Famer willingness to adopt mitigation measures for water quality improvements

Abstract

Diffuse pollution from agriculture continues to be a significant threat to waterbodies. This study investigates the role of diverse farming objectives on a farmers' openness to adopt a suite of mitigative measures that could have a positive effect on water quality. Based on a farmer survey, factor analysis was used to reduce a long list of potential farming objectives to three: Long Term Economic objectives (LTE), Short Term Economic objectives (STE) and Environmental objectives (ENV). The results indicate that farming objectives are a highly significant predictor of openness to adopt mitigation measures that have the potential to improve water quality. Our findings suggest that farmers with LTE and ENV objectives are more open to adopting many of the same mitigation measures while farmers with STE objectives are less open.

Key words: Farmer objectives; Mitigation measures; diffuse pollution; water quality improvements.

1 Introduction

In 2019, 43% of Irish river water bodies assessed over the period 2017-2019 were in moderate, poor or bad quality, and failed to meet the required status of high or good biological quality as set out in the Water Framework Directive 2000/60/EC (EPA 2020). Agricultural practices and land use decisions have been highlighted as a significant driver of ecological degradation in freshwater systems (Dupas, Tavenard et al. 2015, McDowell, Snelder et al. 2018, Mellander, Jordan et al. 2018). A number of agricultural based mitigation measures have been identified which have the potential to reduce the risk of nitrogen and phosphorus transferring from agricultural land to watercourses (Cherry, Shepherd et al. 2008, Jeppesen, Kronvang et al.

2009). However, the effectiveness of these measures is lost if farmers do not adopt. Understanding the key drivers of farmer decision making and farmers openness to adopt new measures or adapt existing farm management practices is important if policy makers wish to influence behavioural changes at farm level (Greer 2005, Buckley, Hynes et al. 2012, Vrain, Lovett et al. 2014, Lastra-Bravo, Hubbard et al. 2015, Vrain and Lovett 2016, Mills, Gaskell et al. 2017).

The decision to adopt is a complex multi-criteria process, strongly influenced by the judgments of their peers and various institutional mechanisms like legal instruments, economic rewards, provision of advice and voluntary collective actions (Blackstock, Ingram et al. 2010). Previous adoption literature, that focused specifically on key factors influencing farmer behaviour around measures that have the potential to improve water quality stress the importance of linking advice and behavioural changes (OECD 2012, Gabel, Home et al. 2018). It is also important to have an understanding of how to provide farmers with farm and location specific advice (Birner, Davis et al. 2009, Mills, Gaskell et al. 2017, Mills, Gaskell et al. 2018, Eastwood, Ayre et al. 2019). The highly heterogeneous and dynamic nature of agriculture is also an important factor in understanding the decision to adopt (Blackstock, Ingram et al. 2010). Influencing farmers to adopt requires tailoring advice and linking it to specific behavioural changes, a theoretical understanding of the practice clearly presented by knowledge transfer specialists and an understanding of different audiences (Blackstock, Ingram et al. 2010).

At its core, farmer decisions to adopt any practice with environmental benefits has a public good element, in which those who provide the good incur all the costs but have no way of capturing the economic benefits, since the benefits are the public good benefits such as increased security or wellbeing which have no market value. However, some mitigation measures do have the potential to provide private economic benefits such as increased efficiencies and reduced costs, especially on the nutrient management side and are often referred to as “win-win” situations (Buckley and Carney 2013, Norton, Suryaningrum et al. 2020). Studies have also found that farmers are resistant to environmentally targeted agricultural policies as they perceive these policies to be costly, reduce farming choices and affect production efficiency (Arovuori 2011). As well as the perception that these measures are costly, farmers feel that investment in mitigation actions at farm level may ultimately constrain agricultural production and hence farmers face an additional hidden cost (Andersen, Blicher-Mathiesen et al. 2014). A socio economic study of farmers in Scotland found that farmers rarely consider environmental issues beyond the boundaries of their farms and did not believe they were responsible for any water quality problems (Macgregor and Warren 2006).

The objective of this study is to investigate the importance of heterogeneous farming objectives on a farmers’ willingness to adopt a suite of mitigation measures that have the potential to improve water quality. The adoption of these measures may involve a behavioural change around existing practices or additional costs where the measures involve construction costs. The effectiveness or success of the measures can also be difficult to identify because of the many stakeholders involved or a substantial lag time before improvements are observed (Melland, Fenton et al. 2018). Farmers may also have different farming objectives, for some, financial gain is important and as with any business these farmers will have a predominantly profit maximizing objective. For others a range of social, environmental and lifestyle objectives are also important (Vanclay 2004, Howley, Buckley et al. 2015). The literature also finds that while farming objectives play an important role in adoption, policy measures needed to encourage different types of farmers may differ (Brown, Daigneault et al. 2019). Farmers who have a predominantly financial objective may respond to financial incentives whereas farmers with an environmental objective may not respond as positively to financial incentives if they do not fully accept the environmental benefits of the measures. The importance of understanding the decision making process of key actors is crucial in influencing change across multiple levels of planning, decision-making and action. A key challenge is enabling implementation of local management action, which can be influenced by a range of factors across multiple levels (Patterson, Smith et al. 2013, Wiering, Boezeman et al. 2020).

1.1 Theoretical framework

Since the objective of the various mitigation measures in this study is to protect and improve water quality the theoretical bases for this study falls outside the traditional profit maximization model of behaviour, since water quality is a non-marketed good. Although the nutrient management measures do have the potential to reduce costs and increase efficient nutrient uses, farmers were asked whether they were open to adopt these measures specifically for water quality improvements. We therefore place this study within the rational choice theory, and follow a utility maximization framework to analyse farmer behaviour with respect to public good provision based on the framework outlined by (Jongeneel and Ge 2010). The utility maximization framework can capture the role of farmer attitudes and objectives and as such, a farmer will adopt a mitigation measure for the provision of public goods if and only if the adoption of the mitigation measure increases his/her maximised utility (Jongeneel and Ge 2010). Consider that the agricultural producer's utility is determined by his farm income (profit from producing agricultural goods, income from an off farm job), non-pecuniary benefits from on-farm production activities (and possible provision of public goods), and leisure.

We define a farmer's utility function U, as follows:

$$u(I, B, R)$$

Where:

I = monetary income;

B = non-pecuniary benefits of farm production, modelled as a function of family labour used for on-farm production and possible additional land endowments;

R = Leisure.

We assume an additive utility form such that

$$u(I,B,R) \ = \ U(I) \ + \ B(h+l) \ + \ R(r) \ ,$$

Where:

$$I = py + mw - xq - vl - F$$

Where:

y = marketed output

p = output price (vector of output prices in case of multiple outputs)

w = wage at the labour market

l = amount of land

m = off-farm labour work

r = leisure time

h = family labour used for on-farm production

x = marketed variable input (vector of marketed inputs in case of multiple inputs, including hired labour)

q = input price (vector of input prices in case of multiple inputs)

v = fixed costs per hectare, these are fixed costs related to the use of land

F = fixed costs per farm, examples of the fixed costs are for example maintenance costs of machinery, rent costs for buildings, etc.

The farmer solves the utility maximization problem as follows

$$Max\ u(I,B,R) = U(I) + B(h+l) + R(r)$$

Subject to

$$l \leq A$$

$$h + m + r = H$$

$$l, h, m, r, x \geq 0$$

A = total land area

H = total family labour

Using this framework a farmer will adopt a mitigation measure for water quality improvements if the adoption of such measures increases his/her maximum utility, that is

$$du(l, h, x, m, r, Q) \geq 0$$

Where

Q = Q non-commodity outputs (such as possible public goods)

Therefore, if a farmer is to adopt a mitigation measure, the utility he/she receives from the adoption of the measure must be equal to or greater than the opportunity cost of the measure. The opportunity costs depends on an individual's marginal utility of income. This implies that for the same level of compensation farmers with already high incomes are more prone to accept the compensation than farmers with relatively low income. This holds even if the marginal productivity of land is the same for both farmers (Jongeneel and Ge 2010).

The paper is organised as follows: section 2 outlines methods including data used in the analysis, a description of the different mitigation measures, the factor analysis methodology and the empirical model, which is a multivariate, ordered probit model. Section 3 presents the results of the multivariate ordered probit model and summary statistics. In section 4 we discuss the results which are presented in the previous section and in Section 5 we conclude with a summary of the main findings of the paper.

2 Methods

2.1 Data

The data for this analysis were derived from a survey of 402 farmers within twelve river catchments throughout the Republic of Ireland. All catchment areas were selected to be representative of intensive grassland and arable agricultural systems in Ireland where there is a potential risk of P and N transfer and subsequently tend to represent more intensive farming systems (Buckley, Howley et al. 2015)Geographic Information Systems multi-criteria decision analysis was employed to select these case study catchments. The criteria used for selection included maximisation of agricultural intensity (based on percentage arable or forage area and livestock grazing intensity), minimisation of non-agricultural land uses (forestry, residential housing density) and the selection of a range of soil and geology types that were indicative of high N or P transport risk. The size of the catchment areas ranged from 4km^2 to 12 km^2, with two larger catchment areas of approximately 30 km^2. The method for catchment selection is described in detail by (Fealy, Buckley et al. 2010).

A questionnaire was designed to collect data from farmers across a range of topics including attitudes to farming and the environment, farm structures and profile, socio-demographics, contact with extension services and adoption of a range of nutrient management best practices. This questionnaire aimed to establish a baseline in terms of nutrient management practices, assess farmer willingness to provide ecosystem services and explore farmer opinion on regulations post EU Nitrates Directive implementation across the Republic of Ireland. A team of professional recorders to collected the data from 402 farmers across 12 catchment areas.

Twenty potential mitigative measures to combat diffuse pollution, avoid nutrient loss to watercourses and maintain a nutrient balance in the soil were identified in consultation with research and extension specialists in the area. These represented a comprehensive list of measures, which, based on site characteristics, and farming system have the potential to reduce the transfer of nutrient from agricultural land to watercourses. Of the twenty potential measures included in the survey, only eight of the mitigation measures were applicable to both livestock and tillage farmers. These form the basis of this study. Respondents were asked to rank how open they were to adopting each measure using a Likert scale index, ranging from 1 = "not at all open" , 2 = "not very open", 3 = "neutral", 4 = "somewhat open" to 5 = "very open".

The eight mitigation measures included in this study are listed in Table 1. This list of measures can be divided into two distinct types, nutrient management best practice measures or land use management measures. Nutrient management best practice measures refer to when, where, how and how much fertilizer is applied. These measures cover the four "R's" which are considered best practice for nutrient management practice, the right fertilizer in the right place at the right time and the right rate. These measures represent a change in behaviour around farm management practices that are currently in place on the farm. On the other hand, land use management measures involve a once off decision with additional costs to the farmer and a possible long-term reduction in farm size depending on the farms proximity to a river and the length of river running through the farm. These land management measures could result in long-term implication for farm production, and therefore result in financial costs as well as opportunity costs.

Table 1. Different Mitigation Measures, type of measure and benefits of measure

Mitigative measures	Type	Benefits
Avoid spreading fertilizers at high risk times - RIGHT TIME	Nutrient Management	Timing fertiliser applications during periods of rapid growth will result in more efficient nutrient use and reduces the risk of nutrient losses
Not applying phosphorous fertilizers to soils already high in phosphorus –RIGHT RATE	Nutrient Management	The availability of nutrients, and the clear understanding of their benefits can lead to more efficient nutrient use and reduces the risk of nutrient losses
Not applying fertilizers to areas of high risk for nutrient loss – RIGHT PLACE	Nutrient Management	Ensuring the right product is used in the right locations reduces the risk of potential loss to

		waterbodies, especially on fields with high connectivity to water bodies
Use of slurry band or injection spreading machinery – RIGHT METHOD	Nutrient Management	The use of precision techniques reduces the amount of run off and the risk of nutrient losses, increases nutrient availability to plants and prevents damage to fields
Establishing Riparian Buffer Strips along watercourses	Land Management	Creating buffer zones where little or no agricultural activity takes place helps to intercept nutrients transported via overland flow
Re-siting gateways away from high risk areas	Land Management	Preventing run off reduces the risk of nutrient transfer to waterbodies
Fencing off watercourses	Land Management	Unrestricted cattle access to waterways can have a negative impact on water quality, therefore fencing off watercourses reduces this risk
Establishing and maintaining artificial wetlands	Land Management	Artificial wetlands retain sediment and associated pollutants, they also help with nutrient cycling and can provide positive water quality outcomes

2.2 Factor Analysis

This study employs factor analysis, a statistical technique that is used to reduce a large number of variables/statements into smaller groups of latent variables that capture the similarities of the variables in the latent construct (Ford, MacCallum et al. 1986, Hayton, Allen et al. 2004). There are a number of steps involved in this type of analysis. First the reliability of the questionnaire is measured using Cronbach’s alpha, which is a measure of the internal consistency of the data and is used under the assumption that a number of statements are measuring the same underlying latent construct. Cronbach’s alpha can be expressed as

$$\alpha = \frac{n\,\overline{r}}{1 + \overline{r}\,(n-1)}$$

Where *n* is the sample size and $\overline{r}$ is the mean correlation between statements. Cronbach's alpha ranges between 0 and 1 where a value greater that 0.7 is considered acceptable (Lavrakas 2008).

Once the reliability of the data has been validated there are three steps in factor analysis (i) an assessment of the suitability of the data for factor analysis, (ii) factor extraction and (iii) factor rotation and analysis (Shrestha 2021).

We first assess the suitability of the data for factor analysis using A Kaiser-Meyer-Olkin [KMO] measure of sampling adequacy. This measures the adequacy of the sample size and measures the sampling adequacy for each variable in the model and for the complete model. The KMO measure is given by

$$KMO = \frac{\sum_{i \neq j} R_{ij}^2}{\sum_{i \neq j} R_{ij}^2 + \sum_{i \neq j} U_{ij}^2}$$

Where R_{ij} is the correlation matrix and U_{ij} is the partial covariance matrix. KMO values range for 0 to 1 and values between 0.8 and 1.0 indicate the sample size is adequate (Shrestha 2021). Bartlett's test of Sphericity is used to test for the adequacy of the correlation matrix. The Bartlett's test of Sphericity is highly significant at $p < 0.001$, which shows that the correlation matrix has significant correlations among at least some of the variables. This means that the variables are not orthogonal and (Shrestha 2021). Table 2 gives the results of KMO and the Bartlett's test of sphericity; both tests confirm that factor analysis is a suitable technique to use on this data set.

Table 2. Kaiser-Meyer-Olkin and Bartlett's Test of Sphericity

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.916
Bartlett's test of sphericity	Approx. Chi-square	3730.3
	df	190
	p- value	0.000

The second step in factor analysis is to identify the least number of factors that can be used to represent the interrelationships among the statements; this is the factor extraction stage. This is a critical step in the analysis as the researcher needs to balance the need for parsimony with adequately representing the underlying correlations (Hayton, Allen et al. 2004). If too few factors are retained then important information is lost, specifying too many factors can lead to focusing on minor factors at the expense of major ones. In general, the researcher should retain factors until additional factors account for trivial variance (Hayton, Allen et al. 2004). One of the most commonly used methods to assess the number of factors to keep is the Kaiser criterion, which retains factors with eigenvalues greater than 1 (Kaiser 1960). Table 3 shows the eigenvalues and total variance explained by the twenty variables included in the data set that provides the justification for the number of factors to be extracted. Three variables have eigenvalues greater than 1. The results show that 60% of the common variance shared by 18 variables can be accounted for by these three factors. The extraction method of factor analysis used in this study is principal component analysis

Table 3. Eigenvalues, Proportion and cumulative variance explained

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	7.54092	5.44465	0.4189	0.4189
Factor2	2.09627	0.91565	0.1165	0.5354
Factor3	1.18061	0.30791	0.0656	0.601
Factor4	0.8727	0.02347	0.0485	0.6495

The third step is to rotate the factors; in general, the data is rotated if more than one factor emerges, as the results are easier to interpret. The two main approaches to rotation are orthogonal (uncorrelated) and oblique (correlated). In this study, we used an extraction method based on principal component analysis and an orthogonal varimax rotation based on the Kaiser criterion. Three factors emerged; the statements that loaded on each factor and the factor loading are in Table 4.

Table 4. Factor Loadings and statements related to farm objectives

Variable	Factor1	Factor2	Factor3
	Long term economic	Short term economic	Environmental
Reinvesting in the farm	0.7824		
Meeting challenges	0.6975		
Being innovative by adapting new technologies & practices	0.6956		

Having up to date machinery and equipment	0.6868		
Expanding the farm business	0.6655		
Producing high quality products	0.6377		
Trying new crops / breeds	0.5751		
Maximizing production levels	0.5149	0.5605	
Achieving highest yields possible		0.7902	
Paying attention to market prices		0.771	
Maximizing and making the best use of my farm resources		0.7019	
Maximizing farm profits		0.6882	
Encouraging wildlife and protecting water quality			0.7546
Preventing pollution from agricultural production			0.748
Operating my farm in an environmentally friendly way			0.7358
Avoiding risky options			0.718
Avoiding a cross compliance violation			0.5597
Keeping farm debt as low as possible			0.5401

In this analysis we rename Factor 1, Long Term Economic (LTE), factor 2, Short Term Economic (STE) and factor 3 Environmental (ENV). These names are based on the factor loading of each statement. LTE objectives describe the objectives of farmers who are rate statements around the potential and of the farm to provide into the future. They include reinvestment, meeting future challenges and being innovative. These farmers have long-term plans that include producing high quality products now while at the same time, expanding their farm business. Having up to date machinery is also an investment on both current and future production levels and these farmers are open to trying out new breeds of crops or livestock. Their decision-making process takes account of the long-term effects of current investments. STE objectives describe the objectives of farmers who are interested in short-term economic returns, which are very much in line with micro-economic production theory. They are interested in producing high yields, maximizing profits and they pay attention to current market conditions. ENV objectives describe the farming objectives of farmers who wish to farm in an environmentally friendly way. These farmers are risk adverse, prefer to keep debt low and remain compliant with farming regulations. They are interested in preventing pollution, protecting water quality and encouraging wildlife. There is some cross loading on the objective of "Maximizing production levels", which loaded on LTE and STE, this points the importance of productivity to both long term and short term economic objectives.

2.2.2 Empirical Model

In reality, farmers could adopt multiple mitigation measures that have the potential to reduce the risk of nutrient transfer to watercourses. To evaluate the effect of farmer objectives on a farmer's openness to adopt these measures, it is important to use a model that can estimate the effect of farmer objectives on a number of mitigation measures simultaneously. A multivariate ordered probit model is used to assess the effect of farming objectives on a farmers openness to adopt eight mitigation measures. The multivariate model estimates the effect of farmer objectives on their openness to adopt all the measures simultaneously while the individual ordered probit model considers the level of openness towards the adoption of each measure (Lauer 2003, Wang, Jin et al. 2021, Musafiri, Kiboi et al. 2022).

The data is a Likert scale index from one to five, which results in an ordinal dependent variable that takes on five discrete values, 5 means the farmer is more open to adopt the measure than 4, and 4 is more open to adopt than 3 and so on. However, it is unlikely the distance between each of the categories will be constant. In other words, it may take a bigger change in an independent variable to get over the "threshold" into one category than it takes to get into the next category. An ordered probit model estimates both the effects of the independent variables (through the systematic component) and the thresholds of the dependent variable (through the stochastic component) at the same time.

Our hypothesis is that an individual's farming objective Xi determines the level of openness to adoption of mitigation measures denoted Yij. The subscript i indicates the i^{th} farmer where

$i = (1 \dots n)$, and the subscript j indicates the j^{th} mitigation measure where $j = (1 \dots n)$. Therefore, we can state that:

$$Y_{ij} = f(X_i) \; \forall \; i = 1, \dots, n, \forall \; j = 1, \dots, n$$

Since the dependent variable is an ordered, qualitative variable, we estimate the relationship between Y and X with an ordinal response model. We assume that the level of openness of farmer i to adopt mitigation measure j, denoted Y_{ij}^{*} is a continuous function of farmer objectives, denoted by Xi, a vector of parameters of dimension $(k \; x \; 1)$, denoted by β , and a disturbance term, ε, which is normally, identically, and independently distributed, $\varepsilon \sim N(0, \sigma^2)$. Increasing values of Y_{ij}^{*} indicate an increasing level of openness to adopt.

$$Y_{ij}^{*} = \beta' X_i + \varepsilon$$

The probabilities of falling into the ordered categories 1 to 5 are given by the following

$$\Pr(Y_{ij} = 1) = \Phi(\mu_1 - \beta' X)$$

$$\Pr(Y_{ij} = 2) = \Phi(\mu_2 - \beta' X) - \Phi(\mu_1 - \beta' X)$$

$$\Pr(Y_{ij} = 3) = \Phi(\mu_3 - \beta' X) - \Phi(\mu_2 - \beta' X)$$

$$\Pr(Y_{ij} = 4) = \Phi(\mu_4 - \beta' X) - \Phi(\mu_3 - \beta' X)$$

$$\Pr(Y_{ij} = 5) = 1 - \Phi(\mu_4 - \beta' X)$$

Where the $\mu's$ are unknown threshold parameters (cut-points) to be estimated with β, and the ranking depends on certain measurable factors x and certain unobservable factors Є. Since the disturbances are normally distributed, these probabilities are distributed according to the cumulative normal distribution *Φ*. The ordered probit model is estimated using the method of maximum likelihood via the Newton-Raphson algorithm (Long 1997)

3 Results

The objective of this study is to investigate the importance of different farming objectives on a farmers' willingness to adopt a suite of mitigation measures that have the potential to improve water quality.

Table 5 presents summary statistics and scores of the Likert scale data for each mitigation measure.

Table 5. Summary statistics and scores for individual mitigation measures

Variable	Obs.	Mean	Std. Dev.	Min	Max
Establishing Riparian Buffer Strips along watercourses	402	4.69	1.25	1	5
Not applying fertilizers to areas of high risk for nutrient loss	402	4.67	1.01	1	5
Avoid spreading fertilizers at high risk times	402	4.81	0.77	1	5
Not applying phosphorous fertilizers to soils already high in phosphorus	402	4.74	0.88	1	5
Use of slurry band or injection spreading machinery	402	4.34	1.41	1	5
Re-siting gateways away from high risk areas	402	4.23	1.09	1	5
Establishing and maintaining artificial wetlands	402	3.80	1.46	1	5
Fencing off watercourses	402	4.66	1.13	1	5

The results of a multivariate ordered probit model, which simultaneously estimated the effect of the three farming objectives on eight mitigation measures, are presented in Table 6. The results show that farming objectives are a highly significant predictor of a farmer's openness to adopt a range of different mitigation measures and that a farmers objectives in relation to his/her farming business can determine whether they are more open to adopting some measures while resistant to adopting others.

Farmers with LTE objectives, along with increasing productivity and profitability, have an eye on the future, are interested in investing in the farm and are open to adopt new technologies. Farmers with a LTE objective are were positively and highly significantly open at the 0.01 level of significance, to the adoption of (5) Use of slurry band or injection spreading machinery, (6) Re-siting gateways away from high-risk areas and (8) Fencing off watercourses from livestock. They were also open, at 0.05 level of significance, to adopting (1) Establishing riparian buffer strips along watercourses, and (7) Establish and maintain artificial wetlands. Farmers who loaded on this factor were open to adopting mitigation measures that could potentially incur additional costs. This indicates that they are willing to make investments for the future of their farms acknowledging that in addition to financial gains they also have a role to play in protecting and improving water quality for current and future generations. Farmers with this farming objective were the only group who were open to adopting (1) Establishing riparian buffer strips along watercourses even though riparian buffer strips have been promoted for many years as an efficient nitrate removal method (Hawes and Smith 2005). Farmers with a high loading on this factor were open to all land use management measures and not as open to the nutrient management changes. It is possible that these farmers consider the land management changes as important for the future development of the farm and see them as an addition to their farm rather than just an additional cost.

Farmers with STE objectives are interested in short-term economic gains, maximizing profits and yields and making the most of the farm resources while at the same time keeping an eye on market conditions. Farmers with a STE farming objective were positively and significantly open, at the 0.01 level of significance, to adopt (3) Avoid spreading fertilisers at high-risk times and (6) Re-siting gateways away from high-risk areas. At the 0.05 level of significance, these farmers were also open to (2) not applying fertilisers to areas of high risk for nutrient loss. Farmers with this objective are the most reluctant to undertake changes around nutrient management practices or land use management changes. It is possible that these farmers are more risk adverse than other groups and prefer to leave things the way they are rather than make any behavioural changes or incur additional costs or debt.

Farmers with ENV objectives are interested in farming in an environmentally friendly way, avoiding diffuse losses from agriculture, risky options and breaches of farming regulations. Farmers with an ENV objective were positively and significantly open, at the 0.01 level of significance, to adopt the following mitigation measures (2) Not applying fertilisers to areas of high risk for nutrient loss (7) Establish and maintain artificial wetlands and (8) Fencing off watercourses from livestock. At the 0.05 level of significance they were also open to (4) Not applying phosphorus fertiliser to soils already high in phosphorus, (5) Use of slurry band or injection spreading machinery and (6) Re-siting gateways away from high-risk areas and while less significant were also positive towards. Water quality issues are of importance to farmers with an ENV objective and they are open to measures involving a behavioural change as well as measures requiring additional cost at farm level. There are a number of similarities between farmers with LTE and ENV objectives; this is somewhat surprising given that there is often a conflict between these two objectives (Ahtiainen, Pouta et al. 2015, Jean-Christophe 2020).

Table 6. Multivariate Ordered Probit model of the relationship between farmer objectives and individual mitigation measures

	1	2	3	4	5	6	7	8
	Establishing Riparian Buffer Strips along watercourses	Not applying fertilisers to areas of high risk for nutrient loss	Avoid spreading fertilisers at high-risk times	Not applying phosphorus fertiliser to soils already high in phosphorus	Use of slurry band or injection spreading machinery	Re-siting gateways away from high-risk areas	Establish and maintain artificial wetlands	Fencing off watercourses from livestock
Long Term Economic	0.146**	0.134	0.098	0.180	0.200***	0.300***	0141**	0.228***
	(2.03)	(1.81)	(1.26)	(2.35)	(2.88)	(4.23)	(2.07)	(3.20)
Short Term Economic	-0.066	0.162**	0.255***	0.128	0.003	0.204***	0.127	0.071
	(-0.93)	(2.23)	(3.35)	(1.78)	(0.05)	(3.08)	(1.95)	(1.05)
Environmental	0.117	0.207***	0.127	0.179**	0.161**	0.196**	0.273***	0.206***
	(1.48)	(2.61)	(1.52)	(2.18)	(2.11)	(2.53)	(3.57)	(2.60)
N = 402								
t statistics in parenthesis								
* p < 0.10, ** p < 0.05, *** p < 0.01								

4 Discussion

In recent decades, the multifunctionality of agriculture has been recognised, and the important role farmers have to play in protecting the environment has been acknowledged (Garland, Banerjee et al. 2021). Previously, the focus had been on maximising yields with the assumption that the natural resources are both free and self-correcting. But as demands on these natural resources increases management decisions are needed to compliment and protect these self-regulating properties (DeFries and Nagendra 2017). The role that farmers have to play in protecting and improving water quality falls under the category of protecting and managing these natural resources. However, there is a public good element to this role and the benefits accruing to the farm in terms of financial rewards are not always obvious. Farmers may also feel that they are not to blame for the environmental problems arising from diffuse pollution, and therefore do not accept responsibility for adopting additional measures (Macgregor and Warren 2006, Blackstock, Ingram et al. 2010).

In addition, diffuse pollution has been described as a “Wicked problem” (Patterson, Smith et al. 2013, Thornton, Harding et al. 2013, DeFries and Nagendra 2017). Wicked problems are complex problems that can have multiple resolutions and are caused by number of different of factors (Ritchey 2013). This wicked problem of diffuse pollution is a difficult problem to solve because it involves linking complex natural systems and human activity which results in a complex, dynamic, multi-actor, and multi-scalar problem (DeFries and Nagendra 2017). Two major difficulties associated with these types of dilemmas are (i) assuming that there is an easy solution and (ii) the overwhelming complexity of the problem can lead to no action at all. Therefore an incremental and adaptive approach to the problem is suggested (DeFries and Nagendra 2017).

An incremental approach could involve the adoption of a number of mitigation measures at farm level. Understanding the problem, understanding the different audiences and matching mitigation measures to problems, which are location specific, is important (Blackstock, Ingram et al. 2010). For such an incremental approach to be successful, we need a good understanding of all these elements. It is also important to monitor the progress of the various measures, since the length of time it takes for improvements to occur can be substantial (Melland, Fenton et al. 2018). It is important to acknowledge when goals have been achieved since constructive feedback adds value to the work carried out and can motivate farmers to continue with the practices (Lopez-Garrido 2021), and it is also important to carry out objective analysis of when measures do not perform as it was thought they should. Within these multi-criteria of possible solutions, the role of farmer objectives plays an important part, and since farmer objectives maybe difficult to change, it may be easier to operate in a way that is consistent with prior objectives. This could include highlighting the economic benefits, which are an important to farmers with both LTE and STE objectives while at the same time highlighting the important environmental contributions of the measures that are important to farmers with an ENV objective.

There are also a number of measures which are acceptable to farmers with and ENV objective and a LTE objectives. These two objectives often conflict whereby farmers face a trade-off between financial economic objectives and protecting the environment. The similarities between the measures acceptable to farmers with these different farming objectives may point to the growing awareness among farmers of the importance of environmental conditions for the long term viability of their farm.

5 Conclusion

In this paper, we investigated the relationship between farming objectives and farmers' openness to adopting a range of mitigation measures that may have a positive effect on water quality outcomes. This fits within the adaptive management section of this complex problem and results indicate that farming objectives are a significant predictor of openness to adopt. In line with previous literature, economic objectives were found to be important; however, there were significant differences between farmers who have long-term objectives and farmers with a more short-term economic objective. There were also similarities between farmers with a LTE objective and those with an ENV objective indicating that farmers recognise the importance of environmental conditions on the long-term economic viability of their family farm and vice versa.

Nutrient management best practice has been encouraged for many years now and while there are varying degrees of farmer openness to all the measures, there is no measure that farmers of all three farming objectives were open to adopt. Farmers with an ENV objective were open to adopting three of the four measures, (2) not applying fertilisers to areas of high risk for nutrient loss, (4) not applying Phosphorus to soils already high in Phosphorus and (5) the use of band injection spreading. Farmers with a STE objective were the only ones open to adopting (3) Avoid spreading fertilisers at high-risk times. The only nutrient management measure that farmers with a LTE objective were open to adopt was (5) the use of band injection spreading. While classified as a nutrient management measure, this mitigation measure could involve an additional cost if farmers were to purchase machinery themselves, but interestingly the farmers with a LTE and an ENV objective were open to adopt this measure. The significance of these results indicate that farmers are open to adopt some, but not all nutrient management best practice measures. If these measures are the gold standard and have the potential for a win-win situation for farmers, this message needs to be targeted in a manner that fits in with all three farming objectives.

Of the land use management measures farmers with a STE objective were the least open to adopting these measures although they were open to (6) Re-siting gateways away from high-risk areas. Farmers with LTE and ENV objectives were significantly open to adopting almost all of the measures (6) Re-siting gateways away from high-risk areas, (7) Establish and maintain artificial wetlands and (8) Fencing off watercourses from livestock. This result is encouraging as adopting mitigation measure (8) requires giving up an area of the farm, resulting in an opportunity cost of the production foregone from the loss of the land area and also an additional financial cost (Kilgarriff, Ryan et al. 2020). Given the fact that farmers are open to adopting this measure, this indicates that they consider the benefits, and the utility they receive out weights the additional opportunity and financial costs.

The only mitigation measure that all farmers were open to adopting was (6) Re-siting gateways away from high-risk areas. Re-siting gateways is a simple way to decrease local and global hydrological connectivity, thus reducing pollution via these preferential flow pathways (Schoumans, Chardon et al. 2014). This measure was also the measure that had the highest level of adoption amongst farmers in survey of English farmers (Vrain, Lovett et al. 2014). This measure is a very visible way of dealing with potential pollution problems and in the overall complexity of the diffuse pollution problem is one that farmers can see and understand. On a practical level, re-siting gateways may also make it easier to move livestock or machinery at farm level. On the other hand, farmers with a LTE objective were the only ones open to adopting mitigation measure (1) Establishing riparian buffer strips along watercourses, even though this mitigation measure has been promoted for many years. Previous literature found that constraints to adoption of riparian buffer strips include interference with production, nuisance effects and loss of production in small field systems (Buckley, Hynes et al. 2012).

Tackling diffuse water pollution at farm level and encouraging farmers to adopt mitigation measures is complex and very often location specific, where different measures are needed to tackle different forms of diffuse pollution. Farming objectives play a crucial role in farmer openness to adopt but the benefits of the measures need to match their farming goals. Future research needs to continue to investigate and quantify, if possible, the specific benefits to each farm from adopting measures to help with diffuse water pollution. The steps are incremental and all stakeholders need to take actions.

References:

Ahtiainen, Heini, Eija Pouta, Eero Liski, Sami Myyrä, and Aino Assmuth. 2015. "Importance of economic, social, and environmental objectives of agriculture for stakeholders—A meta-analysis." *Agroecology and Sustainable Food Systems* 39 (9):1047-68.

Andersen, Hans Estrup, Gitte Blicher-Mathiesen, Marianne Bechmann, Arvydas Povilaitis, Arvo Iital, Ainis Lagzdins, and Katarina Kyllmar. 2014. "Mitigating diffuse nitrogen losses in the Nordic-Baltic countries." *Agriculture, Ecosystems & Environment* 195:53-60.

Arovuori, Kyösti. 2011. "Explaining Finnish Farmers' Policy Responses with Environmental Attitudes."

Birner, Regina, Kristin Davis, John Pender, Ephraim Nkonya, Ponniah Anandajayasekeram, Javier Ekboir, Adiel Mbabu, David J Spielman, Daniela Horna, and Samuel Benin. 2009. "From best practice to best fit: a framework for designing and analyzing pluralistic agricultural advisory services worldwide." *Journal of agricultural education and extension* 15 (4):341-55.

Blackstock, K. L., J. Ingram, R. Burton, K. M. Brown, and B. Slee. 2010a. "Understanding and influencing behaviour change by farmers to improve water quality." *Sci Total Environ* 408 (23):5631-8. doi: 10.1016/j.scitotenv.2009.04.029.

Blackstock, Kirsty L, John Ingram, Rob Burton, Katrina M Brown, and Bill Slee. 2010b. "Understanding and influencing behaviour change by farmers to improve water quality." *Science of The Total Environment* 408 (23):5631-8.

Brown, Philip, Adam Daigneault, and Joshua Dawson. 2019. "Age, values, farming objectives, past management decisions, and future intentions in New Zealand agriculture." *Journal of Environmental Management* 231:110-20.

Buckley, Cathal, and Patricia Carney. 2013. "The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level." *Environmental science & policy* 25:118-26.

Buckley, Cathal, Peter Howley, and Phil Jordan. 2015. "The role of differing farming motivations on the adoption of nutrient management practices." *International Journal of Agricultural Management* 4 (4):152-62.

Buckley, Cathal, Stephen Hynes, and Sarah Mechan. 2012. "Supply of an ecosystem service—Farmers' willingness to adopt riparian buffer zones in agricultural catchments." *Environmental Science & Policy* 24:101-9.

Cherry, KA, M Shepherd, PJA Withers, and SJ Mooney. 2008. "Assessing the effectiveness of actions to mitigate nutrient loss from agriculture: A review of methods." *Science of The Total Environment* 406 (1-2):1-23.

DeFries, Ruth, and Harini Nagendra. 2017. "Ecosystem management as a wicked problem." *Science* 356 (6335):265-70.

Dupas, Rémi, Romain Tavenard, Ophélie Fovet, Nicolas Gilliet, Catherine Grimaldi, and Chantal Gascuel-Odoux. 2015. "Identifying seasonal patterns of phosphorus storm dynamics with dynamic time warping." *Water Resources Research* 51 (11):8868-82. doi: 10.1002/2015wr017338.

Eastwood, Callum, Margaret Ayre, Ruth Nettle, and Brian Dela Rue. 2019. "Making sense in the cloud: Farm advisory services in a smart farming future." *Njas-Wageningen Journal of Life Sciences* 90:100298.

EPA. 2020. "Water Quality in 2019 An Indicators Report." In, edited by s O'Boyle W Trodd. Johnstown castle, Wexford, Ireland.

Fealy, R. M., C. Buckley, S. Mechan, A. Melland, P. E. Mellander, G. Shortle, D. Wall, and P. Jordan. 2010. "The Irish Agricultural Catchments Programme: catchment selection using spatial multi-criteria decision analysis." *Soil Use and Management* 26 (3):225-36. doi: 10.1111/j.1475-2743.2010.00291.x.

Ford, J Kevin, Robert C MacCallum, and Marianne Tait. 1986. "The application of exploratory factor analysis in applied psychology: A critical review and analysis." *Personnel psychology* 39 (2):291-314.

Gabel, Vanessa M, Robert Home, Matthias Stolze, Simon Birrer, Beatrice Steinemann, and Ulrich Köpke. 2018. "The influence of on-farm advice on beliefs and motivations for Swiss lowland farmers to implement ecological compensation areas on their farms." *The Journal of Agricultural Education and Extension* 24 (3):233-48.

Garland, Gina, Samiran Banerjee, Anna Edlinger, Emily Miranda Oliveira, Chantal Herzog, Raphaël Wittwer, Laurent Philippot, Fernando T Maestre, and Marcel GA van Der Heijden. 2021. "A closer look at the functions behind ecosystem multifunctionality: A review." *Journal of Ecology* 109 (2):600-13.

Greer, Alan. 2005. *Agricultural policy in Europe*: Manchester University Press.

Hawes, Ellen, and Markelle Smith. 2005. "Riparian buffer zones: Functions and recommended widths." *Eightmile River Wild and Scenic Study Committee* 15:2005.

Hayton, James C, David G Allen, and Vida Scarpello. 2004. "Factor retention decisions in exploratory factor analysis: A tutorial on parallel analysis." *Organizational research methods* 7 (2):191-205.

Howley, Peter, Cathal Buckley, Cathal O Donoghue, and Mary Ryan. 2015. "Explaining the economic 'irrationality'of farmers' land use behaviour: the role of productivist attitudes and non-pecuniary benefits." *Ecological Economics* 109:186-93.

Jean-Christophe, Pereau. 2020. "Conflicting objectives in groundwater management." *Water Resources and Economics* 31:100122.

Jeppesen, Erik, Brian Kronvang, Mariana Meerhoff, Martin Søndergaard, Kristina M Hansen, Hans E Andersen, Torben L Lauridsen, Lone Liboriussen, Meryem Beklioglu, and Arda Özen. 2009. "Climate change effects on runoff, catchment phosphorus loading and lake ecological state, and potential adaptations." *Journal of Environmental Quality* 38 (5):1930-41.

Jongeneel, R, and L Ge. 2010. "Farmers' behavior and the provision of public goods: towards an analytical framework." In.: Wettelijke Onderzoekstaken Natuur & Milieu.

Kaiser, Henry F. 1960. "The application of electronic computers to factor analysis." *Educational and psychological measurement* 20 (1):141-51.

Kilgarriff, Paul, Mary Ryan, Cathal O'Donoghue, and Stuart Green. 2020. "Livestock exclusion from watercourses: Policy effectiveness and implications." *Environmental Science & Policy* 106:58-67.

Lastra-Bravo, Xavier B., Carmen Hubbard, Guy Garrod, and Alfredo Tolón-Becerra. 2015. "What drives farmers' participation in EU agri-environmental schemes?: Results from a qualitative meta-analysis." *Environmental Science & Policy* 54:1-9. doi: 10.1016/j.envsci.2015.06.002.

Lauer, Charlotte. 2003. "Family background, cohort and education: A French–German comparison based on a multivariate ordered probit model of educational attainment." *Labour Economics* 10 (2):231-51.

Lavrakas, Paul J. 2008. *Encyclopedia of survey research methods*: Sage publications.

Long, J Scott. 1997. "Regression models for categorical and limited dependent variables (Vol. 7)." *Advanced quantitative techniques in the social sciences* 219.

Lopez-Garrido, Gabriel. 2021. "Self-determination theory and motivation." *Simply Psychology*.

Macgregor, Colin J, and Charles R Warren. 2006. "Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm." *Agriculture, Ecosystems & Environment* 113 (1-4):108-19.

McDowell, R. W., T. Snelder, S. Harris, L. Lilburne, S. T. Larned, M. Scarsbrook, A. Curtis, B. Holgate, J. Phillips, and K. Taylor. 2018. "The land use suitability concept: Introduction and an application of the concept to inform sustainable productivity within environmental constraints." *Ecological Indicators* 91:212-9. doi: 10.1016/j.ecolind.2018.03.067.

Melland, AR, O Fenton, and P Jordan. 2018. "Effects of agricultural land management changes on surface water quality: A review of meso-scale catchment research." *Environmental science & policy* 84:19-25.

Mellander, P. E., P. Jordan, M. Bechmann, O. Fovet, M. M. Shore, N. T. McDonald, and C. Gascuel-Odoux. 2018. "Integrated climate-chemical indicators of diffuse pollution from land to water." *Sci Rep* 8 (1):944. doi: 10.1038/s41598-018-19143-1.

Mills, Jane, Peter Gaskell, Julie Ingram, and Stephen Chaplin. 2018. "Understanding farmers’ motivations for providing unsubsidised environmental benefits." *Land Use Policy* 76:697-707.

Mills, Jane, Peter Gaskell, Julie Ingram, Janet Dwyer, Matt Reed, and Christopher Short. 2017. "Engaging farmers in environmental management through a better understanding of behaviour." *Agriculture and human values* 34 (2):283-99.

Musafiri, Collins M, Milka Kiboi, Joseph Macharia, Onesmus K Ng'etich, David K Kosgei, Betty Mulianga, Michael Okoti, and Felix K Ngetich. 2022. "Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: do socioeconomic, institutional, and biophysical factors matter?" *Heliyon* 8 (1):e08677.

Norton, David A, Febyana Suryaningrum, Hannah L Buckley, Brad S Case, C Hamish Cochrane, Adam S Forbes, and Matt Harcombe. 2020. "Achieving win-win outcomes for pastoral farming and biodiversity conservation in New Zealand." *New Zealand Journal of Ecology* 44 (2):1-9.

OECD. 2012. *Farmer Behaviour, Agricultural Management and Climate Change*.

Patterson, James J, Carl Smith, and Jennifer Bellamy. 2013. "Understanding enabling capacities for managing the ‘wicked problem’of nonpoint source water pollution in catchments: A conceptual framework." *Journal of Environmental Management* 128:441-52.

Ritchey, Tom. 2013. "Wicked problems." *Acta morphologica generalis* 2 (1).

Schoumans, OF, WJ Chardon, ME Bechmann, C Gascuel-Odoux, Georges Hofman, B Kronvang, GH Rubæk, B Ulén, and J-M Dorioz. 2014. "Mitigation options to reduce phosphorus losses from the agricultural sector and improve surface water quality: a review." *Science of The Total Environment* 468:1255-66.

Shrestha, Noora. 2021. "Factor analysis as a tool for survey analysis." *American Journal of Applied Mathematics and Statistics* 9 (1):4-11.

Thornton, Jeffrey A, William R Harding, Mark Dent, Rob C Hart, Hebin Lin, Claudia L Rast, Walter Rast, Sven-Olof Ryding, and Thomas M Slawski. 2013. "Eutrophication as a ‘wicked’problem." *Lakes & reservoirs: Research & management* 18 (4):298-316.

Vanclay, Frank. 2004. "Social principles for agricultural extension to assist in the promotion of natural resource management." *Australian journal of experimental agriculture* 44 (3):213-22.

Vrain, Emilie, AA Lovett, Lister Noble, Fiona Grant, Pete Blundell, and Will Cleasby. 2014. "Farmer Attitudes Towards Diffuse Pollution Mitigation Measures in England." *Report to Defra, University of East Anglia, Norwich*.

Vrain, Emilie, and Andrew Lovett. 2016. "The roles of farm advisors in the uptake of measures for the mitigation of diffuse water pollution." *Land Use Policy* 54:413-22. doi: 10.1016/j.landusepol.2016.03.007.

Wang, Tong, Hailong Jin, Urs Kreuter, and Richard Teague. 2021. "Expanding grass-based agriculture on marginal land in the US Great Plains: The role of management intensive grazing." *Land Use Policy* 104:105155.

Wiering, Mark, Daan Boezeman, and Ann Crabbé. 2020. "The water framework directive and agricultural diffuse pollution: fighting a running battle?" *Water* 12 (5):1447.

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