmental Quality Incentive Program). The production and environmental impacts of agri-environmental payments in the US have been addressed for example in Wu et al. (2004), a paper close to the present work in terms of the modeling approach. Wu et al. analyze a set of micro-level discrete choice models predicting farms' land allocation and tillage decisions, and link these decisions with environmental production functions to predict the impact of conservation payments on nitrate runoff and leaching and on water and wind erosion. While they find that payments for conservation practices increase the use of these practices, the overall environmental benefits are small. Goodwin and Smith (2003) use county-level data to estimate a system of equations where soil erosion, Conservation Reserve Program (CRP) participation, crop insurance participation, conservation effort and fertilizer use are the endogenous variables. Their results suggest that the CRP has been effective in reducing erosion, but that part of the reduction has been offset by other income support programs.

This analysis complements the empirical literature on the impacts of the EU AEPs on agricultural input use beginning with Pufahl and Weiss (2009) and Chabé-Ferret and Subervie (2012). The structural approach taken here is different from the treatment effect approach in Pufahl and Weiss and Chabé-Ferret and Subervie in that we explicitly model farms' production decisions and link them with environmental production functions. The approach enables making consistent predictions of production choices and environmental outcomes, which can serve both to evaluate the impact of present AEP payments and to forecast the impacts of alternative policy interventions, such as taxes on polluting inputs. In this sense our approach is similar to the one adopted by Wu et al. (2004). Of course, the choice of methodology is also dictated by the policy to be evaluated. As participation in the FAEP is almost universal, the treatment effect approach – which requires a "treatment group" of participants and a "comparison group" of non-participants – is not applicable. The structural approach in contrast can evaluate policies with universal participation by using functional form and support conditions to substitute for the lack of comparison group (see e.g. Heckman and Vytlacil 2005, Heckman 2010). An advantage of explicitly modeling farms' input demands and land allocation is that linking the estimated model with environmental production functions lends itself to relatively precise cost-benefit analysis: one can predict the impact of program payments on measurable environmental outcomes – reductions in nutrient runoffs – with counterparts in valuation studies.

Furthermore, we examine an AEP setting that is very different from the German and French systems analyzed by Pufahl and Weiss (2009) and Chabé-Ferret and Subervie (2012), respectively. Finland has one nationwide AEP. Germany has implemented AEPs at both national and constituent state level, and more than 100 different agri-environmental schemes are available within the framework. The share of agricultural land managed under AEPs in Germany in contrast is markedly smaller than in Finland, ranging from 20 to 50% across the constituent states (Pufahl and Weiss 2009). France has implemented numerous nationwide agri-environmental schemes, with some adjustments at the regional level. The requirements for farms entering a scheme are more detailed than in the Finnish AEP, and the area covered by AEPs smaller than in other European countries, with agri-environmental support amounting to some 25% of rural development spending as opposed to the 37% EU average (Chabé-Ferret and Subervie 2012). The present study provides a complementary analysis of AEP impacts. Our findings support the idea that AEPs provide environmental benefits through reducing fertilizer use. However, we also find evidence that the payments through the FAEP increased areas in grain production at the expense of grassland.

2. Background

Agriculturally-produced water pollution, in particular nutrient enrichment of surface waters, is viewed as a major environmental issue in Finland. The adjacent Baltic Sea suffers from severe nutrient-related water quality degradation, with intensive agriculture the largest nutrient source (e.g. Helcom 2010). Since Finland's geography is characterized by numerous lakes, agricultural chemicals are easily transported into the environment – drainage waters from some 90% of agricultural land flow to lakes or rivers, and a large proportion of agriculturally-sourced nutrients eventually enters the Baltic Sea (Puustinen et al. 1994, Lepistö et al. 2006). Launched upon Finland's accession in the EU in 1995, the FAEP emphasizes pollution control, although measures targeting biodiversity and landscape protection are also included. The first two program periods (1995-1999 and 2000-2006) targeted a 30-40% reduction in agriculturally-produced nutrient loads relative to the loads in the early 1990's (MAF 2000). However, monitoring data do not indicate significant reduction in nutrient loading or improvement in water quality (Ekholm et al. 2007).

The Finnish agri-environmental program allows all land, not just environmentally sensitive land, to receive payments to support environmentally beneficial farming practices. The program is divided into general and special sub-programs. Farms participating in the general sub-program sign renewable five-year contracts wherein they agree to follow a set of mandatory environmental protection measures, identical across farms within a production line. For grain production, the mandatory measures include limits on fertilizer use and construction of field margins and filter strips along waterways. In southern Finland farms are also required to choose one additional measure, such as stricter constraints on fertilization use, promotion of biodiversity, or wintertime vegetation on part of the arable area (a mandatory measure in southern Finland in the first program period 1995-1999). In northern Finland the additional measures are all optional. The general scheme also lists a number of mandatory, albeit loosely defined environmentally beneficial practices.[3] Farms participating in the general sub-program are compensated through an area-based payment. The overall general sub-program participation rate was 84% in 1995-1999 and 90% in 2000-2006 (MMM 2004). The special sub-program targets more specific environmental management measures, such as establishment and management of riparian zones or wetlands. Farms opting to join the special sub-program sign a five to ten year contract, for which participation in the general sub-program is a prerequisite. Financial support for most of the special sub-program measures is tailored to cover the investment and management costs as estimated by the farm, up to a support ceiling set by the EU. Other production aid available to grain farms includes CAP arable area and less favored areas payments, and national aid to crop production.

Approximately 5% of participating farms are audited each year. The audit focuses on farms' compliance with the program requirements rather than on environmental outcomes. Nearly 40% of the farms randomly selected for audit in 2006 received a complaint or sanction for non-compliance (NAOF 2008).[4] Sanctions are cuts in the current year's program payments, up to 30% for the general sub-program and up to 100% for the special sub-program. Violations of the limits on fertilizer application, for example, result in at most a 9% cut in the current year's program payments (ARA 2011). Nitrogen fertilization rates for the sample of grain farms included in our empirical analysis also reflect weak enforcement of the FAEP input constraints. The proportion of farms that receive agri-environmental payments and appear to have violated the constraint on nitrogen application ranges from 33 to 61% over the study period.[5]

3. Farmers' behavioral model

Our goal is to assess the impact of FAEP payments on agriculturally-produced nutrient pollution on a representative sample of Finnish grain farms participating in the FAEP general sub-program. As almost all farms in the original sample (98%) participate in the general sub-program, we are not able to estimate the factors affecting program participation, or measure program impact through

[3] These include farmer training, farm environmental planning and monitoring, environmentally sound use of plant protection products, maintenance of biodiversity, and landscape management.
[4] Of the total number of audited farms 75% are chosen through risk-based sampling and 25% through random sampling.
[5] Nitrogen fertilization rates for each year have been computed by dividing fertilizer expenditure by fertilizer price, under the assumption that farms use the compound fertilizer typically used in grain production in Finland (20% nitrogen content). Such rates are an approximation of the true application each year, also in that fertilizers can be stored, and thus inputs purchased in a given year have not necessarily been applied that year.

comparing the performance of participants with that of matched non-participants, as for example Pufahl and Weiss (2009) and Chabé-Ferret and Subervie (2012) have done. Instead, we adopt the following structural approach: we first estimate a system of equations including farms' profit function, input choices and land allocation, and then use the estimated land allocation and input demands to simulate a counterfactual no-policy scenario where the agri-environmental subsidies are removed from the set of agricultural support payments. We focus on agriculturally-produced nutrient pollution, the main environmental issue pertaining to agriculture in Finland. In order to determine the impact of the FAEP payments on farms' production decisions, we compare the predicted land allocation and input demands under the counterfactual no-policy scenario to those under a "factual" scenario, predicted with the FAEP payments present.

The agricultural support payment rates are graded over seven support regions that were delineated at the time of Finland's EU accession in 1995 and reflect regional climatic conditions. We focus on the four southernmost regions (labeled A to C2), Finland's grain production area (see Figure 1). The variation in compensatory payment rates across support regions and over time allows us to identify the impact of the subsidies on production decisions. Variation in the payment rates across regions arises for several reasons: support to crop production is determined on the basis of historical reference yields; general agri-environmental support is calculated based on the regional average costs of implementing the required changes in farming practices; southern Finland was initially not eligible for EU less favored areas support (the support was extended to all of Finland in 2000); and at the time of accession Finland bargained for the right to pay additional northern aid to areas north of the 62 parallel north. Part of the northern aid is paid in conjunction with the agri-environmental support. Changes in payment rates over time have also been asymmetric across support regions.[6]

[6] The asymmetries arise from renegotiations with the EU on which parts of Finland are eligible for less favored areas support, from transitional support only payable through the first years in the EU and gradually phased out, and national payments in Southern Finland that have been renegotiated with the Commission every few years.

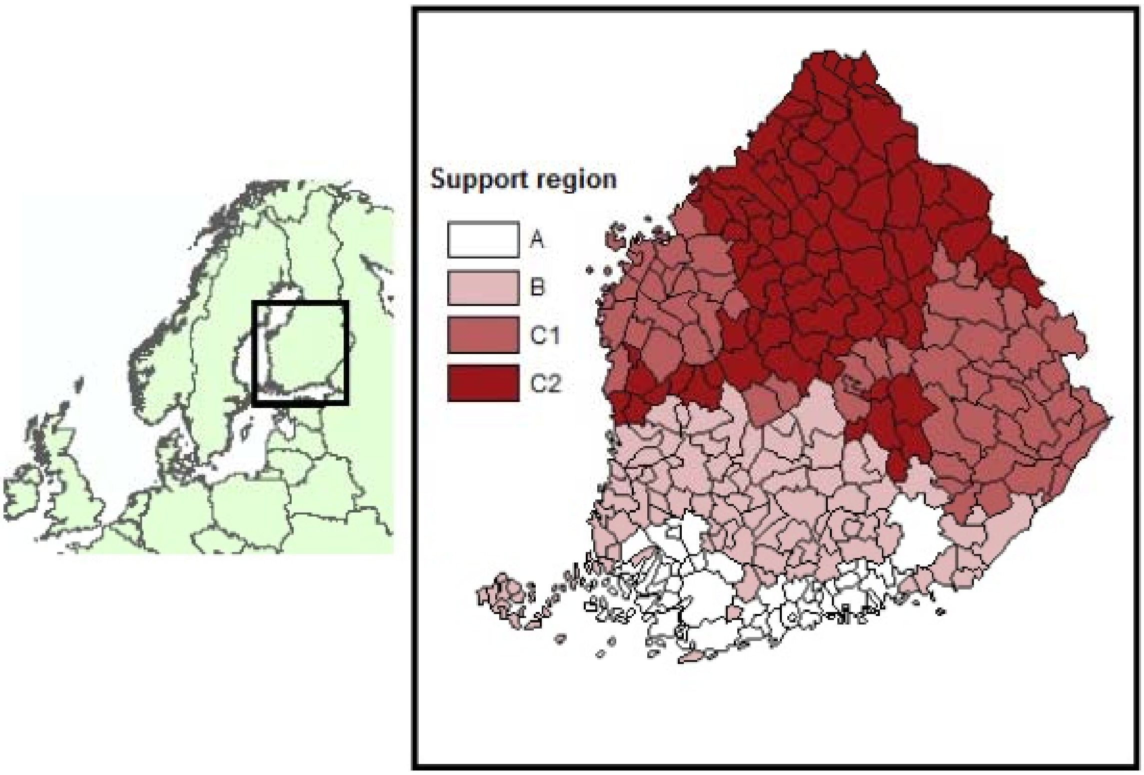

Figure 1. Study area and delineation of agricultural support regions within the study area

3.1. Profit function, land use and input demand

Farms maximize total profits over a set of crops. We assume that they consider input and output prices and proportional to land-area agricultural support payment rates as exogenous (including general agri-environmental support rates).[7] Finland's overall cereal production amounted to 1-2% of the European Union cereal production in years 1997-2007 (Eurostat), so price feedbacks are likely to be minor. Support payment rates are determined in negotiations between Finland and the EU and are based on historical yields, regional average costs of agri-environmental measures, and geographic location. In the estimation stage we control for province and farm fixed effects, possibly correlated with the historical reference yields and average costs. We assume that the remaining variation in the payment rates is exogenous.

[7] Based on the results in Koundouri et al. (2009), we assume that farmers are risk-neutral. Using the same profitability bookkeeping data as the present study over the years 1992-2003, Koundouri et al. (2009) found evidence that farmers were risk-averse prior to Finland's accession in the European Union in 1995 and risk-loving after the accession, due to the increase in the non-random part of farm income brought along by the introduction of the Common Agricultural Policy. For the period 1995-2003, Koundouri et al. estimated the risk premium to be between -2 and 2 percent of farm profit. Given the small magnitude of the risk premium, we consider the assumption of risk-neutrality over the 1996-2005 period a reasonable approximation.

The farms in the sample produce grain crops (barley, wheat, oats and rye), which are similar in terms of agricultural support payment rates, use of agri-chemicals, and environmental impacts. In Finnish conditions grains also have similar nutrient loading potential, and they are typically grouped together in land use analyses (see e.g. Helin et al. 2006 and Ekholm et al. 2007). Thus, for simplicity, we aggregate across the grains in the analysis to follow. Farms may also keep land uncultivated as set-aside, which receives lower support payments and produces lower nutrient losses than land in grain production.

A farm engaged in grain production decides how to allocate land to grains and set-aside depending on their relative profitability. Once this decision is taken, the farm determines the profit-maximizing output level. By assumption, a farm considers only the private net benefits of farming, ignoring any environmental impacts. Grains and set-aside are both entitled to positive subsidy payments, proportional to land area, that include the CAP arable area and less favored areas subsidies as well as Finnish national subsidies to crop-production. Farms participating in the FAEP receive additional environmental subsidies, also proportional to land area. Further, farms participating in the special sub-program within the FAEP earn special subsidy payments that are in general based on the land area under a specific agri-environmental measure, such as riparian zone or wetland.

Let *L* denote total land area of the farm, l_g the land allocated to grains, l_f set-aside, s_g and s_f per hectare subsidy rates for grains and for set-aside, p_g grain price, q_g per hectare grain yield, w_k the *k*th component of the input vector, r_k the corresponding input price, s_e the special agri-environmental subsidy rate, and l_e the land area under special environmental protection measures, which takes on a positive value only for farms that have signed contracts for undertaking special environmental protection measures.[8] Farm profit is given by

$$\Pi = l_g \left[p_g q_g + s_g \right] + l_f s_f - \sum_{k=1}^{K} r_k w_k + l_e s_e . \qquad (1)$$

[8] The data used in the analysis report special environmental subsidies received by each farm, but not the special environmental protection measures adopted.

The representative farm is assumed to maximize profits taking as given the total land area *L*, the output price p_g, the vector of subsidy rates $\mathbf{s}$, and the vector of input prices $\mathbf{r}$. Maximizing the profit function yields optimal land allocation, input and output decisions $l_g(\mathbf{p},\mathbf{r},\mathbf{s})$, $l_f(\mathbf{p},\mathbf{r},\mathbf{s})$, $l_e(\mathbf{p},\mathbf{r},\mathbf{s})$, $w_k(\mathbf{p},\mathbf{r},\mathbf{s})$ and $q_g(\mathbf{p},\mathbf{r},\mathbf{s})$. While the FAEP imposes limits on fertilizer use, we assume that farms do not consider this limit as a constraint in their input decision. In light of the relatively high non-compliance rates within our sample and the fact that audits also frequently reveal non-compliance, we think that the assumption is in line with observed farm behavior.

A well-behaved profit function must satisfy the following regularity conditions: homogeneity of degree one in prices, convexity in prices, monotonicity, and symmetry. The assumption of a given total land area imposes an additional land adding-up condition:

$$l_g + l_f + l_e = L \Leftrightarrow \frac{\partial l_g}{\partial p_g} + \frac{\partial l_f}{\partial p_g} + \frac{\partial l_e}{\partial p_g} = \frac{\partial l_g}{\partial s_j} + \frac{\partial l_f}{\partial s_j} + \frac{\partial l_e}{\partial s_j} = \frac{\partial l_g}{\partial r_k} + \frac{\partial l_f}{\partial r_k} + \frac{\partial l_e}{\partial r_k} = 0 \quad \forall\, k,\ \forall\, j\ , \tag{2}$$

$$\frac{\partial l_g}{\partial L} + \frac{\partial l_f}{\partial L} + \frac{\partial l_e}{\partial L} = 1, \tag{3}$$

where s_j denotes the *j*th component of the subsidy vector.

3.2. Model specification

We specify a quadratic profit function written as a function of the exogenous variables p_g, $\mathbf{s}$, and $\mathbf{r}$. The quadratic form provides a flexible approximation of the true profit function. We normalize the profit function by dividing the profit, prices, and subsidies by the price of one input, labor. Conditions (2) and (3) as well as homogeneity of profit with respect to prices are then easily imposed. The quadratic profit function is

$$\overline{\Pi} = \beta_0 + \beta_g^p \overline{p}_g + \sum_{j=1}^{J} \beta_j^s \overline{s}_j + \sum_{k=1}^{K-1} \beta_k^r \overline{r}_k + \sum_{k=1}^{K-1} \beta_k^{pr} \overline{p}_g \overline{r}_k + \sum_{j=1}^{J} \sum_{k=1}^{K-1} \beta_{jk}^{sr} \overline{s}_j \overline{r}_k$$
$$+ \frac{1}{2} \beta_{gg}^{pp} \overline{p}_g^2 + \frac{1}{2} \sum_{j=1}^{J} \sum_{j'=1}^{J} \beta_{jj'}^{ss} \overline{s}_j \overline{s}_{j'} + \frac{1}{2} \sum_{j=1}^{J} \beta_{gj}^{ps} \overline{p}_g \overline{s}_j + \frac{1}{2} \sum_{k=1}^{K-1} \sum_{k=1}^{K-1} \beta_{kk'}^{rr} \overline{r}_k \overline{r}_{k'} \quad (4)$$
$$+ \gamma_g^p \overline{p}_g L + \sum_{j=1}^{J} \gamma_j^s \overline{s}_j L + \sum_{k=1}^{K-1} \gamma_k^r \overline{r}_k L,$$

where *J* indexes the subsidy rates (for grains, set-aside, and special agri-environmental measures) and *K* the inputs (fertilizers, plant protection products, labor), and the upper bar indicates normalized profit, price and subsidy variables. That is, $\overline{\Pi} = \Pi / r_K$, $\overline{p}_g = p_g / r_K$, $\overline{s}_j = s_j / r_K$, $\overline{r}_k = r_k / r_K$, where r_K is the price of the numeraire, here labor.

Differentiating the profit function with respect to prices and per hectare subsidy rates yields

$$l_g q_g = \frac{\partial \Pi}{\partial \overline{p}_g} = \beta_g^p + \sum_{k=1}^{K-1} \beta_k^{pr} \overline{r}_k + \beta_{gg}^{pp} \overline{p}_g + \sum_{j=1}^{J} \beta_{gj}^{ps} \overline{s}_j + \gamma_g^p L \, , \quad (5)$$

where $l_g q_g$ is the total grain output;

$$l_j = \frac{\partial \Pi}{\partial \overline{s}_j} = \beta_j^s + \sum_{k=1}^{K-1} \beta_{jk}^{sr} \overline{r}_k + \sum_{j'=1}^{J} \beta_{jj'}^{ss} \overline{s}_{j'} + \beta_{gj}^{ps} \overline{p}_g + \gamma_j^s L \, , \quad J = \text{(grains, set-aside)}; \quad (6)$$

where l_g and l_s are land allocated to grains and set-aside, respectively; and

$$-w_k = \frac{\partial \Pi}{\partial \overline{r}_k} = \beta_k^r + \beta_k^{pr} \overline{p}_g + \sum_{j=1}^{J} \beta_{jk}^{sr} \overline{s}_j + \sum_{k'=1}^{K-1} \beta_{kk'}^{rr} \overline{r}_{k'} + \gamma_k^r L, \quad K = 1, \ldots, K-1; \quad (7)$$

where w_f and w_{pp} represent input demand in fertilizers and plant protection, respectively.

We are only able to estimate land allocation equations for grains (l_g) and set-aside (l_f) since our data do not state the land area under special agri-environmental protection measures (l_e) but only the total amount of special agri-environmental subsidies received ($l_e s_e$). The estimation stage controls for the fact that some farms receive the special agri-environmental subsidy as well as for the amount received, and for the implications of the payments for farms' input use, land allocation, and grain yield (selection bias).

The elasticities of output, inputs, and grain and set-aside areas with respect to any price or subsidy rate can be recovered easily from equations (5) to (7). They are computed by multiplying the corresponding parameter (coefficient of price or subsidy rate in the land or output equation) by the ratio of the normalized price (or subsidy rate) and land area, output or input level. For example, the elasticity of grain area with respect to the (normalized) price of grain, ε_{l_g,p_g}, is calculated as follows:

$$\varepsilon_{l_g,p_g} = \beta_{gg}^{ps} \times \left(\frac{\overline{p}_g}{l_g} \right). \tag{8}$$

From equations (6), the land adding up condition (2) implies the following parameter constraints:

$$\begin{aligned} &\sum_{J=1}^{J} \beta_{jk}^{sr} = \sum_{j=1}^{J} \beta_{jj'}^{ss} = \sum_{j=1}^{J} \beta_{gj}^{ps} = 0 \quad \forall k,\ \forall j'; \\ &\sum_{j=1}^{J} \gamma_j^s = 1. \end{aligned} \tag{9}$$

A further constraint is imposed by the CAP mandatory set-aside mechanism, which requires farms to leave a proportion of land uncultivated each year.[9] Small farms are exempt from the requirement. The set-aside subsidy is only paid to set-aside area exceeding the mandatory area. To deal with the presence of voluntary and mandatory set-aside, we proceed as follows: if a farm's observed set-aside area exceeds the CAP requirement, we treat the difference as voluntary set-aside and include it in the land set-aside equation. If the observed set-aside is less than the CAP requirement, we assume that the farm is exempt, and the entire set-aside area is voluntary. Finally, if the reported set-aside area equals the CAP requirement, we assume that there is no voluntary set-aside, and assign value zero to set-aside in the land allocation equation.

Land allocation and output are also influenced by factors that are unobserved to the analyst. These factors can be either period specific (e.g. weather, pests) or farm specific (e.g. soil quality, farmer skills) (Wu et al 2004, Lacroix and Thomas 2011). Using panel data allows us to partly compensate for the lack of farm level soil and weather information, and facilitates the control of unobserved individual heterogeneity.

[9] Set-aside was compulsory for farms receiving EU CAP arable area payments in 1992-2007. The requirement was initially set at 15% of total land, then altered between 5% and 10% from 1996 on. As a rule vegetation cover must be maintained on set-aside and the use of fertilizers is not permitted.

3.3. Estimation methodology

We estimate the profit function simultaneously with the demand functions (derived from the profit function) for fertilizers and plant protection products (labor is the numeraire), the equations for land allocated to grains and set-aside, and total grain output, under the constraints implied by the land-adding up conditions (equations 9). The system of equations for farm *i* in year *t* is written as follows:

$$\begin{cases} \Pi_{it} = g_1\left(\overline{p_g}, \overline{\mathbf{s_j}}, \overline{\mathbf{r_k}}, L; \boldsymbol{\beta}_1\right) + \mu_{1i} + u_{1,it} \\ l_{g,it} = g_2\left(\overline{p_g}, \overline{\mathbf{s_j}}, \overline{\mathbf{r_k}}, L; \boldsymbol{\beta}_2\right) + \mu_{2i} + u_{2,it} \\ l_{f,it} = g_3\left(\overline{p_g}, \overline{\mathbf{s_j}}, \overline{\mathbf{r_k}}, L; \boldsymbol{\beta}_3\right) + \mu_{3i} + u_{3,it} \\ l_q q_{it} = g_4\left(\overline{p_g}, \overline{\mathbf{s_j}}, \overline{\mathbf{r_k}}, L; \boldsymbol{\beta}_4\right) + \mu_{4i} + u_{4,it} \\ w_{f,it} = g_5\left(\overline{p_g}, \overline{\mathbf{s_j}}, \overline{\mathbf{r_k}}, L; \boldsymbol{\beta}_5\right) + \mu_{5i} + u_{5,it} \\ w_{pp,it} = g_6\left(\overline{p_g}, \overline{\mathbf{s_j}}, \overline{\mathbf{r_k}}, L; \boldsymbol{\beta}_6\right) + \mu_{6i} + u_{6,it} \end{cases} \quad (10)$$

The exogenous explanatory variables are the output price p_g, the vector of subsidy rates $\mathbf{s}$ (CAP arable area and less favored areas subsidies, Finnish national crop production subsidy, and basic environmental subsidy), the vector of input prices $\mathbf{r}$, and total land *L*. All prices and subsidies are normalized by the price of labor. As described in the previous section, the function $g_1(.)$ is quadratic in all parameters, while the functions $g_2(.)$ to $g_6(.)$ are linear. The terms μ_{1i} to μ_{6i} represent farm-specific unobserved effects and are assumed to be fixed parameters. The terms $u_{1,it}$ to $u_{6,it}$ are idiosyncratic error terms, possibly correlated across equations, and by assumption of mean zero.

Three main econometric issues have to be dealt with: i) some farms do not have any land in voluntary set-aside (i.e., $l_{f,it} = 0$), ii) a subset of farms receives the special agri-environmental subsidy, iii) the farm-specific effects (μ_{1i} to μ_{6i}) could be correlated with some explanatory variables.

In order to deal with the problem of corner solutions for set-aside land, we follow the approach by Shonkwiler and Yen (1999). For about 13% of observations in our sample, voluntary set-aside (l_f) is equal to zero. The Shonkwiler and Yen approach, which allows estimating a system of equations when some of the dependent variables are censored, involves working with the non-conditional expectation of the censored variables. Details are provided in Appendix 1.

The special agri-environmental subsidy is received only by the farms that agreed to undertake some specific environmental protection measures. We only observe the total amount of the special agri-environmental subsidies, not the type of measures adopted or the area under these measures. Because our primary purpose is to analyze the impact of the FAEP on farms' production decisions, it is important to control for the fact that some farms receive this subsidy and for the amount received, since these may have direct implications for farms' input use, land allocation, and grain yield. In order to control for possible selection bias due to farms contracting to receive the special environmental subsidy, we run a first-stage random-effects Tobit regression with the amount of the special agri-environmental subsidies received by the farm as the dependent variable. The independent variables in this model are farmer's age, the price of plant protection products, the price of labor, the share of the total land which is rented, the price of grain, the number of animals on the farm, total farm size, and province dummies (our sample covers 17 provinces). The estimation of the Tobit model takes into account the panel form of the data and relies on the assumption that the farm unobserved effects are uncorrelated with the explanatory variables. The predicted amount of the special agri-environmental subsidies obtained from the estimation of the random-effect Tobit model is then incorporated on the right-hand-side of each equation in the system.

In order to control for possible correlation between unobserved farmer-specific effects and some of the explanatory variables when estimating the system of equations, we estimate the model using a Within Seemingly Unrelated Regression (SUR) estimation method (that is, we apply the SUR estimator on the system of equations in which all variables are deviated from their individual means).

4. Data

This study uses farm-level data on physical and financial variables for agricultural production, obtained from bookkeeping records that provide the Finnish data for the European Commission's

Farm Accountancy Data Network (FADN).[10] The records are collected annually following EU accounting guidelines and contain information on crop areas, crop yield, expenditures on fertilizers and plant protection products, work hours, and compensatory payments received, including agri-environmental payments for on the whole approximately 900 farms each year. While the data distinguish payments through the FAEP general and special sub-programs, they do not identify the agri-environmental measures adopted or the area under contract-based special measures. The analysis comprises years 1996-2005, from Finland's second year in the EU to the last year when crop-specific CAP arable area payments were in use.[11] The final sample used in the analysis includes farms that are located in one of the four southernmost support regions, had some land allocated to grain crops, and connected a maximum of 30% of their total variable costs to animal production, altogether 343 farms and 1564 observations (an unbalanced panel).[12]

Full-time farm enterprises tend to be overrepresented in the bookkeeping data, and consequently the average farm size is larger than the national average. This feature is also present in our sample. The patterns of farm size across time and geographic location, however, are similar for our sample and for national data on grain farms. Average farm size has been increasing over the years, and decreases from south to north (from support region A to C2; Tables A2.1 and A2.2 in Appendix 2). In terms of farm geographic location, Southern Finland (EU support regions A and B) is somewhat overrepresented in our sample (Tables A2.3 and A2.4 in Appendix 2). This is likely to be related to farms surveyed for the bookkeeping data being larger on average than Finnish farms on the whole, and the proportion of relative large farms being greater in southern than in more northern parts on the country. Fertilizer purchases in proportion to cultivated land on our sample also show a pattern that is similar to national statistics on total fertilizer sales in proportion to total cultivated land - both nitrogen and phosphorus purchases have decreased over the study period, albeit for phosphorus the decrease has been smaller than the decrease at the national level (Tables A2.5 and A2.6 in Appendix 2).

[10] The bookkeeping records are collected by Finland's FADN Liaison Agency (MTT Agrifood Research Finland). The FADN data are harmonized across EU countries in that the bookkeeping principles are the same.

[11] The bookkeeping data do not have separate entries for agri-environmental support and other compensatory payments in Finland's EU accession year 1995. The EU single farm payment, result of the 2003 CAP reform, was introduced in Finland in 2006. The single farm payment pays farmers for the land that they manage or own, not based on the crops that they produce, as an attempt to decouple agricultural support from production.

[12] The support regions A to C2 are located between the 60th and 65th latitudes and contain 98% of Finland's grain area. In terms of FADN farming type classification, we selected farms operating in lines 1, 2 and 8 (field crops, horticulture, and mixed in FADN8 typology).

The farm data were complemented with average national crop prices collected from MTT Agrifood Research's annual publication Finnish Agriculture and Rural Industries, and with fertilizer and plant protection product price indices (index is 100 in 2005) and labor prices obtained from Statistics Finland (Table A3.1 in Appendix 3). The average hourly wage for forest maintenance work was used as a proxy for labor price as statistics on agricultural wages are not available. The same input price indexes were applied to all farms, that is, indexes vary only across years. For grain price we computed region-specific values using the farm-level data on revenues, yields, and areas for barley, wheat, oats and rye, complemented with the national statistics on crop prices. Total grain output for each farm was calculated as the ratio of grain revenue to the region-specific grain price. Because data on grain revenue was missing for some farms, and in order to avoid misreporting error, grain revenue for each farm and each year was computed as the median (per hectare) grain revenue in the support region in that year multiplied by the grain area of the farm. The per hectare subsidy rates for grains and set-aside used in the analysis are the sums of the CAP arable crop, CAP less favored areas, national crop production and northern aid, and general agri-environmental support rates applicable to each land use and each support region. The subsidy rates were also collected from the Finnish Agriculture and Rural Industries publications and differ across the support regions. The CAP arable crop subsidy for each support region was calculated as the weighted average of the subsidies for barley, wheat, oats and rye, where the weights were the average shares of land allocated to each crop in the support region on our sample.

Summary statistics (Table 1) show that on average the grain area per farm has increased over the study period. This trend is similar to the one observed for Finland on the whole (see e.g. Niemi and Ahlstedt 2005). The intensity of production in terms of fertilizer use has decreased on average, also similarly to the trend for Finland on the whole (Table A2.5). The use of plant protection products instead has increased over the same time period.

Table 1. Mean levels of grain and set-aside areas and fertilizer use in the sample

Year	Grain area (hectares)	Set-aside area (hectares)	Fertilizer use per hectare (quantity index)
1996	34.3	3.1	145.3
1997	36.8	3.6	153.2
1998	36.9	3.2	147.3
1999	39.2	3.7	151.1
2000	40.5	2.4	144.6
2001	40.0	2.9	128.8
2002	41.7	3.1	127.8
2003	41.5	3.9	126.1
2004	44.5	4.2	126.3
2005	45.1	3.3	124.5

As shown in Table 2, the total subsidies in proportion to land area have increased over the study period. This entry includes the CAP arable area and CAP less favored areas subsidies, national crop production aid and general environmental subsidies to both grain and set-aside areas. The subsidies to area in grain production have increased on average while the subsidies to set-aside (in constant terms) have decreased over the study period. The general FAEP payments in proportion to land area have decreased slightly on average. The proportion of farms participating in the FAEP special sub-program in our sample has increased over the study period; whereas the average amount of special environmental subsidies in proportion to farm land area among special sub-program participants has decreased.

Table 2. Percentages of farms receiving general and special FAEP payments and mean levels of subsidies received in proportion to land area (EUR 2005)

Year	Mean total subsidies[a] (euros/ha)	Mean subsidies to grains[a] (euros/ha)	Mean subsidies to set-aside[a] (euros/ha)	Mean FAEP general subsidies (euros/ha)	Farms with special FAEP payments (%)	Mean FAEP special subsidies[b] (euros/ha)
1996	471	475	440	122	12%	91
1997	478	483	431	122	14%	66
1998	495	502	423	118	19%	59
1999	460	464	418	120	20%	55
2000	548	561	380	91	15%	44
2001	535	551	370	87	21%	57
2002	554	571	377	86	19%	49
2003	535	554	374	84	25%	46
2004	543	559	373	85	29%	43
2005	560	578	369	97	29%	51

[a] Includes the CAP arable area and CAP less favored areas subsidies, national crop production aid, and FAEP general subsidies.
[b] Mean payments in proportion to land area for farms that participate in the FAEP special sub-program.

5. Estimation results

The first-stage Tobit regression, with the amount of the FAEP special sub-program payments received by the farm as the dependent variable, is significant overall (the Wald test statistic is significant at the 1% level).[13] Farmer's age has a statistically significant negative effect on the amount of special sub-program payments, whereas the price of labor, the number of animals on the farm, and farm size have a statistically significant positive effect. These signs are consistent with expectations. Younger farmers are likely to be more educated and have longer horizons of farm operation, which in turn is likely to make them more competent and more willing to invest time and effort in farm environmental planning involved in participating in the special sub-program. The special sub-program measures applicable to a grain farm typically remove land from production through conversion into riparian zones or wetlands. The finding that a higher price of labor, a higher time commitment for animal care, and larger farm size increase the amount of special sub-program payments received is consistent with the removal of land from production and thus reduced labor requirement. Location in a province along the west coast of Finland also

[13] The full Tobit regression results are available from the authors upon request.

has a statistically significant positive effect. This finding may be explained by proximity to the Baltic Sea and consequently greater awareness of its nutrient-related water quality problems.

In the second stage, the six-equation system as described in (10) is estimated using the Within-SURE method on a total of 1564 observations; the standard errors and *t*-statistics are obtained using bootstrapping techniques.[14] Chi-squared tests indicate overall significance of each of the six equations. Our main interest is the impact of crop area-based subsidies, set-aside subsidies and special environmental subsidies on land allocated to grain and set-aside, as well as on fertilizer and plant protectant products application. The estimated coefficients for the corresponding four equations are shown in Table A4 in Appendix 4.[15]

Table 3 presents the median elasticities calculated on the basis of the estimated coefficients. All subsidy elasticities of grain and set-aside areas and input use are statistically significant. Area-based subsidies for grains and set-aside both have a fairly small impact on the grain area. The median elasticity of grain area with respect to the grain subsidies is 0.15, which is close to the estimate reported in Lacroix and Thomas (2011). Using individual farm data from France, these authors found an elasticity of 0.16 for land planted with cereals with respect to area-based subsidies to cereals. Area-based subsidies for set-aside area instead have a large impact on the set-aside area on our sample: the median elasticity is 1.52, whereas Lacroix and Thomas report an elasticity of 0.12. Area-based subsidies to grains also increase total fertilizer and plant protectant use, although the impacts are small in magnitude (elasticities of 0.01 and 0.04). The special environmental subsidies have a positive but very small impact on land planted with grains and a negative impact on land set-aside, for the farms that participate in the FAEP special sub-program. We also find that the subsidies provided through the FAEP special sub-program decrease total fertilizer use but the impact is small in magnitude – one percent increase in the special agri-environmental subsidy results in only a 0.05 percent decrease in total fertilizer use. The special environmental subsidies increase the total use of plant protection products but this effect is also small in magnitude.

To check for the consistency of our estimates, we also calculated own price elasticities, which were also all statistically significant (at the 1 percent level of significance). The (median) elasticity

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[14] Monetary values have been converted into 2005 EUR using the consumer price index (source: Statistics Finland).
[15] The full set of estimated coefficients is available from the authors upon request.

of grain area to grain price is 0.30 whereas the own price elasticities of fertilizer and plant protectant demands are -0.91 and -1.96, respectively.

Table 3. Elasticities of land allocation and agrichemical input use

Variable	Elasticity	Significance[a]
Elasticities with respect to total land-area based subsidies to grains		
Grain area	0.149	***
Set-aside area	-2.012	***
Total fertilizer use	0.010	***
Total plant protectant use	0.036	***
Elasticities with respect to total set-aside subsidies		
Grain area	-0.108	***
Set-aside area	1.516	***
Total fertilizer use	-0.008	***
Total plant protectant use	-0.028	***
Elasticities with respect to the special environmental subsidy[b]		
Grain area	0.007	**
Set-aside area	-0.095	**
Total fertilizer use	-0.052	*
Total plant protectant use	0.063	**

[a] ***, **, * indicate significance at the 1%, 5% and 10% level, respectively.
[b] Calculated on the sub-sample of farmers receiving the special environmental subsidy.

To assess the impact of the FAEP payments on agriculturally-produced nutrient pollution, we apply the estimated land allocation and fertilizer demand functions to simulate two policy scenarios: (1) a “factual” scenario, where the FAEP payments are set at their historical values in 1996-2005, and (2) a counterfactual no-policy scenario, where FAEP payments (both general and special) are set at zero. All other variables, including compensatory payments through the CAP and national crop production aid, remain at their actual historical values under both scenarios, so as to identify the effects of the FAEP payments. Comparing the factual simulation with the counterfactual allows us to isolate the effects on land allocation and input use of the FAEP payments, assuming all else has remained constant.

The results in Table 4 indicate that the impacts of the FAEP payments on land allocation and fertilizer use on our sample are minor. In terms of land allocation, the impact is counterproductive in that the payments increase the grain area and reduce set-aside (grassland), which other things equal would increase nutrient loading. Our findings that the FAEP payments increase the area under cultivation are in line with previous findings. Pufahl and Weiss (2009) found that the area under cultivation for participants in the German AEPs has been growing by 7.7 percent on average from 2000 to 2005, while the growth rate was only 4.2 percent for farmers not participating in the AEP. Results from a comprehensive analysis of land-use changes in the United States, based on micro-level data, also suggest that federal farm payments have boosted crop acreage, partially offsetting cropland retirement induced by the CRP and falling crop net returns (Lubowski, Plantinga and Stavins 2008). Findings from a farm-level analysis of the production effects of US farm programs also suggest that government programs, even largely decoupled payments, increase growth in farm size (Key, Lubowski and Roberts 2005).

In terms of fertilizer use, the impact goes in the desired direction but is small in magnitude: the FAEP payments provide a less than 2% reduction in fertilizer use on the sample, again in line with findings by Pufahl and Weiss (2009) for Germany.

Table 4. Land allocation and fertilizer input levels on the sample under the prevailing agri-environmental policy and under a counterfactual scenario, where FAEP payments equal zero.

Variable	EU agricultural policy and FAEP agri-environmental subsidies (prevailing policy)	EU agricultural policy and no agri-environmental subsidies (counterfactual)	Percentage change produced by agri-environmental subsidies (%)
Total grain area (ha)	64396	63042	2.1
Total set-aside area (ha)	5237	6591	-20.5
Total fertilizer use (1 000 kg)	35262	35803	-1.5

6. Benefits and costs of the agri-environmental payments

Changes in land allocation and fertilizer use will affect agriculturally-produced nutrient pollution. We employ environmental production functions to assess the impact of FAEP payments on this environmental outcome on our sample of grain farms. Specifically, we use the predicted land allocation and fertilizer intensity under the "factual" baseline and the no-policy counterfactual as inputs in nitrogen and phosphorus runoff functions, and quantify the impact of program payments on nutrient pollution. To evaluate program-induced reductions in nutrient pollution in monetary terms, we couple the simulated nutrient load reductions with results from a valuation study assessing the benefits of reducing nutrient loads from Finland to the Baltic Sea.

In addition to changes in nutrient inputs and land use, nutrient runoffs are affected by adopted conservation measures. Among key measures that the FAEP imposes on grain farms are field margins along main drains and filter strips along waterways.[16] Farms participating in the FAEP special sub-program may also have agreed to construct wider riparian zones along waterways. In what follows, we refer to all of these buffers as vegetative filter strips. Another common conservation measure is wintertime vegetation on part of the arable area (a mandatory measure in southern Finland in the first program period 1995-1999). Unfortunately, our data do not record the extent of vegetative filter strips and wintertime vegetation on the sample farms. As an approximation, we apply field area shares of vegetative filter strips and wintertime vegetation that reflect the situation for all farms participating in the FAEP, based on information from farm surveys, farmer interview studies, and administrative records on FAEP additional measures and special sub-program contracts, as summarized in MAF (2004). The FAEP-imposed vegetative filter strips and wintertime vegetation are removed in the no-policy scenario, while CAP requirements for field margins remain in place under both scenarios.

We use nitrogen and phosphorus runoff functions developed in Simmelsgaard (1991) and Simmelsgaard and Djurhus (1998), and Uusitalo and Jansson (2002), respectively. These functions predict the impact of fertilization intensity on runoff, with coefficients that capture the impacts of crop choice, tillage practice, soil and field characteristics, and climatic factors. Helin, Laukkanen and Koikkalainen (2006) have calibrated the coefficients to correspond to the average soil

[16] The FAEP requires a 1 m wide field margin with permanent vegetation along main drains and 3 m wide filter strips with permanent vegetation along streams and other waterways. The CAP arable crop payments also require field margins of 0.6 m width along main drains and waterways.

characteristics, field slope and climatic conditions in southern Finland. As we do not have information on farm environmental characteristics, we apply the parameterization for average conditions in southern Finland as an approximation.[17] All in all, the results for runoff volumes also conform to findings for different land uses and fertilizer intensities in Finnish field experiments. Similar environmental production functions have been applied in Lankoski, Ollikainen and Uusitalo (2006) and Laukkanen and Nauges (2011). We next describe the environmental production functions briefly; for a more detailed description, we refer the reader to Helin, Laukkanen and Koikkalainen (2006) and Lankoski, Ollikainen and Uusitalo (2006).

6.1. Environmental production functions

The notation in the environmental production functions is as follows: indexes *N, DP* and *PP* refer to nitrogen, dissolved phosphorus and particulate phosphorus; $\phi_{m,j}$ is a parameter summarizing the impact of land use and tillage *j* (grains, grains with wintertime vegetation, set-aside) and local soil, field and climatic conditions on the runoff of nutrient *m,* with $m \in \{N, DP, PP\}$; s_m and d_m are the shares of nutrient *m* runoff carried through surface and drainage flow; *B* denotes the share of land allocated to VFS and b_m is a parameter capturing the effect of VFS on the loss of nutrient *m;* $\overline{N}$ is a reference nitrogen fertilization level, and θ soil phosphorus level. We consider a compound fertilizer with 20% nitrogen and 3% phosphorus content.[18] Given a predicted fertilizer quantity x, the applied amounts of nitrogen and phosphorus are $x_N = 0.20x$ and $x_P = 0.03x$.

Drawing on the nitrogen runoff function by Simmelsgaard (1991) and Simmelsgaard and Djurhus (1998), the nitrogen load (kg/ha) under land use *j* is given by

$$z_{N,j} = \phi_{N,j}\left[\left(1 - B^{b_N}\right)s_N + d_N\right]\exp\left\{0.71\left[x_N / \overline{N} - 1\right]\right\}, \quad (10)$$

[17] The study region in Helin, Laukkanen and Koikkalainen covers approximately support regions A and B in our study. The calibration draws on physical models predicting nitrogen and phosphorus runoffs (SOIL-N and IceCream, respectively) and monitoring data on nitrogen and phosphorus runoff from agricultural land.

[18] This mix was the most commonly used mix for grains in the study period in Finland, recommended for example by the Pro Agria agricultural advisory center's on-line farm management tool Tuottopehtori.

Total phosphorus runoff contains two forms of phosphorus, dissolved and particulate. Drawing on Saarela et al. (1995) and Uusitalo and Jansson (2002), the dissolved phosphorus runoff (kg/ha) is given by

$$z_{DP,j} = \phi_{DP,j}\left[\left(1-B^{b_{DP}}\right)s_{DP} + d_{DP}\right]\left[2\left(\theta + 0.01x_P\right) - 1.5\right]\cdot 10^{-4} \tag{11}$$

and the particulate phosphorus runoff (kg/ha) by

$$z_{PP,j} = \phi_{PP,j}\left[\left(1-B^{b_{PP}}\right)s_{PP} + d_{PP}\right]\left\{250\ln\left[\theta + 0.01x_P\right] - 150\right\}\cdot 10^{-6}. \tag{12}$$

Table 5 shows the nutrient runoff parameters $\phi_{m,j}$ calibrated by Helin, Laukkanen and Koikkalainen (2006) and the reference nitrogen fertilization level for each crop. We consider aggregate grain production and consequently use a weighted average of the parameters in Table 5 to describe runoff from grain areas. Based on MAF (2004), the share of field area under VFS on farms that participate in the FAEP was set at 0.29% for 1996-1999 and 0.40% in 2000-2005, while the share of field area under VFS on non-participating farms was set at 0.04% (CAP field margin). The parameter estimates for VFS impact, $b_N = 0.2$, $b_{DP} = 1.3$ and $b_{PP} = 0.3$, were obtained from Lankoski, Ollikainen and Uusitalo (2006).[19] The proportions of nutrient runoff incurring through surface flow (s_m) were set at 0.5, 0.7 and 0.7 for nitrogen, dissolved phosphorus and particulate phosphorus, respectively, which correspond to average values in Turtola and Paajanen (1995). The soil phosphorus levels (θ) used in the analysis are 1996-2000 and 2001-2005 soil test averages for each province in our sample, obtained from Viljavuuspalvelu (Soil Testing Service), the market leader in soil testing in Finland.[20] The share of field area under wintertime vegetation was set at 30% in support regions A and B and 0% elsewhere in years 1996-1999, which is an approximation based on the FAEP requirements in the time period. In years 2000-2005 the share was set at 14.8%, the average on farms participating in the FAEP in the period (MAF 2004). The most common way to realize winter time vegetation has been reduced tillage (MAF 2004), and we apply nutrient load parameters $\phi_{m,j}$ corresponding to reduced tillage to the grain area under wintertime vegetation. The price of the compound fertilizer was set at the 2002 price, 0.23 EUR/kg.

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[19] Lankoski, Ollikainen and Uusitalo (2006) have calibrated the model to data from Finnish experimental studies on grass filter strips (Uusi-Kämppä and Yläranta 1992, Uusi-Kämppä and Yläranta 1996).

[20] Soil testing once in every five years is required for farms participating in the FAEP.

Table 5. Nutrient runoff parameters (from Helin, Laukkanen and Koikkalainen 2006).[21]

Crop	Spring wheat		Winter wheat		Barley		Oats		Set-aside	
Tillage[a]	CT	RT	CT	RT	CT	RT	CT	RT	CT	RT
ϕ_N	24	24	21	21	21	20	12	12	12	12
ϕ_{DP}	326	357	355	355	316	342	323	347	197	197
ϕ_{PP}	1471	634	1415	1384	1373	540	1401	563	56	56
$\overline{N}$	100	100	120	120	90	90	90	90	0	0

[a] CT, conventional tillage; RT, reduced tillage (chisel plough).

6.2. Monetary benefits of reduced nutrient pollution

Assessing the welfare effects of the agri-environmental payments calls for a monetary measure of the benefits of reduced nutrient pollution. Developing a monetary measure of the non-market benefits is complicated by the fact that surface water quality degradation in the Baltic Sea, the main recipient of Finland's agriculturally-sourced nutrient loads, is governed by the joint presence of nitrogen and phosphorus (see e.g. Tamminen and Anderson 2007). Accordingly, valuation studies generally address water quality improvements that are attributable to the combined effect of changes in nitrogen and phosphorus loads entering the water ecosystem (Söderqvist 1996, 1998, Markowska and Zylicz 1999, Kosenius 2010). A composite measure of nitrogen and phosphorus loads is then needed for assessing the benefits of reduced nutrient pollution on the basis of valuation studies.

We consider a weighted sum of nitrogen and phosphorus as such a composite measure. Thus, environmental damage in our analysis is connected to a composite nutrient load z_{NP}, defined as

$$z_{NP} = z_N + az_P , \qquad (13)$$

where z_N is the nitrogen load and z_P the sum of dissolved and particulate phosphorus loads. As a base case parameterization, phosphorus is given weight $a = 7.2$ to reflect the prevalence of nitrogen fixing blue-green algae in the Baltic Sea. These organisms are able to tie nitrogen from the atmosphere to phosphorus in the water. Due to nitrogen fixation, phosphorus entering a

[21] For particulate phosphorus Helin, Laukkanen and Koikkalainen (2006) report parameter values corresponding to bioavailable nutrients. We have divided these values by the bioavailability coefficient for particulate phosphorus, 0.16, to obtain ϕ_{PP} parameters corresponding to total particulate phosphorus load as the benefit estimates used in this study pertain to total nutrients.

water ecosystem can result in conversion of an average of 7.2 times its weight of atmospheric nitrogen into a form available to aquatic plants, and phosphorus may thus cause 7.2 times more eutrophication than nitrogen.[22] We also consider the unweighted sum of nitrogen and phosphorus runoff, with $a = 1$, as an alternative measure.

We use results by Kosenius (2010) to assess the benefits of reduced nutrient pollution. Kosenius conducted a choice experiment to assess Finns' willingness to pay (WTP) for water quality improvements associated with reducing land-based nitrogen and phosphorus loads to coastal areas in the Baltic Sea adjacent to Finland (the Gulf of Finland and the Archipelago Sea). The water quality attributes in the choice experiment corresponded to forecasts by Baltic Sea ecosystem models. The scenario relevant to this study reduced Finland's nitrogen and phosphorus loads by 7986 and 525 tons per year, relative to the 1997-2002 levels, over a 20 year time frame.[23] The estimated annual WTP for these nutrient load reductions by the Finnish population range from 652 million euros for a multinomial logit to 945 million euros for a random parameters logit model, with 95% confidence intervals of [602;702] and [891;998] million euros.[24] We computed a constant marginal benefit by dividing the annual national WTP by the annual nutrient load reduction underlying the choice experiment scenario, measured in terms of a composite nutrient load reduction (equation 13). Table 6 displays the constant marginal benefit measures corresponding to the multinomial logit and random parameters logit models (in 2005 prices).

Table 6. Constant marginal benefit of reducing nutrient loads from Finland, in euros per kg of composite nitrogen-phosphorus load (95% confidence intervals in parenthesis)

Composite nutrient load measure	Multinomial logit	Random parameters logit
Phosphorus weight 7.2	55 (51-60)	80 (76-85)
Phosphorus weight 1	77 (71-83)	111 (105-117)

[22] The algae production function is essentially a fixed proportions one, with the ratio of nitrogen and phosphorus in algae output averaging 7.2 (Redfield, Ketchum and Richards 1963).

[23] The other scenarios concerned intensified wastewater treatment in Russia and reductions in Polish loads to the Baltic Proper. The ecosystem model forecasts and the load reduction scenarios are described in Pitkänen et al. (2007).

[24] The choice experiment in Kosenius (2010), carried out in 2005, presented respondents with a scenario where a tax would be imposed for 20 years to finance the load reductions, and water quality improvements would be realized at the end of the 20 year time frame. Kosenius also studied a latent class model. We do not consider the willingness to pay estimates from this model in our analysis as they were not weighted for population representativeness.

6.3. Benefit-cost comparison

The impact of agri-environmental payments on social welfare comprises changes in consumer surplus and producer surplus. Our approach enables assessing both. However, to enable transparent comparisons with a previous EU AEP study by Chabe-Ferret and Subervie (2012), we focus on consumer surplus, measured by the environmental benefits in terms of nutrient load reductions attributable to the FAEP payments.[25] On the cost side we consider the direct costs of the FAEP payments (agri-environmental subsidies paid to farms), administrative costs, and the opportunity cost of public funds. Based on NAOF (2008), the administrative costs of the FAEP amount to approximately 10% of program payments. A plausible value for the opportunity cost of public funds in Finland is 1.15.[26]

Nutrient load reductions attributable to the FAEP payments were simulated using the environmental production functions (10) to (12), the land allocation and input use under the factual simulation and the no-policy counterfactual (Table 4), and vegetative filter strip and wintertime vegetation shares attributable to the FAEP according to MAF (2004). The estimated effect of the FAEP payments was to reduce nitrogen loading from the sample of grain farms by 2.5 kg/ha or 11%, and phosphorus loading by 0.2 kg/ha or 13% over 1996-2005. The consequences of these changes for surface water quality related damage in the Baltic Sea are reported in Table 7.[27] Part A in the table displays the estimated damage from nutrient loading sourced from the sample farms for each scenario and for alternative damage parameterizations. The simulated nitrogen and phosphorus loads have been summarized into a composite nutrient load, which has then been priced at the constant marginal damage estimates in Table 6. Part B shows the overall change in damage and the benefit-cost ratio for the FAEP payments to the sample farms. Overall the effect of the FAEP payments was to reduce the damage from grain production by 11 to 12%. These

[25] Also, the impact of the FAEP payments on producer surplus on our sample is small, amounting to on average 1 €/ha/year over the 1996-2005 period.

[26] Kuismanen (2000) estimated the dead-weight loss of Finnish taxation to be 15% using a labor supply model.

[27] While a significant proportion of the farm-sourced nutrient loading in Finland is transported into the Baltic Sea, part of the nutrients are retained in inland waters. As our damage estimates are for the Baltic Sea, the damage measures in Table 7 have been calculated on basis of the nutrient loads estimated to reach the sea. For nitrogen we set the proportion retained in inland waters at 22%, the average for Finland (Lepistö et al. 2006). The retention rate for phosphorus was determined from an empirical regression model that predicts nutrient fluxes with field and lake percentages as explanatory factors (Rankinen et al. 2010). The resulting phosphorus retention rate is 46%. Thus, approximately 78% of the nitrogen load and 54% of the phosphorus load from the study area finds its way into the Baltic Sea. We thank Petri Ekholm, Finnish Environment Institute, for assessing the retention rate from the regression model.

estimates combine the reduction in the per hectare nutrient load from grain areas induced by decreased fertilizer use and the increase in grain area and decrease in set-aside area attributable to the agri-environmental payments.

Table 7. Benefits and costs of the nutrient load reductions attributable to agri-environmental payments on the sample of grain farms, 1996-2005

Parameterization[a]	MNL estimate P weight 7.2		RPL estimate P weight 7.2		MNL estimate P weight 1		RPL estimate P weight 1	
A. Simulated damage	Total 1000 €	Average €/ha	Total 1000 €	Average €/ha	Total 1000 €	Average €/ha	Total 1000 €	Average €/ha
Prevailing policy	75,561	1,085	109,906	1,578	83,873	1,205	120,908	1,736
Counterfactual	85,624	1,230	124,543	1,789	94,662	1,359	136,461	1,960
B. Effect of FAEP payments								
Change in total damage (%)[b]	-12		-12		-11		-11	
Benefit-cost ratio[c]	0.68		0.99		0.73		1.05	

[a] MNL: evaluated at the marginal damage derived from Kosenius' (2010) multinomial logit model.
RPL: evaluated at the marginal damage derived from Kosenius' (2010) random parameters logit model.
[b] The difference between the counterfactual and prevailing policy simulation divided by the counterfactual simulation.
[c] The total reduction in damage divided by the total cost of the FAEP payments (includes administrative costs and the opportunity cost of public funds).

The total damage avoided on the sample is robust to the choice of composite nutrient load measure but quite sensitive to the model used to obtain the underlying WTP estimates. For the MNL specification the benefits produced by the FAEP payments to our sample clearly fall short of the costs, with benefit-cost ratios estimated at 0.68 to 0.73. For the RPL specification the benefits are approximately on par with the costs, with benefit-cost ratios estimated at 0.99 to 1.05. The superiority of one WTP model over another is not straightforward. However, Kosenius (2010) found support for heterogeneous preferences for water quality attributes, which speaks for the use of the RPL model over the basic MNL. It should be noted that our environmental benefit assessment focuses on the implications of the FAEP payments for surface water quality in the Baltic Sea. Additional benefits may be attributable to reductions in plant protection product applications and increases in biodiversity, as well as water quality in Finland's inland waters. We have not been able to evaluate these changes as there are no empirical studies available on the relevant impacts and non-market benefits. All in all, our findings indicate that the FAEP has merits in terms of reducing agriculturally-produced nutrient loading.

7. Conclusion

Since the introduction of the EU agri-environmental regulation in 1992, over one hundred regional or national conservation schemes have been introduced. By 2002 a quarter of the EU utilized agricultural area was enrolled in an agri-environmental program. These programs are essentially voluntary regulation that provides incentives, but not mandates, for reducing agriculture's environmental damage. In the US in turn the 2002 federal farm bill contained a notable increase in funding for conservation initiatives. Critics argue that many of the agri-environmental programs in the EU and in the US are merely a trade-friendly way to ease the transition from production to non-production payments under the WTO's "Green Box". As the debate over agricultural policy continues, it is important for policymakers to have reliable information on how these programs actually perform – are they successful in reducing agriculture's environmental impact over and beyond what would have happened anyway?

This study presents a structural econometric model designed to evaluate the consequences of payments through the Finnish Agri-Environmental Program, one of the most extensive AEPs in the EU, for nutrient pollution originating from grain production. We estimated farms' land allocation and input decisions in the presence of proportional to land area compensatory payments, including agri-environmental subsidies. We used the estimated land allocation and input demands to predict the impact of the agri-environmental payments on grain and set-aside areas and fertilizer application intensity. We combined the predicted land allocation and input use with environmental production functions to assess the water protection impact of program payments. We used a structural econometric approach, rather than a treatment effect one, because participation in the Finnish Agri-Environmental Program is almost universal and it is thus not possible to specify a "treatment group" of participants and a "control group" of non-participants.

The econometric and simulation analyses indicate that the agri-environmental payments to grain farms had a fairly small effect on fertilizer use and land in grain production over 1996-2005. At -1.5% the impact on fertilizer use is smaller than what Pufahl and Weiss (2009) indicated for German AEPs (average treatment effect of -9.5%). By raising the profitability of land in grains, the payments also had the counterproductive impact that they reduced land in set-aside. Similar impacts of government farm payments have been reported in other research (Key, Lubowski and Roberts 2005; Lubowski, Plantinga and Stavins 2008). Accounting for specific water protection measures, vegetative filter strips and wintertime vegetation, the preventive impact of the payments was to reduce nitrogen loading by 11% and phosphorus loading by 13% relative to what would have happened otherwise over 1996-2005. Combined with monetary estimates for damage from nutrient pollution, the results indicate that the agri-environmental payments reduced the damage from grain production by 11 to 12 per cent, with the estimated ratio of benefits produced by program payments to costs ranging from 0.68 to 1.05.

Overall the agri-environmental payments have reduced farm-sourced nutrient pollution. This finding is consistent with results by Chabe-Ferret and Subervie (2012) for the impact of French agri-environmental schemes targeted at reducing nitrogen loading. However, the load reductions achieved fall short of Finland’s water protection targets and load reductions that would be needed for significant improvements in Baltic Sea water quality. This suggests that more targeted policies would be needed to further reduce farm-sourced nutrient loading, such as taxes on fertilizers and emphasizing payments for specific water protection measures. Furthermore, the incentives provided by the FAEP payments for converting set-aside into grain production should be reconsidered.

The modeling approaches predictive ability regarding grain and set-aside areas and fertilizer use is strong. Prediction of the effects of agri-environmental payments on nutrient loading is less reliable given that the environmental production functions have been calibrated for southern Finland and thus provide only an approximation for the study area on the whole. Furthermore, as our data do not permit estimating distinct land allocation functions for the four cereals grown in the study region, we considered aggregate grain production and consequently aggregated over crop specific impacts on runoff. Our results could be refined if we could estimate distinct selection rule for each grain, as Lacroix and Thomas (2011) have done.

Our estimate of the FAEP benefits is based on reductions in farm-sourced nutrient pollution as the program's main focus is on water protection objectives. However, the program also seeks to reduce the risks associated with the use of plant protection products and, starting from the second program phase 2000-2006, maintain biodiversity and rural landscapes. Possible benefits produced in terms of these additional objectives are not included in our benefit estimate. The benefit estimate is derived under the assumption of constant marginal damage of nutrient loading, which is a simplification. However, as the predicted changes in nutrient loading are fairly small, the constant marginal damage provides a reasonable approximation.

The empirical modeling framework presented in this study could be applied to examine the effects of fertilizer taxes, as well as alternative agri-environmental payment rates and emphases on payments provided through general and more targeted agri-environmental schemes. We leave comparing the cost-effectiveness of different types of policies on agriculturally-produced pollution as a topic for future study.

References

Aakkula, J., Manninen, T. and Nurro, M. (eds.) 2010. Follow-up Study on the Impacts of Agri-Environment Measures (MYTVAS 3) – Mid-term Report. In Finnish (with extended English summary). Reports of the Ministry of Agriculture and Forestry 1.

Agency for Rural Affairs (ARA) 2010. Agri-environmental support. On-line presentation on the agri-environmental program (in Finnish).

Agency for Rural Affairs (ARA) 2011. Guidebook on monitoring of the arable land and animal support. In Finnish.

Baylis, K., Peplow, S., Rausser, G. and Simon, L. 2011. Agri-environmental programs and trade negotiations in the United States and the European Union. EuroChoices 10(2).

Baylis, K., Rausser, G. and Simon, L. 2004. Agri-environmental programs in the United States and the European Union. In G. Anania, M. Bohman, C.A. Carter and A.F. McCalla (eds.). Agricultural Policy Reform and the WTO: Where Are We Heading? Cheltenham, UK. Edward Elgar.

Buller, H. 2000. Regulation 2078: patterns of implementation. In Buller, H., Wilson, G. and Höll (Eds.), Agri-Environmental Policy in the European Union. Ashgate Publishing, Aldershot, England.

Buller, H., Wilson, G. and Höll, A. 2000. Introduction: the emergence of regulation 2078. In Buller, H., Wilson, G. and Höll (Eds.), Agri-Environmental Policy in the European Union. Ashgate Publishing, Aldershot, England.

Chabé-Ferret, S. and Subervie, J. 2012. How much green for the buck? Estimating additional and windfall effects of the French agro-environmental schemes by DID-matching. Working Paper (revise and resubmit, *Journal of Enviromental Economics and Management*).

Commission of the European Communities (CEC). 2002. Communication from the Commission to the Council and the European Parliament: Mid-Term Review of the Common Agricultural Policy. COM(2002), July 20, 2002. Brussels: European Commission.

Darnall, N. and Sides, S. 2008. Assessing the performance of voluntary environmental programs: does certification matter? *The Policy Studies Journal 36(1): 95-117.*

Di Falco, S. and Rensburg, T. (2008). Making the commons work: conservation and cooperation in Ireland. *Land Economics 84(4): 620-634.*

Ekholm, P., Granlund, K., Kauppila, P., Mitikka, S., Niemi, J., Rankinen, K., Räike, A. and Räsänen, J. 2007. Influence of EU policy on agricultural nutrient losses and the state of receiving surface waters in Finland. *Agricultural and Food Science* 16: 282-300.

Gren, I.-M., 2001. International versus National Actions against Nitrogen Pollution of the Baltic Sea. *Environmental and Resource Economics* 20 (1): 41– 59.

Gren, I-M. and Folmer, H. 2003. Cooperation with Respect to Cleaning of an International Water Body with Stochastic Environmental Damage: the Case of the Baltic Sea. *Ecological Economics* 47:33– 42.

Hanley, N. and Oglethorpe, D. 1999. Emerging policies on externalities from agriculture: an analysis for the European Union. *American Journal of Agricultural Economics* (81)5: 1222-1227.

Hanley, N., Whitby, M., and Simpson, I. (1999). Assessing the success of agri-environmental policy in the UK. *Land Use Policy* 16: 67-80.

Hanrahan, C., and Schnepf, R. (22 January 2007). "WTO Doha Round: The Agricultural Negotiations" (PDF). Congressional Research Service. http://www.nationalaglawcenter.org/assets/crs/RL33144.pdf (retrieved November 28, 2011).

Heckman, J. (2010). Building bridges between structural and program evaluation approaches to evaluating policy. *Journal of Economic Literature* 48(2), 356-398.

Heckman, J. and Vytlacil, E. 2007. Econometric Evaluation of Social Programs, in Heckman, J. and Leamer, E. (eds), Handbook of Econometrics, Volume 6. Elsevier, Amsterdam.

HELCOM (2010). The Extended Summary of the Main Results of the Fifth Pollution Load Compilation (Draft May 7, 2010). http://www.helcom.fi/stc/files/Moscow2010/PLC_summary.pdf (retrieved November 28, 2011).

Helin, J., Laukkanen, M. and Koikkalainen, K. 2006. Abatement costs for agricultural nitrogen and phosphorus loads: a case study of crop farming in south-western Finland. *Agricultural and Food Science* 15: 351-374.

Key, N., Lubowski, R. and Roberts, M. 2005. Farm-level production effects from participation in government commodity programs: Did the 1996 Federal Agricultural Improvement and Reform Act make a Difference? *American Journal of Agricultural Economics* 87(5): 1211-1219.

Koehler, D. 2007. The effectiveness of voluntary environmental programs - a policy at a crossroads? *Policy Studies Journal* 35(4), pp. 689-722.

Kuismanen, M. 2000. Labour supply and income tax changes: a simulation study for Finland. Bank of Finland Discussion Paper, 5/2000.

Lacroix, A. and Thomas, A. 2011. Estimating the Environmental Impact of Land and Production Decisions with Multivariate Selection Rules and Panel Data. *American Journal of Agricultural Economics* 93(3): 784-802.

Lankoski, J., Ollikainen, M. and Uusitalo, P. 2006. No-till technology: benefits to farmers and the environment? Theoretical Analysis and application to Finnish agriculture. *European Review of Agricultural Economics* 33(2): 193-221.

Laukkanen, M. and Nauges, C. 2011. Environmental and production cost impacts of no-till in Finland: Estimates from observed behavior. *Land Economics* 87(3): 508-527.

Lepistö, A., Granlund, K., Kortelainen, P. and Räike, A. 2006. Nitrogen in river basins: Sources, retention in the surface waters and peatlands, and fluxes to estuaries in Finland. *Science of the Total Environment* 365: 238–259.

Lubowski, R., Plantinga, A. and Stavins, R. 2008. What drives land-use change in the United States? A national analysis of landowner decisions. *Land Economics* 84(4): 529-550.

Marggraf, R. (2003). Comparative assessment of agri-environmental programmes in federal states of Germany. *Agriculture, ecosystems and the environment* 98: 507-516.

Markowska, A. and Zylicz, T. 1999. Costing an International Public Good: the Case of the Baltic Sea. *Ecological Economics* 30: 301-316.

Ministry of Agriculture and Forestery (MAF) 2004. Mid-term Evaluation of the Horizontal Rural Development Program (In Finnish, with English summary). MAF Publications 1/2004.

Ministry of Agriculture and Forestry (MAF) 2010. http://www.mmm.fi/fi/index/etusivu/maaseudun_kehittaminen/maaseudunjamaatalouden ymparistonhoito/vesiensuojelu.html Accessed 22.11.2011.

National Audit Office of Finland (NAOF) 2008. Reducing agriculturally-produced nutrient pollution. Audit Report 175/2008.

Niemi, J. and Ahlstedt,J. 2005. Finnish Agriculture and Rural Industries – Ten Years in the European Union. Agrifood Research Finland, Economic Research (MTTL). Publications 105a.

OECD 2003. The Greening of the WTO Green Box. Paris: OECD.

Pitkänen, H., Kiirikki, M., Savchuk, O., Räike, A., Korpinen, P. and Wulff, F. 2007. Searching efficient protection strategies for the eutrophied Gulf of Finland: the combined use of 1D and 3D modeling in assessing long-term state scenarios with high spatial resolution. *Ambio* 36(2-3), 272-279.

Primdahl, J., Peco, B., Schramek, J., Andersen, E. and Onate, J.J. (2003). Environmental effects of agri-environmental schemes in Western Europe. *Journal of Environmental Management* 67: 129-138.

Pufahl, A. and Weiss, C. (2009). Evaluating the effects of farm programmes: results from propensity score matching. *European Review of Agricultural Economics* 36 (1): 79-101.

Puustinen, M., Merilä, E., Palko, J. and Seuna, P. 1994. ”Drainage Status, Cultivation Practices and Factors Affecting Nutrient Loading from Finnish Fields.” Publications of the National Board of Waters and the Environment, Series A (198). National Board of Waters and the Environment, Finland (in Finnish).

Rankinen, K., Ekholm, P, Sjöblom, H., Rita, H. and Vesikko, L. 2010. Material fluxes in river basins and their determinants. In Aakkula, J., Manninen, T. and Nurro, M. (eds.) Follow-up Study on the Impacts of Agri-Environment Measures (MYTVAS 3) – Mid-term Report. In Finnish (with extended English summary). Reports of the Ministry of Agriculture and Forestry 1.

Redfield, A.C., Ketchum, B.H. and Richards, F.A. (1963). The influence of organisms on the composition of seawater. In: Hill MN (ed.) The Sea, vol 2. Wiley, New York

Saarela, I., Järvi, A., Hakkola, H. & Rinne, K. 1995. Phosphorus fertilizer trials, 1977-1994: effects of the rate of annual phosphorus application on soil fertility and yields of fields crops in long-term field experiments. (In Finnish, with summary in Engllish). Agrifood Research Finland, *Tiedote* 16/95.

Shonkwiler, T.S., and S.T. Yen, 1999. Two-step estimation of a censored system of equations. *American Journal of Agricultural Economics* 81(4): 972-982.

Simmelsgaard, S. E. & Djurhuus, J. 1998. An empirical model for estimating nitrate leaching as affected by crop type and the long-term fertilizer rate. *Soil Use and Management* 14: 37-43.

Simmelsgaard, S.E. 1991. Estimation of nitrogen leakage functions – nitrogen leakage as a function of nitrogen applications for different crops on sandy and clay soils. In: Rude, S. (ed.). Nitrogen fertilizers in Danish Agriculture – present and future application and leaching, (In Danish, with English summary). Copenhagen: Institute of Agricultural Economics Report 62 pp. 135-150.

Söderqvist, T. 1996. Contingent Valuation of a Less Eutrophicated Baltic Sea. Beijer Discussion Papers Series No. 88, Stockholm, Sweden.

Söderqvist, T. 1998. Why Give up Money for the Baltic Sea? Motives for People's Willingness (or Reluctance) to Pay. *Environmental and Resource Economics* 12, 249–254.

Tamminen, T. and Andersen, T. 2007. Seasonal phytoplankton nutrient limitation patterns as revealed by bioassays over Baltic Sea gradients of salinity and eutrophication. *Marine Ecology Progress Series* 340, 121-138.

Turtola, E. and Paajanen, A. 1995. Influence of improved sub-surface drainage on phosphorus losses and nitrogen leaching from a heavy clay soil. *Agricultural Water Management 28: 295-310.*

Uusi-Kämppä, J. & Yläranta, T. 1992. Reduction of sediment, phosphorus and nitrogen transport on vegetated buffer strips. *Agricultural Science in Finland* 1: 569-575.

Uusi-Kämppä, J. & Yläranta. T. 1996. Effect of buffer strip on controlling erosion and nutrient losses in Southern Finland. In G. Mulamoottil, B. G. Warner, E & McBean, A. (eds.). *Wetlands: environmental gradients, boundaries and buffers*. Boca Raton: CRC Press/Lewis Publishers. p. 221-235.

Uusitalo, R and Jansson, H. 2002. Dissolved reactive phosphorus in runoff assessed by soil extraction with an acetate buffer. *Agricultural and Food Science in Finland* 11, 343-353.

Uusitalo, R., & Jansson, H. 2002. Dissolved reactive phosphorus in runoff assessed by soil extraction with an acetate buffer. *Agricultural and Food Science in Finland* 11, 343-353.

Whitby, M. (Ed.) (1996). The European environment and CAP reform. Policies and prospects for conservation. CAB International, Guildford.

Wu, J., Adams, R.M., Kling, C. and Tanaka, K. 2004. From Microlevel Decisions to Landscape Changes: An Assessment of Agricultural Conservation Policies. *American Journal of Agricultural Economics* 86(1): 26-41.

Appendix 1. (Description of Shonkwiler and Yen's approach to control for censoring of land set-aside):

In our model, the non-conditional expectation of land set-aside for farmer *i* at time *t* ($l_{f,it}$) can be written as follows:

$$E\left(l_{f,it}\right) = \text{Prob}\left(l_{f,it} > 0\right) \times E\left(l_{f,it} \left| l_{f,it} > 0\right.\right) + \text{Prob}\left(l_{f,it} \le 0\right) \times 0 = \text{Prob}\left(l_{f,it} > 0\right) \times E\left(l_{f,it} \left| l_{f,it} > 0\right.\right).$$

Let's denote by d_{it} the variable taking the value 1 if $l_{f,it} > 0$ and 0 otherwise.

We assume the following specifications for the corresponding (unobserved) latent variables:

$$l_{f,it}^{*} = g_3\left(\mathbf{x}_{it}, \boldsymbol{\beta}_3\right) + \mu_{3i} + \varepsilon_{it} \text{ and } d_{it}^{*} = \mathbf{z}_{it}^{'}\boldsymbol{\alpha} + v_{it},$$

with $\boldsymbol{\beta}_3$ and $\boldsymbol{\alpha}$ vectors of unknown parameters, $\mathbf{x}_{it}$ the vector of explanatory variables including the price of output, the price of fertilizer and plant protection, the set of subsidies and total land. The vector $\mathbf{z}_{it}^{'}$ contains explanatory variables that are assumed to influence farmer's decision to have some land set-aside ($\mathbf{x}_{it}$ and $\mathbf{z}_{it}^{'}$ can have variables in common), and ε_{it} and v_{it} are random errors assumed to follow a bivariate normal distribution with $\text{cov}\left(\varepsilon_{it}, v_{it}\right) = \delta$. We have the following relationships:

$$d_{it} = \begin{cases} 1 \text{ if } d_{it}^{*} > 0 \\ 0 \text{ if } d_{it}^{*} \le 0 \end{cases} \text{ and } l_{f,it} = d_{it} \times l_{f,it}^{*}.$$

The unconditional mean of $l_{f,it}$ is (Shonkwiler and Yen, 1999):

$$E\left(l_{f,it} \left| \mathbf{x}_{it}, \mathbf{z}_{it}^{'}\right.\right) = \Phi\left(\mathbf{z}_{it}^{'}\boldsymbol{\alpha}\right) g_3\left(\mathbf{x}_{it}, \boldsymbol{\beta}_3\right) + \delta\phi\left(\mathbf{z}_{it}^{'}\boldsymbol{\alpha}\right)$$

where $\phi(.)$ and $\Phi(.)$ are the standard normal probability density function and cumulative distribution function, respectively.

Hence the corresponding equation for land set-aside to be estimated in the system is as follows:

$$l_{f,it} = \Phi\left(\mathbf{z}_{it}^{'}\boldsymbol{\alpha}\right) g_3\left(\mathbf{x}_{it}, \boldsymbol{\beta}_3\right) + \delta\phi\left(\mathbf{z}_{it}^{'}\boldsymbol{\alpha}\right) + \mu_{3i} + u_{3,it}.$$

The estimation procedure involves two steps. In the first step, estimates $\hat{\boldsymbol{\alpha}}$ of $\boldsymbol{\alpha}$ are obtained from the estimation of a random-effect Probit model using the binary decision to set-aside land ($d_{it} = 1, 0$). We use as independent variables the proportion of land planted with grain in the previous period, the prices of fertilizer, plant protection and labor, the per ha area-based subsidies (including CAP, less favored areas and basic environmental subsidies), the per-ha subsidy to set-aside, the price of grass, and dummies for support regions. The estimates $\hat{\boldsymbol{\alpha}}$ of $\boldsymbol{\alpha}$ are then used to calculate $\Phi\left(\mathbf{z}_{it}^{'}\hat{\boldsymbol{\alpha}}\right)$ and $\phi\left(\mathbf{z}_{it}^{'}\hat{\boldsymbol{\alpha}}\right)$. In the second stage, the system is estimated with the following equation for land set-aside:

$$l_{f,it} = \Phi\left(\mathbf{z}_{it}^{'}\hat{\boldsymbol{\alpha}}\right) g_3\left(\mathbf{x}_{it}, \boldsymbol{\beta}_3\right) + \delta\phi\left(\mathbf{z}_{it}^{'}\hat{\boldsymbol{\alpha}}\right) + \mu_{3i} + u_{3,it} .$$

Estimation results of the first-stage random-effect Probit model are not shown here but are available upon request.

Appendix 2. Summary statistics for the sample and the population of Finnish grain farms

Table A2.1. Average farm size (ha) by year and agricultural support region, sample

Support region Year	A	B	C1	C2
1996	52	39	37	32
1997	56	37	37	32
1998	61	36	35	30
1999	62	42	41	35
2000	64	42	33	37
2001	61	45	38	32
2002	62	45	41	43
2003	64	45	45	43
2004	63	46	44	49
2005	62	53	47	46

Table A2.2. Average farm size (ha) by year and agricultural support region, all Finnish grain farms (source: Finnish farm registry)

Support region Year	A	B	C1	C2
1996	33	24	18	18
1997	34	25	19	19
1998	35	26	20	19
1999[a]	-	-	-	-
2000	37	27	21	21
2001	39	28	22	22
2002	39	29	23	23
2003	40	30	24	24
2004	41	30	24	25
2005	43	31	25	26

[a] The farm registry data were not collected in 1999.

Table A2.3. Proportion of farms located in each agricultural support region by year and over the entire study period, sample

Support region Year	A	B	C1	C2
1996	27 %	53 %	11 %	8 %
1997	29 %	53 %	10 %	8 %
1998	27 %	47 %	16 %	10 %
1999	30 %	48 %	14 %	8 %
2000	29 %	51 %	11 %	9 %
2001	28 %	49 %	10 %	13 %
2002	31 %	46 %	11 %	12 %
2003	29 %	45 %	14 %	13 %
2004	31 %	43 %	16 %	11 %
2005	34 %	38 %	14 %	13 %
Total	29 %	47 %	13 %	11 %

Table A2.4. Proportion of farms located in each agricultural support region by year and over the entire study period, all Finnish grain farms (source: Finnish farm registry)

Support region Year	A	B	C1	C2
1996	24 %	39 %	24 %	13 %
1997	23 %	39 %	24 %	14 %
1998	23 %	38 %	24 %	15 %
1999 [a]	-	-	-	-
2000	22 %	38 %	24 %	16 %
2001	21 %	38 %	25 %	16 %
2002	21 %	38 %	25 %	17 %
2003	20 %	38 %	25 %	17 %
2004	20 %	37 %	25 %	18 %
2005	20 %	37 %	25 %	18 %
Total	22 %	38 %	24 %	16 %

[a] The farm registry data were not collected in 1999.

Table A2.5. Fertilizer purchases in proportion to cultivated area (kg/ha), sample

Year	Nitrogen	Phosphorus
1996	119	18
1997	126	19
1998	121	18
1999	124	19
2000	119	18
2001	106	16
2002	105	16
2003	103	16
2004	104	16
2005	102	15

Approximation based on recorded fertilizer expenditure and the assumption that farms used the compound fertilizer typically used in grain production, with a 20% nitrogen content and 3% phosphorus content.

Table A2.6. Fertilizer purchases in proportion to cultivated area (kg/ha), all of Finland

Year	Nitrogen	Phosphorus
1996	92	16
1997	86	12
1998	85	11
1999	81	11
2000	84	10
2001	83	11
2002	81	10
2003	80	10
2004	76	9
2005	75	9

Source: Information Center Agriculture (TIKE). The kg/ha estimate has been calculated as the ratio of the fertilizers sales in Finland and the total cultivated area.

Appendix 3. Price statistics

Table A3.1. Mean grain price, mean labor price, and fertilizer and plant protection product price indexes (base 100 in 2005)

Year	Grain price	Labor price	Fertilizer price index	Plant protection product price index
	(EUR 2005/t)	(EUR 2005/hour)	(base 100 in 2005)	
1996	150.4	8.7	93.9	126.8
1997	138.3	8.7	92.4	121.3
1998	124.2	8.8	89.6	118.6
1999	115.4	8.8	87.3	115.9
2000	114.3	8.7	88.9	113.6
2001	111.3	9.1	96.3	109.5
2002	106.6	9.3	94.3	107.3
2003	101.0	10.0	93.5	102.3
2004	89.0	10.3	96.0	102.7
2005	80.6	11.0	100.0	100.0

Appendix 4. Estimation results (four equations out of six)

Table A4. Within-SURE estimation results (main equations of interest), 1 564 observations

	Estimated coefficient	Bootstrapped standard errors	p-value
Land allocated to grains			
Fertilizer price	-0.784	0.263	0.003
Plant protectant price	-0.900	0.133	0.000
Price of grain	0.820	0.061	0.000
Land-area based subsidies to grains	0.087	0.014	0.000
Set-aside subsidies	-0.087	0.014	0.000
FAEP special subsidies	0.002	0.001	0.037
Total farm area	0.882	0.014	0.000
Land set-aside			
Fertilizer price	0.784	0.263	0.003
Plant protectant price	0.900	0.133	0.000
Price of grain	-0.820	0.061	0.000
Land-area based subsidies to grains	-0.087	0.014	0.000
Set-aside subsidies	0.087	0.014	0.000
FAEP special subsidies	-0.002	0.001	0.037
Total farm area	0.118	0.014	0.000
Additional term[a]	5.436	3.831	0.156
Use of fertilizer			
Fertilizer price	-401.032	46.269	0.000
Plant protectant price	279.185	32.096	0.000
Price of grain	-10.961	1.278	0.000
Land-area based subsidies to grains	0.784	0.263	0.003
Set-aside subsidies	-0.784	0.263	0.003
FAEP special subsidies	-1.496	0.784	0.056
Total farm area	6.852	2.385	0.004
Use of plant protection			
Fertilizer price	279.185	32.096	0.000
Plant protectant price	-229.437	25.389	0.000
Price of grain	4.414	0.769	0.000
Land-area based subsidies to grains	0.900	0.133	0.000
Set-aside subsidies	-0.900	0.133	0.000
FAEP special subsidies	0.702	0.291	0.016
Total farm area	-2.270	1.827	0.214

[a] Additional term to control for selection bias (see Appendix 1).