# A Structural Equation Model of Farmers Operating within Nitrate Vulnerable Zones (NVZ) in Scotland

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*Abstract.* **Structural Equation Modelling (SEM) offers a theoretical basis for developing an understanding of the relationships between attitudes and behaviour. This paper imposes the SEM framework to a compulsory regulation which focuses on reducing diffuse water pollution, namely Nitrate Vulnerable Zones (NVZ). We use a data set collected through a farm survey within NVZs in Scotland in 2007. The model includes six latent variables expressing farmers' nitrate reducing behaviour, nitrate reducing and profit maximising behavioural propensities and the underlying determining factors, namely attitude (risk perception) and socio-economic latent variables (access to information and stocking density). The results indicate that the model has an adequate fit to the data and access to information is the strongest determinant of farmers' nitrate reducing behaviour.**

*Keywords.* **Nitrate Vulnerable Zones, Structural equation modelling with latent variables, Scotland**

## I. INTRODUCTION

The application of the Nitrates Directive (91/676/EEC) and the establishment of Nitrate Vulnerable Zones (NVZ) is a concerted effort by the European Union to reduce nitrate pollutants at a catchment level. NVZs impose limits on the rates of organic nitrogen application and to the timing of these applications on agricultural land. One of the complaints against the regulation is that the limits imposed by the regulation are the same across the EU and take no account of a particular country's geo-physical and climatic conditions. Some states, such as Denmark and Northern Ireland, have adopted NVZ status on a country wide basis. However, others, such as Scotland, have targeted particular regions which have catchments where there may be potential problems with nitrate levels within surface and groundwaters. In Scotland, areas were identified that may be at risk of exceeding limits, but do not actually breach maximum levels. There are at present four regional NVZs in Scotland, these are Moray, Aberdeenshire, Banff and Buchan, Strathmore and Fife, Lothian and Borders and Lower Nithsdale. In total these cover around 12,000 farmers operating within Scotland.

The Action Programme for Nitrate Vulnerable Zones (Scotland) Regulations 2003 (SI 2003 no. 51) establishes the current programme, monitoring, offence procedures where the rules have been contravened and appeals procedures. The NVZ rules are reviewed at regular intervals and have generally increased restrictions upon a farmer's agricultural activity, for example, by limiting the amount of nitrogen fertilisers than can be applied to crops and by imposing additional slurry storage requirements.

Little work has been conducted on farmers' general attitudes and behaviour towards NVZ regulations. Accordingly, it would seem that understanding the factors which restrict, or act as obstacles to, the adoption of regulatory standards is crucial to the success of policy aimed at reducing environmental harm. This paper examines the relationships between farmer attitudes and practices towards nitrate reduction in the Scottish NVZ areas using a structural equation modelling approach. The paper is structured as following: section 2 briefly reviews the literature identifying the determinants of farmers' conservation behaviour and, more specifically, nitrate reduction behaviour. Sections 3 and 4 present the case study and the methodology. Section 5 discusses the results and section 6 presents some conclusions.

## II. WATER POLLUTION AND FARMERS' ATTITUDES AND BEHAVIOUR

There is a large body of research analysing the determinants of farmers' environmental conservation behaviour. Most of these studies examine the influence of socio-economic and structural factors on behaviour and decision-making [1]. Some others use the theory of reasoned action [2] which is based on the assumption that farmers' behavioural intentions and behaviour are directly related to their attitudes [3].

A smaller number of studies have examined farmers' attitudes and behaviour as regards diffuse water pollution issues, e.g., nitrate vulnerable areas, generally finding amongst participants a general lack of knowledge about them. Some work exists on watershed resource management in different countries [4]. This latter study found that farmers operating within the catchment had a 'neutral to slightly positive environmental attitude' overall. A most relevant study for this research is [5] as it is the only research concentrated on the awareness of, and sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland. However, as this was a small study of arable farmers within one catchment it was difficult to generalise findings across other farm types and NVZs within Scotland.

Accordingly, this paper addresses the present gaps in knowledge regarding farmers operating within NVZs in Scotland by testing *a priori* confirmed relationships between farmer attitudes and practices.

## III. DATA COLLECTION METHOD

A telephone survey was conducted in February and March 2007. Names and telephone numbers of 700 holdings were provided by the Scottish Government from the agricultural census. The aim was to obtain a stratified sample with an equal distribution from within each of the four NVZs. These addresses were then supplied to a third party marketing research company who conducted the telephone survey. In total 182 responses were received, giving a return rate of 26%. The survey included a number of sections featuring questions relating to details about the farmer and the farm business, business objectives, decision-making and planning, information sources and sources of advice. Further core sections of the survey investigated farmer attitudes to a range of issues, including production, environmental issues, responsibility for environmental damage, compliance with the regulation, and water management. In addition, farmer goals were investigated, specifically water pollution goals, farm profit goals, innovation goals, social peer goals, and environmental stewardship goals.

## IV. METHODOLOGY

To identify the factors determining farmers' nitrate reducing behaviour, we follow the attitude-behaviour framework as used in most literature on agri-environmental issues. To statistically test the relationships within this framework, we use structural equation modelling (SEM) with latent (unobserved) variables. We first identify the latent variables structuring the model and their constituent indicators. Then, we validate the construction of the latent variables by means of factor analysis and finally, we build and test the structural equation model by assigning the relevant relationships between the different latent variables.

### *A. Indicators and Latent Variables*

We identified and extracted six latent variables expressing the behaviour, behavioural propensity and the underlying determining factors, namely attitude and socio-economic latent variables. The variables are: 'nitrate reducing behaviour', 'nitrate reducing behavioural propensity', 'environmental risk perception', 'profit maximising behavioural propensity', 'agri-environmental information access' and 'stocking density'. The six latent variables are measured by 15 indicators (the constituent observed variables). Table 1 gives an overview of the various variables, including their summary statistics.

The 'profit maximising behavioural propensity' (ecintpr) is measured by the indicators: farmers' behavioural propensity to have the very best high yielding livestock/crops (ecintpr1), farmers' behavioural propensity to make the largest possible profit (ecintpr2) and farmers' behavioural propensity to pay attention to market prices (ecintpr3). The behavioural intentions depicted by the three indicators were measured qualitatively using a six-point Likert scale, namely responses scored from 1 to 6 from ‘strongly disagree’ to ‘strongly agree’.

Table 1. Descriptive statistics

| | Mean | Std. Deviation |
|---|---|---|
| Ecintpr1 (“Farmers should always aim to have the very best high yielding livestock/crops”) | 3.93 | 1.054 |
| Ecintpr2 (“For me it is important to make the largest possible profit”) | 3.85 | 1.016 |
| Ecintpr3 (“It is important for me to pay attention to market prices”) | 4.31 | .761 |
| Risk1 (“Water quality can affect the quality of my crops”) | 3.04 | 1.144 |
| Risk2 (“Water quality can affect the health of my livestock”) | 3.72 | .999 |
| Info1 (“Have you ever travelled abroad in order to look at different farming systems?”) | 1.70 | .460 |
| Info2 (“Do you attend training workshops or farm group meetings, e.g. monitor farms?”) | 1.41 | .493 |
| Info3 (“Do you pick up ideas for the farm business from other farmers?”) | 2.07 | .864 |
| Econ1 (“Stocking Density”) | 2.04 | 1.269 |
| Nvzint1 (“It is important for me to reduce nitrate application”) | 3.16 | 1.302 |
| Nvzint2 (“It is important for me to reduce chemical nitrogen application using organic manures/wastes’) | 3.66 | 1.074 |
| Nvzint3 (“It is important to me to use and store manure/slurry correctly”) | 4.36 | .794 |
| Nvzbhv1 (“Do you prepare a nutrient management plan?”) | 1.45 | .499 |
| Nvzbhv2 (“Do you keep records of fertiliser and manure applications for individual fields?”) | 1.18 | .382 |
| Nvzbhv3 (“What type of fertiliser do you use?”) | 1.29 | .456 |

The attitude latent variable ‘environmental risk perception’ (risk) is measured by the indicators: farmer’s acknowledgment of the threat to crops’ health represented by water pollution in the community (risk1) and farmer’s acknowledgment of the threat to livestock health represented by water pollution in the community (risk2). The two variables are ordinal using a five-point Likert scale from ‘strongly disagree’ to ‘strongly agree’.

The socio-economic latent variable ‘agri-environmental information access’ (info) is measured by the indicators: farmers’ travelling abroad in order to look at different farming systems (info1), farmers attending training workshops or farm group meetings, e.g. monitor farms (info2), farmers picking up ideas for the farm business from other farmers (info3). Variable info1 and info2 are dichotomous variables taking value 1 if farmers have travelled abroad and, respectively, attended training workshops, and value 0 if else. Variable info3 is a categorical variable with four levels taking value 1 if farmers are frequently picking up ideas for the farm business from other farmers, through sometimes / rarely to never picking up ideas from other farmers.

The socio-economic latent variable ‘stocking density’ (econ) is a single-indicator construct representing livestock density. It is a categorical variable with four levels taking value 1 for stocking density equal to, or less than 0.5, value 2 for stocking density between 0.51 and 1.00, value 3 for stocking density between 1.01 and 1.5 and value 4 for stocking density equal to or above 1.51.

The ‘nitrate reducing behavioural propensity’ (nvzint) is measured by the indicators: farmers’ behavioural propensity to reduce nitrate application (nvzint1), farmers’ behavioural propensity to use organic manures/wastes’ (nvzint2) and farmers’ behavioural propensity to use and store manure/slurry correctly (nvzint3). The behavioural intentions depicted by the three indicators were measured qualitatively using a six-point Likert scale, namely responses scored from 1 to 6 from ‘strongly disagree’ to ‘strongly agree’.

The ‘nitrate reducing behaviour’ (nvzbhv) is measured by the indicators: farmers’ preparing a nutrient management plan (nvzbhv1), farmers’ keeping records of fertiliser and manure applications for individual fields (nvzbhv2) and farmers’ choice of fertilisers (nvzbhv3). Variable nvzbhv1 and nvzbhv2 are dichotomous variables taking value 1 if farmers prepare nutrient management plans and, respectively, keep records of fertiliser and manure applications for individual fields, and value 0 if else. Variable nvzbhv3 is a categorical variable with two levels taking value 1 if farmers use inorganic fertilisers or mixed and value 2 for use of organic fertilisers only.

### *B. Validation of Latent Variables Using Factor Analysis*

As a test of the validity of the latent variables, we undertook factor analysis with varimax rotation. Each set of variables loaded onto a separate factor, and only six factors were retained, such that these six factors could be taken to represent the relevant latent variables (Table 2).

Table 2. Factor analysis for identification of the latent variables

| Rotated Component Matrix | | | | | | |
|---|---|---|---|---|---|---|
| | Component | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Ecintpr1 | .053 | **.800** | .097 | -.042 | .039 | .085 |
| Ecintpr2 | -.045 | **.840** | -.095 | -.036 | -.008 | .073 |
| Ecintpr3 | -.414 | **.629** | .156 | .049 | -.155 | -.135 |
| Risk1 | .070 | -.029 | .074 | .363 | **.749** | -.048 |
| Risk2 | .033 | -.022 | .168 | -.192 | **.805** | -.104 |
| Info1 | .373 | .099 | -.119 | **.484** | .185 | .217 |
| Info2 | .508 | -.007 | .141 | **.567** | -.221 | .000 |
| Info3 | .066 | -.091 | .092 | **.812** | .065 | -.181 |
| Econ1 | -.240 | .091 | -.017 | -.108 | -.156 | **.832** |
| Nvzint1 | .214 | -.189 | **.639** | .183 | .270 | .222 |
| Nvzint2 | .119 | .240 | **.718** | .064 | .255 | .054 |
| Nvzint3 | -.208 | .020 | **.701** | -.061 | -.123 | -.276 |
| Nvzbhv1 | **.795** | -.036 | -.034 | -.026 | .034 | -.012 |
| Nvzbhv2 | **.738** | -.038 | .073 | .251 | .068 | -.167 |
| Nvzbhv3 | **.718** | -.098 | .043 | .153 | .054 | -.099 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 7 iterations.
Boldface values indicate items loading most heavily on each factor.
Total Variance Explained 65.82

Once we had established that latent variables could be identified, we undertook a separate factor analysis for each set of indicators. The individual factor analyses each extracted a single factor, with all variable loadings above the 0.5 value threshold and most of them above the recommended value of 0.7. The total variance of the indicators explained by each of the latent variables varied between 51% and 69% which confirmed the choice of observed variables consistent with their empirical significance.

*C. Structural Equation Modelling with Latent Variables*

Structural equation models are generally used to investigate interrelationships amongst variables, some of which may be latent [6]. Often the interest concentrates on the relationship between latent variables of attitude and behaviour and/or behavioural propensity regarding specific issues [2].

The basic SEM consists of two parts, namely the measurement model specifying the relationships between the latent variables and their constituent indicators and the structural equation model designating the causal relationships between the latent variables. The model is defined by the following three equations in matrix terms [7]:

The structural equation model: $\eta = B\eta + \Gamma\xi + \zeta$

The measurement model for y: $y = \Lambda_y \eta + \varepsilon$

The measurement model for x: $x = \Lambda_x \xi + \delta$

where: $\eta$ is an mx1 random vector of endogenous latent variables; $\xi$ is an nx1 random vector of exogenous latent variables; B is an mxm matrix of coefficients of the $\eta$ variables in the structural model; $\Gamma$ is an mxn matrix of coefficients of the $\xi$ variables in the structural model; $\zeta$ is an mx1 vector of equation errors (random disturbances) in the structural model; y is a px1 vector of endogenous variables; x is a qx1 vector of predictors or exogenous variables; $\Lambda_y$ is a pxm matrix of coefficients of the regression of y on $\eta$; $\Lambda_x$ is a qxn matrix of coefficients of the regression of x on $\xi$; $\varepsilon$ is a px1 vector of measurement errors in y; $\delta$ is a qx1 vector of measurement errors in x.

SEM takes into account both direct and indirect causal relations between constructs, which means that one causal relation may be reinforced or counteracted by another. Running alternative models and comparing them with the proposed model may provide additional evidence that the chosen model is the best in representing the reality. We undertake SEM with categorical variables defined on ordinal scales using the statistical package Lisrel 8.50 [7]. The recommended method consistent with the sample size is the normal-theory maximum likelihood (MLE) method [6].

## V. RESULTS AND DISCUSSION

Figure 1 presents the path diagram for the estimated model (standardised solution).

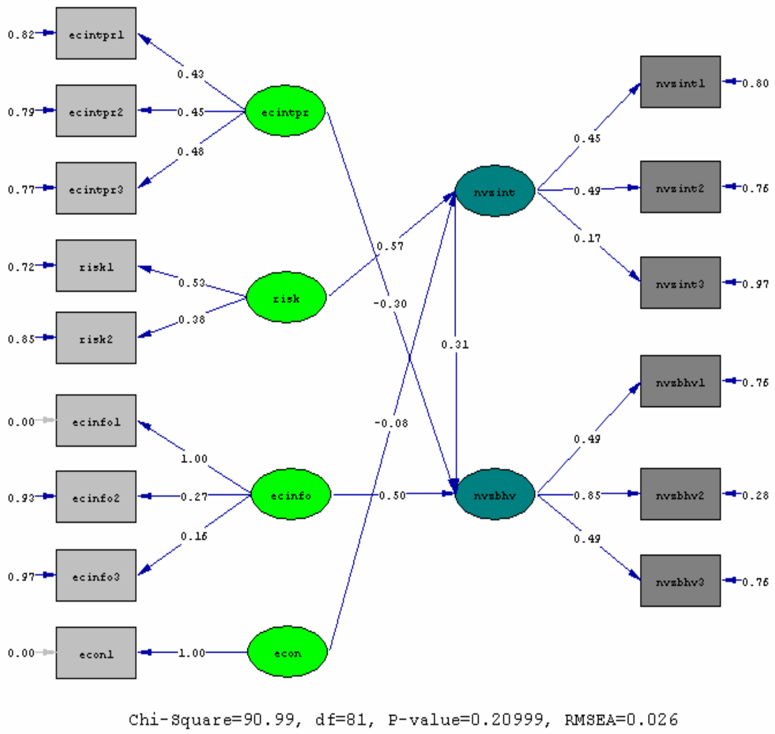


Fig. 1. Path diagram for the estimated model (standardised solution)

The optimal estimated model includes four exogenous latent variables, namely ‘profit maximising behavioural propensity’ as a predictor of ‘nitrate reducing behaviour’; ‘environmental risk perception’ and ‘stocking density’ as predictors of ‘nitrate reducing behavioural propensity’; ‘agri-environmental information access’ as a predictor of ‘nitrate reducing behaviour’). ‘Nitrate reducing behavioural propensity’ is a variable with alternating roles, namely endogenous as predicted by ‘environmental risk perception’ and ‘stocking density’ on the one hand, and exogenous as predictor of ‘nitrate reducing behaviour’ on the other. The behavioural latent variable, ‘nitrate reducing behaviour’ is endogenous as predicted directly or indirectly by all the other latent variables.

The model has an adequate fit according to the measures of absolute, incremental and parsimonious fit [8]. The low chi-square value of 90.99 together with the high p-value of 0.21 for the chi-square test confirm no statistically significant differences between the covariance matrices of the observed sample and estimated model. The normed chi-square (ratio between the chi-square and number of degrees of freedom) value of 1.12 is within the recommended interval of 1 to 3. The root mean square error of approximation (RMSEA) value of 0.026 is safely below the threshold maximum value of 0.10, therefore indicating excellent fit (with a p-value for test of close fit ‘RMSEA < 0.05’ equal to 0.94) . Similarly, the standardised root mean residual (SRMR) value of 0.069 lower than the threshold of 0.08 indicates good fit. The comparative fit index (CFI) value of 0.96, incremental fit index (IFI) value of 0.97, non-normed fit index (NNFI) value of 0.95, goodness of fit index (GFI) value of 0.94, adjusted goodness of fit index (AGFI) value of 0.91 are above the cutoff values for fit indices, the ‘magic 0.90 or 0.95’ [8].

Additional testing of the appropriateness of the model was achieved by comparing the estimated model with two other models that acted as alternative explanations to the proposed model, in a competing nested model approach. The first alternative model added ‘stocking density’ as predictor of ‘environmental risk perception’ and cancelled ‘stocking density’ as predictor of ‘nitrate reducing behavioural propensity’. The second alternative model added ‘agri-environmental information access’ as predictor of ‘environmental risk perception’, cancelled ‘agri-environmental information access’ as predictor of ‘nitrate reducing behavioural propensity’, and added ‘environmental risk perception’ as predictor of ‘nitrate reducing behaviour’. The results across all types of goodness-of-fit measures favoured the estimated model in most cases.

The validity of the structural equation model is assessed in a two-step procedure, measurement model and structural model. The measurement model results show that the sets of indicators for the five multiple-indicator constructs do not all have comparable indicators, but all loadings are statistically significant with the exception of nvzint3, which is nevertheless retained in the model due to its theoretical significance. All the coefficients are well above the recommended minimum value of 0.20 with the exception of info3 and nvzint3 with values close to 0.20 [7], thus supporting the theoretical basis for assignment of indicators to each construct.

After assessing the overall model and aspects of the measurement model, we examined the structural standardised coefficients for both practical and theoretical implications. Table 3 shows that both structural equations contain statistically significant coefficients.

Table 3. Standardised parameter estimates for the structural model. Structural equation coefficients (t values in parentheses)

| Endog. constructs | Endog. constructs | | Exog. constructs | | | | $R^2$ |
|---|---|---|---|---|---|---|---|
| | nvzint | nvzbhv | ecintpr | risk | info | econ | |
| nvzint | 0.0 | 0.0 | 0.0 | 0.57 (2.33) | 0.0 | - 0.08 (-0.64) | 0.35 |
| nvzbhv | 0.31 (2.05) | 0.0 | - 0.30 (-2.51) | 0.0 | 0.50 (4.33) | 0.0 | 0.49 |

In the first basic relationship, the exogenous constructs 'risk' and 'econ' are predictors of 'nvzint'. The relationship between 'risk' and 'nvzint' was found significant (t-value of 2.33) with a high parameter estimate (0.57). However, the relationship between 'econ' and 'nvzint' was found insignificant (t-value of -0.64) with a low parameter estimate (-0.08). The combined effect of the constructs 'risk' and 'econ' achieves an $R^2$ value of 0.35.

Research has demonstrated that farmers' interest in environmental conservation, namely, in our case, water pollution abatement in nitrate vulnerable zones is often triggered by their perception of environmental risk. [9] makes the point that even if people are aware of environmental change, it only becomes an issue if they feel 'threatened'. [10] found that respondents who worried about the impact of environmental problems on their own personal safety were more likely to have an environmentally friendly behaviour. [11] noted that farmers who had experienced agri-chemical-related health problems were more likely to adopt alternative production practices than those who had not. We found that the higher the farmers' perception of crop and animal health risks from water pollution with nitrates, the higher their nitrate reducing behavioural propensity.

The relationship between 'econ' and 'nvzint' (which is the only non-significant relationship in the model) is based on the confirmed link between economic factors and environmental concern, which has been repeatedly investigated in the literature [12]. For our case study one would expect that the higher the stocking density the lower the propensity to act in a nitrate reducing way, as the costs related to manure storage would increase accordingly. The relationship was found to be of correct *a priori* sign (negative), however it was not found significant.

For the causal relationship linking 'nvzint', 'ecintpr' and 'info' with 'nvzbhv', all constructs are statistically significant (with, respectively, t-values of 2.05, -2.51 and 4.33) and of appropriate direction ('nvzint' and 'info' positive and 'ecintpr' negative). The highest estimated parameter is for variable 'info' with a value of 0.50, while 'nvzint' and 'ecintpr' explain 0.31 and, respectively, -0.30 of the 'nvzbhv' variance. The combined effect of the three constructs achieves an adequate $R^2$ value of 0.49, thus explaining about half of the variance of the latent variable 'nvzbhv' [8].

The causal relationship between 'nitrate reducing behavioural propensity' (nvzint) and 'nitrate reducing behaviour' (nvzbhv) is significant and supports the theory of reasoned action [2] which is based on the assumption that behavioural intentions predict behaviour.

The causal relationship between 'profit maximising behavioural propensity' (ecintpr) and 'nitrate reducing behaviour' (nvzbhv) is again significant and of *a priori* correct sign (negative) showing that the stronger the propensity to act in a profit-oriented way the less strong the nitrate reducing behaviour. This supports the literature that have demonstrated in several instances that economic factors will constrain environmental protection behaviour.

The causal relationship between 'nitrate reducing behaviour' (nvzbhv) and 'agri-environmental information access' (info) is the most significant relationship in the model. The relationship between access to information and environmental protection behaviour has been investigated extensively. [13] found that farmers who placed greater importance on information from news media and extension services tended to express greater environmental concern. Various other studies suggest that personal contacts may be more important than any form of mass media, highlighting the importance of the network of acquaintances one has in a community. According to [14], farmers' leading sources of information as regards conservation techniques are other farmers with successful experience, local agricultural dealers, and local government agencies. No matter the source, access to information is one of the undisputed determinants of farmers' environmental protection behaviour.

The model takes into account both direct and indirect causal relationships between constructs, which signifies that one causal relationship may be reinforced or counteracted by another. Specifically, the fact that 55 percent of the farmers operating in NVZs prepare nutrient management plans, 80 percent keep records of fertilisers and manure applications, and 30 percent use only organic fertilisers (which are the three indicators that constitute nitrate reducing behaviour) is then significantly influenced by a combination of the following factors: 30 percent of the farmers have travelled abroad in order to look at different farming systems; 60 percent attend training workshops or farm group meetings; 23 percent frequently pick up ideas for the farm business from other farmers; 60 percent on average show a nitrate reducing behavioural propensity; 40 percent are aware of the impact of nitrate pollution on crop health; 65 percent are aware of the impact of nitrate pollution on livestock health; and 70 percent have a profit-oriented behavioural propensity.

## VI. CONCLUSIONS

This paper has highlighted the complexity of factors influencing Scottish farm decision-making, in terms of their nitrate reducing behaviour. Through measurement of latent variables, the SEM framework allowed us to capture the linkages between various factors which may precede a particular response to the NVZ regulations.

The results indicate that having access to information is the strongest determinant of farmers' nitrate reducing behaviour. Other significant factors are environmental risk perception, nitrate reducing behavioural propensity, and profit maximising behavioural propensity.

Our research has found that, in the interrelationship between attitudes, perceptions and structural circumstances, the influence of attitudes and perceptions on farmers' conservation behaviour was less strong than the structural influences. Namely, while farmers' nitrate-reducing behavioural intentions were significantly influenced by environmental risk perception (positive relationship), their actual nitrate-reducing behaviour was more strongly influenced by farmers' access to information (positive relationship) and their profit-oriented behavioural intentions (negative relationship).

What these key findings suggest is the need for policy makers to provide farmers with information about the potential risks of nitrate pollution in terms of impacts on the health of their livestock and crops and, implicitly, on farm profitability, and about the means to reduce these risks in the context of the NVZ regulatory framework.

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