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Marita Laukkanen

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Marita Laukkanen, Government Institute for Economic Research, Finland

Céline Nauges, The University of Queensland, Australia

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Government Institute for Economic Research
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Abstract

One quarter of the agricultural area in the European Union is registered in agri-environmental programs. Despite the prevalence of such programs and increasing demands for environmental quality in the European Union, ex-post assessments of program benefits are rare. This study uses a structural econometric model to evaluate the impacts of agri-environmental payments provided through the Finnish Agri-Environmental Program, whose primary goal is to reduce nutrient pollution from agricultural land. Drawing on a representative sample of individual grain farms, the research quantifies the effects of agri-environmental payments on farmers' decisions on the use of agri-chemical inputs and on the allocation of land to grain production and set-aside (fallow) over the period 1996–2005. The effects of program payments are ascertained based on exogenous variation in payment rates across regions and over time. We find that the agri-environmental payments have reduced fertilizer inputs but that this impact has been modest. In terms of land allocation, the impact has been counterproductive in that the payments have slightly increased the grain area and reduced set-aside. To quantify the impact of agri-environmental payments on nutrient loading – the environmental outcome of interest – we then combine the predicted land allocation and fertilizer use with environmental production functions. Overall, we estimate that the payments have reduced the damage costs associated with nutrient pollution from grain farming by 11 to 12 percent.

Key words: agri-environmental programs, payments for ecosystem services, farm subsidies, structural models, panel data, policy evaluation, nutrient pollution, cost-benefit analysis

JEL classification numbers: H23, Q18, Q28, Q53, Q58

Tiivistelmä

Neljännes Euroopan unionin maatalousmaasta kuuluu maatalouden ympäristötuen piiriin. Vaikka ympäristötuki on laajassa käytössä ja maatalouden ympäristövaikutukset kasvavan huomion kohteena, perusteelliset empiiriset tutkimukset maatalouden ympäristötukien toteutuneista vaikutuksista ovat harvassa. Tämä tutkimus tarkastelee Suomen maatalouden ympäristötukien vaikutuksia rakenteellisen ekonometrisen mallin avulla. Tutkimus analysoi edustavaa otosta viljatiloista ja määrittää ympäristötuen vaikutukset viljelijöiden tuotantopäätöksiin – lannoitteiden käyttöön sekä vilja- ja kesantoaloihin – vuosina 1996-2005. Ympäristötuen vaikutusten määrittäminen perustuu alueelliseen ja ajalliseen vaihteluun tukitasoissa. Ympäristötuet ovat vähentäneet lannoitteiden käyttöä viljatiloilla mutta vaikutus on ollut vähäinen. Pellonkäytön suhteen tukien vaikutus on ollut ympäristön kannalta haitallinen: tuet ovat lisänneet vilja-alaa ja pienentäneet kesantoalaa. Tukien varsinaisia ympäristövaikutuksia arvioidaan yhdistämällä ekonometrisen mallin ennustamat lannoitusintensiteetti sekä vilja- ja kesantoalat ravinnehuuhtoumia ennustavaan malliin. Kaiken kaikkiaan ympäristötuet ovat vähentäneet ravinnekuormitusta viljatiloilta 11–12 prosenttia.

Key words: maatalouden ympäristötuki, ekosysteemipalvelujen tuottaminen, maataloustuet, rakenteelliset mallit, paneeliaineistot, ravinnekuormitus, kustannus-hyöty -analyysi

Contents

1. Introduction

The European Union's (EU) Agri-environment Regulation 2078/92/EEC, 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 designed to encourage farmers to produce non-market benefits of agriculture and to reduce agriculturally produced pollution. While the policy changes reflect the increasing demands 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 2000, Baylis et al. 2011). The design of national programs was entrusted to the member states. By 1997, more than 130 different programs had been approved (Buller 2000). By 2002, 25% of the agricultural area in the European Union (EU15) was registered in one or more agri-environmental programs (AEP) and the annual EU budget spending on AEPs was on the order of 2,000 billion euros (European Commission 2005).

At the level of the individual farmer, participation in an AEP is voluntary. Incentives are provided through program payments, but the requirements for participating farms tend to be quite general in nature. Payments are largely 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 considerable flexibility in choosing the actions by which they address the environmental impacts of agricultural production, and the administrative burden remains moderate. In contrast to prominent conservation programs in the United States (US), such as the Conservation Reserve Program, EU AEPs generally aim at supporting environmentally friendly production practices on working land rather than encouraging land retirement.

Little is known about whether participation in AEPs actually improves farms' environmental performance. While the evaluation of AEPs is mandatory for the member states, rigorous empirical studies on program impacts are rare.[1] To our knowledge, Pufahl and Weiss (2009) and Chabé-Ferret and Subervie (2012) are the only econometric analyses that explicitly investigate the effects of AEPs on observed farm production decisions.

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[1] There is a substantial ecological literature which investigates AEP impacts. While not an exhaustive list, examples of studies dealing with European programs include Ekholm et al. (2007), on Finland; Marggraf (2003), on German 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 stated goals, in terms of changes in agricultural practices, would have on the environment. It has not attempted to disentangle the effects of AEPs from other factors affecting production decisions such as input and output prices and other agricultural support policies.

This limited knowledge of AEP impacts is a significant shortcoming for two reasons. First, where environmental policy is concerned, it is important that we be able to ascertain whether programs are actually fulfilling their promise as policy measures by reducing the environmental damage or enhancing the positive effects attributable to agriculture vis-à-vis no policy. Second, in terms of trade policy, we need further information on whether programs are actually compensating farmers for non-market production activities or just greenwashing production subsidies; this is an issue that has led to considerable disagreement between the EU and the US – and between these two trading powers and developing countries – in the now-stalled Doha Round of trade liberalization talks (Hanrahan and Schnepf 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 implementation 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 loss from agricultural land and it is considered the primary solution to the country's considerable problems with surface water pollution from agriculture. The FAEP is among the most extensive in the EU, encompassing 90% of all the country's farms and 92% of its agricultural area (Aakkula et al. 2010).[2] Finnish authorities refer to the high participation rate as a measure of the program's 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 costs of meeting program requirements, and thus have a weak relation to actual improvements (see e.g. Hanley and Oglethorpe 1999). Although developed in the context of corporate environmental management and thus 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).

We investigate how crop producers have responded to the FAEP by analyzing a structural econometric model of production decisions, drawing on a representative sample of individual grain farms over the period 1996-2005. We

[2] Accounts of AEPs in several EU countries may be found in Whitby (1996) and Buller, Wilson and Höll (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 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.

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 use the variation in compensatory payment rates across regions and over time to identify the impact of payments on production decisions. We are particularly interested in identifying the impact of FAEP payments on the use of fertilizer inputs and the allocation of land to grain production and set-aside (grassland). These variables are key determinants of the surface water pollution from agriculture. To assess the impact of the FAEP payments on water pollution, we use the estimated input demand and land allocation functions to predict farms' fertilizer use and land allocation under two scenarios: a "factual" case 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 loading. Comparison of the outcomes using the factual baseline and the counterfactual makes it possible to identify 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 (Kosenius 2010), we compute the monetary value of environmental benefits attributable to the FAEP in our sample and compare them to the costs represented by the agri-environmental payments.

Pufahl and Weiss (2009) evaluate the effect of German AEPs on farms' use of inputs, including land allocation and agrichemicals, and output produced. Their approach uses farm-level panel data and difference-in-difference propensity score matching. The analysis reveals that AEP participation increased both the area under cultivation and grassland, and decreased the use of agrichemicals. Chabé-Ferret and Subervie (2012), also applying difference-in-difference matching, estimate the additional and windfall effects of five agri-environmental schemes in France with farm-level data. They find that the schemes promoting crop diversity and cover crops have had limited success, whereas the schemes subsidizing grass buffer strips and organic farming may well be socially efficient.

The present study augments the empirical literature on the impacts of EU AEPs on agricultural input use, a line of inquiry begun by Pufahl and Weiss (2009) and Chabé-Ferret and Subervie (2012). The structural approach taken here is different from the treatment effect approach in those studies in that we explicitly model farms' production decisions and link them with environmental production functions. The approach enables consistent predictions of production choices and environmental outcomes, which can serve to both evaluate the impact of present AEP payments and forecast the impacts of alternative policy interventions, such as taxes on polluting inputs. Of course, the choice of methodology is also dictated by the policy to be evaluated. 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). Germany and France have numerous agri-environmental schemes and only a limited proportion of agricultural land is managed under AEPs. In Finland participation in the single, nationwide AEP is almost universal. Thus, the treatment effect approach, which requires a “treatment group” of participants and a “comparison group” of non-participants, is not applicable. Accordingly, our research design employs the structural approach, in which functional form and support conditions substitute for the lack of a comparison group (see e.g. Heckman and Vytlacil 2007, Heckman 2010, Keane 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 quite precise benefit-cost analysis: one can predict the impact of program payments on measurable environmental outcomes – reductions in nutrient loads – with direct counterparts in valuation studies.

The section to follow begins with a description of the FAEP. We then present the microeconomic behavioral model, which comprises farms’ decisions on land allocation and agrichemical use, and our estimation methodology. This is followed by a presentation of the data and the estimation results for the behavioral model and simulation of the “factual” and counterfactual policy scenarios. We then proceed with a description of the environmental production functions and the monetary benefits of reduced nutrient pollution, and assess the benefits and costs of the FAEP payments for the farms in our sample. The last section summarizes and discusses the results and proposes some directions for further research.

2. Background

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

The FAEP provides payments to support environmentally beneficial farming practices on all, not just environmentally sensitive, land. The program is divided into general and special sub-programs. Farms participating in the general sub-program sign renewable five-year contracts in which they agree to follow a set of mandatory environmental protection measures, identical across farms within a production line. For grain production, the major form of crop production in Finland, the mandatory measures impose limits on fertilizer use and require construction of field margins and vegetative filter strips along waterways. In southern Finland, farms are also required to choose one additional measure, such as stricter constraints on fertilizer use, promotion of biodiversity, or maintenance of wintertime vegetation on part of their arable area; the last of these was 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 (MAF 2004). The special sub-program encourages the implementation of 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

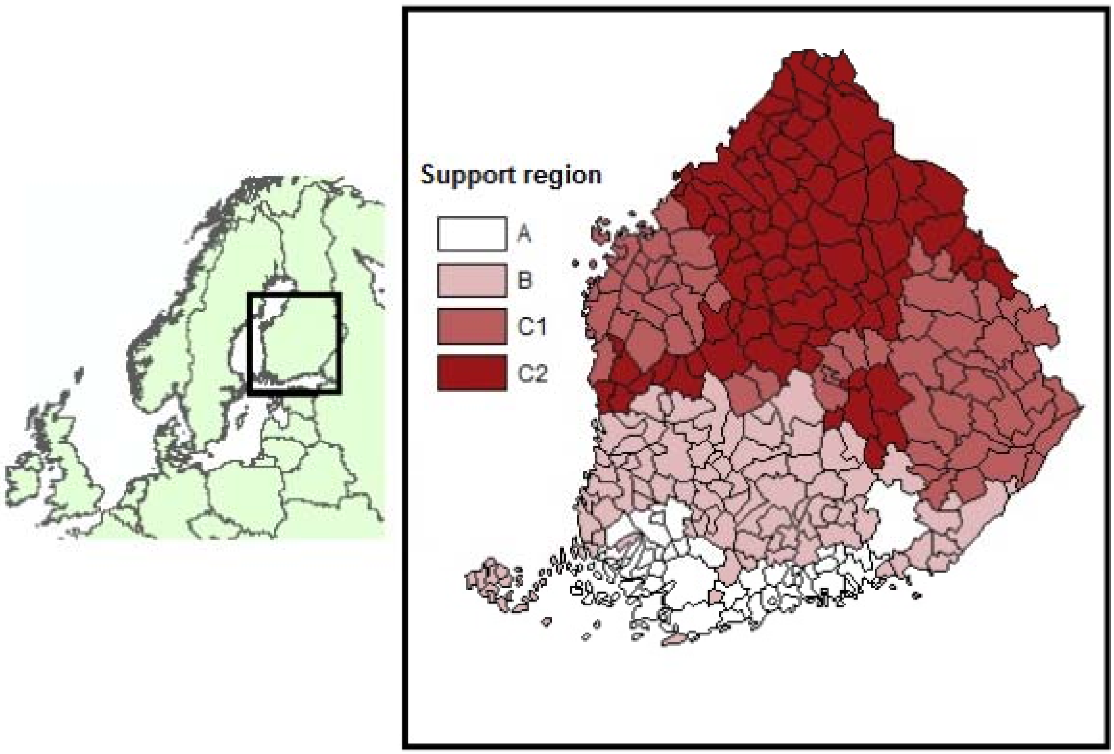
[3] These include farmer training, farm environmental planning and monitoring, environmentally sound use of pesticides, maintenance of biodiversity, and landscape management.

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-area payments and national aid for crop production.

The agricultural support payment rates are graded over seven support regions, which were delineated at the time of Finland's accession to the EU in 1995 and reflect regional climatic conditions. We focus on the four southernmost regions (labeled A to C2), which encompass 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 in the subsequent econometric analysis. Variation in the payment rates arises for several reasons: support for 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-area support (the support was extended to all of Finland in 2000); and at the time of accession Finland bargained for and was granted the right to pay additional northern aid to areas north of the 62nd parallel. In the estimation stage, we control for province and farm fixed effects, which may be correlated with the historical reference yields and average costs. We assume that the remaining variation in the payment rates is exogenous. Changes in payment rates over time have also been asymmetric across support regions.[4]

[4] The asymmetries arise from renegotiations with the EU on which parts of Finland are eligible for less-favored-area support, from transitional support that was only payable during the first years in the EU and was gradually phased out, and from 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.



Approximately 5% of participating farms are audited each year. The audits focus 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 reprimand or sanction for non-compliance (NAOF 2008).[5] Sanctions take the form of cuts in the current year's program payments of 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 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 received agri-environmental payments yet appear to have violated the constraint on nitrogen application ranged from 33 to 61% over the study period.[6]

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[5] Of the total number of audited farms, 75% are chosen through risk-based sampling and 25% through random sampling.

[6] 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; inputs purchased in a given year are not necessarily applied in that year, as fertilizers can be stored.

3. Behavioral model: farms' decisions on land allocation and input use

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 agricultural support payment rates (including general agri-environmental support rates) to be exogenous.[7] Finland's overall cereal production amounted to 1-2% of the EU total in the years 1997-2007 (source: Eurostat), and price feedbacks are thus 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.

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. Under the agricultural conditions in Finland grains also have similar nutrient loading potential, and they are typically grouped together in land use analyses (see e.g. Helin, Laukkanen and Koikkalainen 2006 and Ekholm et al. 2007). Thus, for simplicity, we aggregate across the grains in the analysis to follow. Farms may also leave land fallow, known 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 based 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, which include the CAP arable-area and less-favored-area subsidies as well as Finnish national subsidies for crop production. Farms participating in the FAEP receive additional environmental subsidies, also proportional to land area. Moreover, farms participating in the special sub-program within the FAEP earn special subsidy payments, which are generally based on the land area subject to a specific agri-environmental measure, such as riparian zone or wetland.

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[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. found evidence that farmers were risk-averse prior to Finland's accession to the EU in 1995 and risk-loving thereafter, due to the increase in the non-random part of farm income brought by the introduction of the CAP. For the period 1995-2003, Koundouri et al. estimated the risk premium to be between -2 and 2% 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.

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 kth 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. Farm profit is given by

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

The representative farm is assumed to maximize profits 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 $l_g(\mathbf{p,r,s})$, $l_f(\mathbf{p,r,s})$, $l_e(\mathbf{p,r,s})$, $w_k(\mathbf{p,r,s})$ and $q_g(\mathbf{p,r,s})$. 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 actual 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:

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

$$\frac{\partial l_g}{\partial L} + \frac{\partial l_f}{\partial L} + \frac{\partial l_e}{\partial L} = 1 , \qquad (3)$$

where s_j denotes the jth 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

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

where J indexes the subsidy rates (for grains, set-aside, and special agri-environmental measures) and K the inputs (fertilizers, pesticides, 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

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

where $l_g q_g$ is the total grain output;

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

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

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

where w_f and w_p represent input demand for fertilizers and pesticides, respectively.

We are only able to estimate land allocation equations for grains (l_g) and set-aside (l_f) since our data do not specify the land area subject to 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 they receive, and for the implications the payments have 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 fallow each year.[8] 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 that its 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 the value zero to set-aside in the land allocation equation.

Land allocation and output are also influenced by factors that are unobservable to the analyst. These factors can be either period specific (e.g. weather and pests) or farm specific (e.g. soil quality and 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 control of unobserved individual heterogeneity.

[8] 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 to 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 pesticides (labor being the numeraire), the equations for land allocated to grains and set-aside, and total grain output, all subject to 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:

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

The exogenous explanatory variables are the output price p_g, the vector of subsidy rates $\mathbf{s}$, 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 addressed here: i) some farms do not have any land in voluntary set-aside (i.e., $l_{f,it} = 0$)[9]; ii) a subset of farms receives the special agri-environmental subsidy; and 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 presented by Shonkwiler and Yen (1999). The Shonkwiler-Yen approach, which allows one to estimate 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.

[9] Voluntary set-aside (l_f) is equal to zero for about 13% of observations in our sample.

The special agri-environmental subsidy is received only by farms that agree to undertake certain 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 where these measures are implemented. Because our objective is to analyze the impact of the FAEP on farms' production decisions, it is important to control for the fact that some farms receive the special subsidy and for the amount received, since these may have direct implications for farms' input use, land allocation, and grain output. In order to control for a possible selection bias due to farms opting to join the special sub-program, 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 the farmer's age, the price of pesticides, 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 unobserved farm effects are not correlated with the model's explanatory variables. The amount of the special agri-environmental subsidies predicted from the estimation of the random-effect Tobit model is then incorporated into the right-hand side of each equation in the system.

In order to control for possible correlation between unobserved farm-specific effects and some of the explanatory variables when estimating the system of equations, we apply the Within transformation to all variables and estimate a *Seemingly Unrelated Regression Equations (*SURE) model. The Within transformation, which deviates variables from their individual means, cancels out time-constant unobserved individual effects.

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 pesticides, work hours, and compensatory payments received, including agri-environmental payments, for a total of some 900 farms each year. While the data distinguish payments made through the FAEP general and special sub-programs, they do not specify the agri-environmental measures adopted or the area on which contract-based special measures have been implemented. The analysis spans the years 1996-2005, that is, from Finland's second year in the EU to the last year when crop-specific CAP arable-area payments were used.[11] The final sample used in the analysis includes farms that are located in one of the four southernmost support regions, that had some land allocated to grain crops, and that attributed a maximum of 30% of their total variable costs to animal production. The resulting data comprise 343 farms and 1,564 observations (an unbalanced panel).[12]

Full-time farm enterprises are overrepresented in the bookkeeping data, whereby the average farm size is larger than the national average. This feature is also present in our sample. Otherwise, the sample is representative of grain farms in Finland. The patterns of farm size across time and geographic location are similar for the sample and for national data. Average farm size increases over the period 1996-2005, and decreases from south to north (Appendix 2 Tables A2.1 and A2.2). In terms of the geographic location of the farms, Southern Finland (support regions A and B) is somewhat overrepresented in our sample (Tables A2.3 and A2.4). Fertilizer purchases in proportion to cultivated land in the sample show a pattern that is similar to national statistics (Tables A2.5 and A2.6 in Appendix 2).

The farm data were complemented with average national crop prices collected from *Finnish Agriculture and Rural Industries*, published by MTT Agrifood Research annually, and with price indices for fertilizers and pesticides

[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 for 1995, Finland's year of accession to the EU. The EU single-farm payment, a result of the 2003 CAP reform, was introduced in Finland in 2006. The single-farm payment to farmers is based on the land that they manage or own, not on the crops that they produce.

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

(100=2005) and labor prices, obtained from Statistics Finland (Table A3 in Appendix 3). The average hourly wage for forest maintenance work was used as a proxy for the labor price as statistics on agricultural wages are not available. The same input price indices were applied to all farms; that is, indices vary only across years. For grain price we computed region-specific values using the farm-level data on revenues, yields, and areas used for barley, wheat, oats and rye, complemented by 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.[13] The per-hectare subsidy rates for grains and set-aside used in the analysis are the sums of the CAP arable-area, CAP less-favored-area, national crop production, northern aid, and general agri-environmental support rates applicable to each land use and each support region. The subsidy rates, which differ across the support regions, were ascertained from *Finnish Agriculture and Rural Industries*. 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 the farms in our sample.

Summary statistics (Table 1) show that on average the grain area per farm 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 decreased on average, also reflecting the national trend (Table A2.5).

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

[13] Because data on grain revenue were missing for some farms and we sought to avoid a 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.

As shown in Table 2, the total subsidies in proportion to land area increased over the study period. The subsidies paid for areas in grain production increased on average, while the subsidies for set-aside (in constant terms) decreased over the study period. The general FAEP payments in proportion to land area decreased slightly on average. The proportion of farms participating in the FAEP special sub-program in our sample increased over the study period, whereas the average amount of special environmental subsidies in proportion to farm area among special sub-program participants 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] (EUR/ha)	Mean subsidies for grains[a] (EUR/ha)	Mean subsidies for set-aside[a] (EUR/ha)	Mean FAEP general subsidies (EUR/ha)	Farms with special FAEP payments (%)	Mean FAEP special subsidies[b] (EUR/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 less-favored-area 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 one-percent level).[14] The 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 regarding farm operation, meaning that they are likely to be more competent and more willing to invest time and effort in the environmental planning required by 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 requirements. Location in a province along the west coast of Finland also has a statistically significant positive effect, a finding that may be explained by proximity to the Baltic Sea and the resulting greater awareness among farmers of the sea's nutrient-related water quality problems.

In the second stage, the six-equation system described in (10) was estimated on a total of 1,564 observations; the standard errors and t-statistics were obtained using bootstrapping techniques.[15] Chi-squared tests indicate overall significance in the case 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 the application of fertilizers and pesticides. The estimated coefficients for the corresponding four equations are shown in Table A4 in Appendix 4.[16]

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 had a fairly small impact on the grain-producing 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, those authors found an elasticity of 0.16 for land planted with cereals with respect to area-based subsidies for cereals. By contrast, area-based subsidies for

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

[15] Monetary values have been converted into 2005 EUR using the consumer price index (source: Statistics Finland).

[16] The full set of estimated coefficients is available from the authors upon request.

set-aside area had a large impact on the set-aside area in our sample: the median elasticity is 1.52, whereas Lacroix and Thomas report an elasticity of 0.12. Area-based subsidies for grains also increased total use of fertilizers and pesticides, although the impacts were small (elasticities of 0.01 and 0.04). The special environmental subsidies had 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 have also found that the subsidies provided through the FAEP special sub-program decreased total fertilizer use but that the impact was small in magnitude: a 1% increase in the special agri-environmental subsidy resulted in only a 0.05% decrease in total fertilizer use. The special environmental subsidies increased the total use of pesticides but this effect was also small in magnitude.

To check the consistency of our estimates, we also calculated own price elasticities, which were all statistically significant (at the one-percent level of significance). The (median) elasticity of grain area to grain price is 0.30, whereas the own price elasticities of the demand for fertilizers and pesticides 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 pesticide 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 pesticide 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 pesticide use	0.063	**

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

6. Simulations

To assess the impact of the FAEP payments on nutrient pollution from agricultural land, 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 for 1996-2005, and (2) a counterfactual no-policy scenario, where the 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 in order to identify the effects of the FAEP payments. Comparing the factual simulation with the counterfactual allows us to isolate the effects of the FAEP payments on land allocation and input use, 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 in our sample were 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 being equal, would increase nutrient loading. Our finding that the FAEP payments increased the area under cultivation is in line with previous results. Pufahl and Weiss (2009) found that the area under cultivation for participants in the German AEPs grew by 7.7% on average from 2000 to 2005, while the growth rate was only 4.2% for farmers not participating in an AEP.[17] In terms of fertilizer use, the impact goes in the desired direction, but is small: the FAEP payments resulted in a less than 2% reduction in fertilizer use in the sample, again in line with the findings of Pufahl and Weiss (2009) for Germany.

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[17] Results from a comprehensive analysis of land-use changes in the US, 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 net returns on crops (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).

Table 4. *Land allocation and fertilizer use in the sample under the prevailing policy and under a counterfactual scenario, where FAEP payments equal zero.*

Variable	EU agricultural policy and agri-environmental subsidies at historical values (prevailing policy)	EU agricultural policy and no agri-environmental subsidies (counterfactual)	Percentage change produced by agri- environmental subsidies (%)
Total grain area (ha)	64,396	63,042	2.1
Total set-aside area (ha)	5,237	6,591	-20.5
Total fertilizer use (1,000 kg)	35,262	35,803	-1.5

7. Benefits and costs of the agri-environmental payments

Changes in land allocation and fertilizer use will affect nutrient pollution from agricultural land. We now proceed to assess the impact of FAEP payments on this environmental outcome in our sample of grain farms. Specifically, we use the predicted land allocation and fertilizer intensity under the "factual" baseline and the no-policy counterfactual scenario as inputs in environmental production functions in order to 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.

Nutrient loading is affected by not only changes in nutrient inputs and land use but also the conservation measures adopted. Among the key measures that the FAEP imposes on grain farms are field margins along main drains and filter strips along waterways.[18] 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 maintaining 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 the proportion of the total field area covered by vegetative filter strips and wintertime vegetation for all the farms participating in the FAEP. This information has been obtained from the farm surveys, farmer interview studies, and administrative records on FAEP additional measures and special sub-program contracts that are 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.

7.1 Environmental production functions

Degradation of the surface water quality in the Baltic Sea, the main recipient of nutrient loads from agriculture in Finland, is governed by the joint presence of nitrogen and phosphorus (see e.g. Tamminen and Andersen 2007). We predict nutrient loads using environmental production functions, one for nitrogen and two for the focal forms of phosphorus, dissolved and particulate. The first

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[18] 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-area payments also require field margins 0.6 m in width along main drains and waterways.

function was developed in Simmelsgaard (1991) and Simmelsgaard and Djurhus (1998), and the last two in Uusitalo and Jansson (2002). These functions relate fertilization intensity to nutrient loading using coefficients that capture the impacts of crop choice, tillage practice, soil and field characteristics, and climatic factors. The coefficients have been calibrated by Helin, Laukkanen and Koikkalainen (2006) to correspond to the average soil characteristics, field slope and climatic conditions in southern Finland. As we do not have information on the environmental characteristics of the farms, we apply the parameterization for average conditions in southern Finland as an approximation.[19] All in all, the results for nutrient losses 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).

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 loss of nutrient *m,* with $m \in \{N, DP, PP\}$; s_m and d_m are the shares of nutrient *m* loss carried through surface and drainage flow; *B* denotes the share of land allocated to vegetative filter strips; b_m is a parameter capturing the effect of such strips on the loss of nutrient *m;* $\overline{N}$ is a reference nitrogen fertilization level; and θ is the soil phosphorus level. We consider a compound fertilizer with 20% nitrogen and 3% phosphorus content.[20] Given a predicted fertilizer quantity x, the amounts of nitrogen and phosphorus applied are $x_N = 0.20x$ and $x_P = 0.03x$.

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

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

[19] The study region in Helin, Laukkanen and Koikkalainen (2006) covers approximately support regions A and B in our study. The calibration draws on physical models predicting nitrogen and phosphorus loads (SOIL-N and IceCream, respectively) and monitoring data on nitrogen and phosphorus loads from agricultural land.

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

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

and the particulate phosphorus loss (kg/ha) by

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

Table 5 shows the nutrient loss 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 nutrient loading from grain areas. Based on MAF (2004), the share of field area covered by vegetative filter strips 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 vegetative filter strips on non-participating farms was set at 0.04% (CAP field margin). The parameter estimates for vegetative filter strip impact, $b_N = 0.2$, $b_{DP} = 1.3$ and $b_{PP} = 0.3$, were obtained from Lankoski, Ollikainen and Uusitalo (2006).21 The proportions of nutrient loss occurring 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 the average values in Turtola and Paajanen (1995). The soil phosphorus levels (θ) used in the analysis are soil test averages for each province in our sample for the periods 1996-2000 and 2001-2005, obtained from Viljavuuspalvelu Oy (Soil Testing Service Ltd.).22 The share of field area under wintertime vegetation was set at 30% in support regions A and B and 0% elsewhere in the years 1996-1999, which is an approximation based on the FAEP requirements for that period. In the 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 maintain vegetation in the winter has been reduced tillage (MAF 2004), and we apply nutrient load parameters corresponding to reduced tillage on the grain area covered by wintertime vegetation. The price of the compound fertilizer was set at the 2002 price, 0.23 EUR/kg.

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

[22] Viljavuuspalvelu Oy is a commercial soil test laboratory and the market leader in soil testing in Finland. Soil testing is required for farms participating in the FAEP. Consequently, the soil test data provided by Viljavuuspalvelu Oy provide a reasonable picture of agricultural land in Finland.

Table 5. Nutrient load parameters (from Helin, Laukkanen and Koikkalainen 2006).[23]

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 plow).

7.2 Monetary benefits of reduced nutrient pollution

Assessing the welfare effects of agri-environmental payments calls for a monetary measure of the benefits of reduced nutrient pollution. Developing such a measure of non-market benefits is complicated by the fact that degradation of the quality of surface water in the Baltic Sea is governed by the joint presence of nitrogen and phosphorus. Indeed, 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). Accordingly, what is needed for assessing the benefits of reduced nutrient pollution on the basis of valuation studies is a composite measure of nitrogen and phosphorus loads.

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. We consider two alternative weights on phosphorus: $a = 1$ and $a = 7.2$. The weight $a = 7.2$ reflects the prevalence of nitrogen-fixing blue-green algae in the Baltic Sea. These organisms are able to bind nitrogen from the atmosphere to phosphorus in the water. Due to nitrogen fixation, phosphorus entering the water ecosystem can result in the conversion of an average of 7.2

[23] 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.

times its weight of atmospheric nitrogen into a form available to aquatic plants, thereby potentially causing 7.2 times more eutrophication than nitrogen.[24]

We use results obtained 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 experiment corresponded to forecasts by Baltic Sea ecosystem models. The scenario relevant to this study reduced Finland's nitrogen and phosphorus loads by 7,986 and 525 tons per year, relative to the 1997-2002 levels, over a 20-year time frame.[25] The estimated annual WTP by the Finnish population for these nutrient load reductions ranged 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, respectively.[26] 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).

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

[25] 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).

[26] 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 period. 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.

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 1	77 (71-83)	111 (105-117)
Phosphorus weight 7.2	55 (51-60)	80 (76-85)

7.3 Benefit-cost comparison

The impact of agri-environmental payments on social welfare comprises changes in consumer surplus and producer surplus. Our approach enables an assessment of both. However, to achieve transparent comparisons with a previous EU AEP study, that by Chabe-Ferret and Subervie (2012), we focus on consumer surplus, measured by the environmental benefits in terms of nutrient load reductions attributable to FAEP payments.[27] 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 all program payments. A plausible value for the opportunity cost of public funds in Finland is 1.15.[28]

Nutrient load reductions attributable to the FAEP payments were simulated using environmental production functions (10) to (12), the land allocation and input use under the factual and the no-policy counterfactual simulations (Table 4), and the shares of vegetative filter strips and wintertime vegetation 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.[29] The consequences of these changes for damage to the surface water quality of the Baltic Sea are reported in Table 7.[30] Part A in the table displays the estimated

[27] The impact of the FAEP payments on producer surplus in our sample is also small, amounting on average to 1 EUR/ha/year over the 1996-2005 period.

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

[29] The total nitrogen loads for the factual and counterfactual simulations were 1,335 tons and 1,507 tons, and total phosphorus loads 85 tons and 98 tons. The corresponding average nitrogen loads were 19.2 kg/ha and 21.6 kg/ha, and the average phosphorus loads 1.2 kg/ha and 1.4 kg/ha. The environmental simulation performs well in reproducing magnitudes of nutrient loads that are in line with ecological assessments of nutrient loading from agricultural areas in Finland (Rekolainen et al. 1995, Vuorenmaa et al. 2002).

[30] While a significant proportion of the nutrient loading from farms in Finland is transported into the Baltic Sea, some of the nutrients are retained in inland waters. As our damage estimates are for the Baltic

damage from nutrient loading originating from the sample farms for each scenario and for alternative damage parameterizations. The simulated nitrogen and phosphorus loads have been summarized in 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 estimates combine the reduction in the per-hectare nutrient load from grain areas stemming from decreased fertilizer use as well as the increase in grain area and decrease in set-aside area that are attributable to the agri-environmental payments.

The total damage avoided in 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 multinomial logit 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 random parameters logit 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 random parameters logit model over the basic multinomial logit. It should also be noted that our assessment of environmental benefits focuses on the implications of the FAEP payments for surface water quality in the Baltic Sea. Additional benefits may be attributable to reductions in the application of pesticides, increases in biodiversity and improvements in 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. On balance, our findings indicate that the FAEP has merits in terms of reducing agriculturally produced nutrient loading.

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 of the Finnish Environment Institute for calculating the retention rate from the regression model.

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 1		RPL estimate P weight 1		MNL estimate P weight 7.2		RPL estimate P weight 7.2	
A. Simulated damage	Total 1,000 €	Average €/ha	Total 1,000 €	Average €/ha	Total 1,000 €	Average €/ha	Total 1,000 €	Average €/ha
Prevailing policy	83,873	1,205	120,908	1,736	75,561	1,085	109,906	1,578
Counterfactual	94,662	1,359	136,461	1,960	85,624	1,230	124,543	1,789
B. Effect of FAEP payments								
Change in total damage (%)[b]	-11		-11		-12		-12	
Benefit-cost ratio[c]	0.73		1.05		0.68		0.99	

[a] MNL: evaluated using the marginal damage rate derived from Kosenius' (2010) multinomial logit model.
RPL: evaluated using the marginal damage rate derived from Kosenius' (2010) random parameters logit model.
[b] The difference between the counterfactual and prevailing-policy simulations 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).

8. Conclusion

Over one hundred regional or national conservation schemes have been introduced in the EU since the Agri-environmental Regulation came into force in 1992. By 2002, one quarter of the agricultural area in the EU was registered in an agri-environmental program. The programs are essentially voluntary regulation that provides incentives, but not mandates, for reducing the environmental damage from agriculture. 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 World Trade Organization'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 under a system of compensatory payments that are proportional to land area, including agri-environmental subsidies. The estimated land allocation and input demand functions were then used to predict the impact of the agri-environmental payments on grain and set-aside areas and fertilization intensity. We next combined the predicted land allocation and input use with environmental production functions to assess the impact of program payments on water protection.

The econometric and simulation analyses indicate that the agri-environmental payments to grain farms had a fairly small effect on fertilizer use and area of land used for grain production over the period 1996-2005. At -1.5% the impact on fertilizer use is smaller than that indicated in Pufahl and Weiss (2009) for German AEPs (average treatment effect of -9.5%). By raising the profitability of land used to produce grain, the payments also had the counterproductive impact of reducing the amount of 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 over the period 1996-2005 was to reduce nitrogen loading by 11% and phosphorus loading by 13% relative to what would have happened without agri-environmental subsidies. 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%, 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 nutrient pollution from farms. 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 the reductions needed to significantly improve water quality in the Baltic Sea. This suggests that more specifically targeted policies would be needed to further reduce farm-source nutrient loading, such as taxing 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 predictive ability of our modeling approach 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 as a whole. Our estimate of the benefits from the FAEP is based on reductions in farm-source 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 pesticides and, starting from the second program phase (2000-2006), to maintain biodiversity and rural landscapes. Possible benefits produced in terms of these additional objectives are not included in our benefit estimate. That estimate was also derived under the assumption of constant marginal damage from nutrient loading, which is a simplification. However, as the predicted changes in nutrient loading are not very large, 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, alternative agri-environmental payment rates, and the relative emphases to be placed on payments provided through general and more specifically 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. In the case of nutrient loads, the accuracy of predictions could be improved by integrating the land allocation and fertilizer intensities simulated with the economic model with catchment-scale physical models simulating nutrient loads from different land uses and fertilizer intensities (e.g. INCA, Wade et al. 2002, and SWAT, Arnold and Fohrer 2005).

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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 farm *i* at time *t* ($l_{f,it}$) can be written as follows:

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

Let us 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 and $\mathbf{x}_{it}$ the vector of explanatory variables, which includes the price of output, the prices of fertilizer and pesticides, the set of subsidies and total land. The vector $\mathbf{z}^{'}_{it}$ contains explanatory variables that are assumed to influence the farm's decision to have some 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 $\text{cov}\left(\varepsilon_{it}, v_{it}\right) = \delta$. In addition, we have the following relationships:

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

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

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

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

Hence, the 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, pesticides and labor; the per-hectare area-based subsidies, including CAP arable-area and less-favored-area and basic environmental subsidies); the per-hectare subsidy for 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 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] 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] 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, which has a 20% nitrogen 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 Centre of the Ministry of Agriculture and Forestry (TIKE). The kg/ha estimate has been calculated as the ratio of fertilizer sales in Finland at large and the total cultivated area.

Appendix 3. Price statistics

Table A3. Mean grain price, mean labor price, and fertilizer and pesticide price indices (base 100 in 2005)

Year	Grain price	Labor price	Fertilizer price index	Pesticide 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
Price of pesticides	-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
Price of pesticides	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
Price of pesticides	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 pesticides			
Fertilizer price	279.185	32.096	0.000
Price of pesticides	-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).

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GOVERNMENT INSTITUTE FOR ECONOMIC RESEARCH

Valtion taloudellinen tutkimuskeskus
Government Institute for Economic Research
P.O.Box 1279
FI-00101 Helsinki
Finland

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