Determinants of Nitrogen Surplus at Farm Level in Swiss Agriculture

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Abstract

This paper investigates the determinants of nitrogen surplus and of its two components – nitrogen intensity and nitrogen-inefficiency – at farm level in Swiss agriculture. Our analysis is based on a cross-section of 210 farms from the year 2010. The nitrogen balance of each farm is estimated according to the OECD soil-surface approach. The determinants are analysed by means of a three-equation regression model estimated using a robust SUR approach. Farm size, part-time farming, organic farming, arable cropping and farmer's age are found to negatively affect nitrogen surplus, whilst dairy, pig and poultry farming are associated with a higher nitrogen surplus.

Keywords: environmental performance, nitrogen surplus, farming

1. Introduction

The sustainable use of natural resources, i.e. efficient use of these resources and limiting the environmental impacts associated with their use, is one of the main objectives of Swiss agricultural policy (FOAG, 2010). Nitrogen (N) use is a key environmental issue in agriculture, eutrophication being one of the major environmental problems associated with the use of this nutrient. Water protection, and hence the reduction of nitrogen losses caused by agriculture, are of central importance in Switzerland, owing, among other things, to the country's geographical location and topography, as well as its associated role of major European water reservoir. Since the late 1990s, the national nitrogen surplus from Swiss agriculture has more or less stabilised at around 110,000 tons (Spiess, 2011). Consequently, the Swiss agricultural-policy objective of reducing the national nitrogen surplus from agricultural activities to 95,000 tons by the time horizon of 2005 (Bundesblatt, 2006) has fallen short of the mark. The ability to formulate recommendations for achieving the objective of nitrogen-surplus reduction set by agricultural policymakers presupposes a better understanding of nitrogen use at micro-level – i.e. farm-level – where the decisions regarding the use of this nutrient occur. Relying on a unique and innovative dataset combining agri-environmental indicators and farm accountancy data for a sample of farms from the Swiss FADN, the present paper aims to investigate the determinants of nitrogen surpluses at farm level in Swiss agriculture.

2. Data

2.1. Sample of farms

Our investigation is based on a cross-sectional and non-random sample of 210 farms from the year 2010. The farms of the sample are distributed across almost all strata of the farm population of the Swiss FADN, a stratum being defined according to the Swiss FADN typology as a homogeneous group of farms in terms of farm type (agricultural activity) and agricultural region (plain, hill or mountain region).

2.2. Estimating the farm soil-surface nitrogen balance according to the OECD approach

The nitrogen balance of the farms of the sample is estimated according to the soil-surface approach developed by the OECD (OECD and EUROSTAT, 2007). Nitrogen balance is defined as the difference between nitrogen input and output. Nitrogen input encompasses the following elements: fertilisers (inorganic fertilisers, livestock manure and any other organic fertilisers), biological nitrogen fixation, atmospheric deposition, and nitrogen contained in seeds and planting material (OECD and EUROSTAT, 2007). Nitrogen output comprises the nitrogen removed with the harvested crop (including fodder crop) or with the grazed fodder crop or grass (OECD and EUROSTAT, 2007). In the present paper, nitrogen losses from manure via ammonia volatilisation in farm buildings (livestock housing), during manure storage and during and after manure spreading are included in the balance, thereby implying the use of a gross-balance approach.

Each nitrogen input and output element is assessed on the basis of data collected specifically for this purpose on each farm. A detailed description of the approach used to estimate each separate element of the nitrogen balance can be found in Spiess (2010).

3. Method

3.1. Concept

The determinants of farm nitrogen surplus per ha UAA (Utilised Agricultural Area) are investigated using a three-equation regression model. In the following, we set out the conceptual underpinning of the approach followed. Conceptually, a high nitrogen surplus per hectare can be the result either of high nitrogen intensity, defined as the nitrogen input per ha UAA; of high inefficiency in nitrogen use, 'inefficiency' being defined here as the ratio between nitrogen surplus per ha and nitrogen input per ha; or of both high nitrogen intensity and inefficiency. In order to better understand the causes of high nitrogen surpluses, we must identify not only the determinants of nitrogen surplus, but also those of its two components, nitrogen intensity and inefficiency. In the present study, we therefore estimate three regression models: one explaining the determinants of nitrogen surplus per ha UAA, the second investigating the determinants of nitrogen intensity per ha UAA, and the third examining the determinants of nitrogen inefficiency (in %).

3.2. Specification of the regression models

The potential determinants included in the regression models can basically be classified into five groups: the farm's natural environment; its structural characteristics; its production system; its production orientation (farming activities); and the socio-demographic characteristics of the farm manager.

The natural production conditions of the farms are represented by two dummy variables – hill region and mountain region – derived from the categorical variable 'agricultural production region of the farm', which encompasses three modalities: plain, hill and mountain region. Two variables related to the structural characteristics of the farm were incorporated into the model: farm size and farming form. Farm size is measured by the utilised agricultural area of the farm (in ha). Farming form consists of two dummy variables: full-time farm with secondary income, and part-time farm. The production form, represented by a dummy variable (conventional vs. organic farming), describes the farm's production system. Production orientation, i.e. the type of farming activities found on the farm, is represented by three variables measuring the proportion of output from arable crop, dairy farming and granivores (pigs and poultry) in the farm's agricultural output. For the 'nitrogen surplus' and 'nitrogen intensity' regression models, we also included the squared term of the two regressors 'proportion of output from dairy farming in farm's agricultural output' and 'proportion of output from granivores in farm's agricultural output', owing to the nonlinearity of the relationship between the dependent and independent variable. Thus, for these two variables, the model specification is of the form $b_1x^2+b_2x$. Two variables related to the socio-demographic characteristics of the farm manager were included in the model: the age of the farm manager in years, and a dummy variable for his/her level of agricultural education.

In the regression model analysing the determinants of each of the two components of the nitrogen surplus, the other component was included in the model as a control variable. This was done because the two nitrogen surplus components – nitrogen intensity and nitrogen inefficiency – are correlated (r=0.30, p<0.001). Owing to this property, when analysing the effect of a variable x (e.g. the dummy variable 'mountain region') on one of the two components (e.g. nitrogen inefficiency, hereafter referred to as 'y'), it is necessary to control for the other component (in the example: nitrogen intensity, hereafter referred to as 'z') – i.e. to ensure that the other component is kept constant. This is accomplished by introducing the other component (z) as an independent variable in the regression model.

3.3. Estimation procedure

The classic approach used to estimate a regression model is the OLS or Ordinary Least Squares approach. The three-equation system presented in Section 3.1 will not, however, be estimated via the OLS approach owing to (i) the presence of outliers and (ii) the presence of a contemporaneous correlation between the error terms across equations. To overcome the problem of outliers, we use iteratively reweighted least squares (IRLS), a robust regression technique implemented in the rreg estimation procedure of the Stata software Package (StataCorp, 2011; Hamilton, 1991). The final weights (a weight having been estimated for each observation according to the outlierness of its residual) from the IRLS regression are then used in the second step of the estimation procedure described hereafter. Because the error terms are correlated across equations (Breusch-Pagan test for independent equations, p<0.001), the three-equation model is estimated using the approach developed by Zellner (1962) for seemingly unrelated regressions (SUR). The two-stage FGLS (feasible generalised least squares) procedure is used here to estimate the SUR equation systems.

4. Results

For all three regression models, we can reject the H_0 hypothesis that all coefficients of the model are equal to 0, i.e. that none of the predictors is linearly associated with the predicted variable (F-Test of overall significance, p<0.001). The highest goodness-of-fit can be observed for the regression model explaining the nitrogen intensity (R^2=0.69). The goodness-of-fit is substantially lower for the model explaining the nitrogen balance (R^2=0.47), whilst the model explaining the nitrogen inefficiency has the lowest coefficient of determination (R^2=0.31). The results of the regressions are presented in detail below.

The natural environment of a farm is shown to influence its nitrogen-use pattern. Whereas hill farms do not significantly differ from plain farms with regard to their nitrogen surplus, mountain farms – despite significantly higher nitrogen inefficiency (-12%, p<0.001) – have a lower nitrogen balance (-23 kg N per ha, p=0.003) than plain farms. This is because mountain farms have a significantly lower nitrogen intensity (-109 kg N per ha, p<0.001). Even if farm size (UAA) has a positive effect on nitrogen inefficiency (+0.2% per additional ha UAA, p<0.001), it has a significant negative impact on nitrogen balance (-0.3 kg N per additional ha UAA, p=0.058) due to the negative impact of farm size on nitrogen intensity (-1.8 kg N per additional ha UAA, p<0.001). This negative impact outweighs the positive impact of farm size on nitrogen inefficiency. Farming form is also shown to influence nitrogen balance. Whereas full-time farms with secondary income sources do not differ significantly from full-time farms without secondary income sources in terms of nitrogen balance, part-time farms are characterised by a significantly lower nitrogen surplus (-16.5 kg N per ha, p=0.007) than their full-time counterparts. This stems from the significantly lower nitrogen intensity of part-time as compared to full-time farms (-41 kg N per ha, p<0.001), which is, however, partially offset by the formers' higher nitrogen inefficiency (+2.5%, p=0.059). Production system, represented by the variable 'production form', also turns out to affect the nitrogen balance. Organic farms have a significantly lower nitrogen surplus (-29.7 kg N/ha, p<0.001) than conventional farms, essentially owing to their significantly lower nitrogen intensity (-41.6 kg per ha, p<0.001). Production orientation, depicted by the output-proportion variables, is shown to be an important determinant of nitrogen balance and its components. An absolute increase of 1% in the proportion of farm agricultural output coming from arable crops leads *ceteris paribus* to a decrease in nitrogen balance of 0.4 kg/ha (p=0.027), owing to the fact that this 1% increase is associated with a lower nitrogen intensity (-0.9 kg N per ha, p<0.001). As regards the proportion of farm agricultural output deriving from dairying (referred to hereafter as 'proportion of dairying'), both linear and quadratic terms have a significant effect on the nitrogen balance (p=0.003 and p=0.009, respectively). The marginal effect of the proportion of dairying comes to 0.664-0.012x, and is a decreasing function of x which is positive in the range 0 to 55% and then becomes negative. The proportion of dairying influences both components of nitrogen balance. Its marginal effect on nitrogen intensity amount to 1.124-0.012x while its effect on nitrogen inefficiency is linear and negative, and amounts to -0.06% inefficiency per additional per cent of dairying in the farm output. The proportion of granivores in the farm agricultural output (referred to hereafter as 'proportion of granivores') also has a significant impact on nitrogen balance. Both linear and quadratic terms of this predictor have a significant effect on the predicted variable (p<0.001 for both terms). The marginal effect is equal to 1.909-0.042x. Looking at the components of the nitrogen balance, we discover that the proportion of granivores affects both nitrogen intensity and nitrogen inefficiency. The marginal effect on nitrogen intensity stands 2.314-0.06x. The marginal effect on nitrogen inefficiency is linear, and comes to 0.05% inefficiency per additional per cent of granivores in the farm output. The socio-demographic characteristics of the farm manager are also shown to be important factors for explaining the variability of the nitrogen balance. Farm manager's age is shown to have a negative impact on nitrogen surplus (p=0.005). An additional year's age leads to a decrease in the nitrogen balance of 0.7 kg N/ha. This can be explained by the fact that nitrogen intensity significantly decreases with the age of the farm manager (-1.2 kg N/ha per additional year's age, p<0.001). Inefficiency remains unaffected by the age of the farm manager. The farm manager's education is shown to be an important factor in explaining farm nitrogen balance. Farms with managers of a higher agricultural education level (i.e. above a completed apprenticeship) exhibit a significantly higher nitrogen balance (+9.3 kg N/ha, p=0.056) than those with managers of a lower agricultural education level. This is the result of the significantly higher nitrogen intensity of better-educated managers (+24.4 kg N/ha, p<0.001), which is nevertheless partially outweighed by their lower inefficiency (-1.8%, p=0.102).

5. Discussion

This paper provides evidence that the nitrogen surplus of a farm is dependent on the farm's characteristics, and can therefore be controlled by agricultural policymakers. By increasing farm size (i.e. through scale effects) and promoting organic and part-time farming, major reductions in Swiss agriculture's nitrogen surplus could be achieved. For the three factors under consideration, the reduction in nitrogen surplus occurs through a reduction of nitrogen intensity. The finding that dairy as well as pig and poultry farming lead to a higher nitrogen surplus – especially when combined with other agricultural activities – is not a new one, as the problem of high groundwater nitrate concentrations is also found in regions with these types of farming. The high nitrogen surpluses found in dairy, pig and poultry farming would appear to stem primarily from an intensity problem. This implies that addressing nitrogen intensity is the key to sustainably reducing the nitrogen surpluses associated with this type of animal production. The fact that the hill region has neither a lower nitrogen surplus nor a lower nitrogen intensity than the plain region indicates that, in the hill region, nitrogen fertilisation may not be suited to the natural production conditions. In fact, owing to the shorter vegetation period of the hill region, we would expect a significantly lower nitrogen intensity, and hence a lower surplus, than in the plain region.

More generally, the fact that the goodness-of-fit of the model explaining nitrogen inefficiency is significantly lower than that of the model explaining nitrogen intensity indicates that it may be more challenging to reduce nitrogen surplus by reducing nitrogen inefficiency than by decreasing nitrogen intensity, as the former may be dependent on a multiplicity of factors that could be very difficult to control.

When interpreting the results of this work, the sample-related limitations of the study should be taken into account. The first limitation lies in the fact that the sample was not drawn at random, with the associated consequences in terms of representativeness. The second sample-related limitation lies in the fact that the sample does not cover the whole Swiss farming sector; in fact, a number of farm types are wholly missing from the sample. Last but not least, the fact that this study relies on cross-sectional data is a weakness of which we are aware. In addition to these sample-related issues, when drawing conclusions based on the results of this analysis, it is important to bear in mind that this work focuses on just one dimension of the environmental performance of a farm – i.e. the local dimension. The global environmental performance of a farm – defined as the ability of a farm to produce a maximum output per unit of environmental impact generated over the entire production chain up to the farm gate (Jan et al., 2012) – has not been taken into account.

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