Journal of Environmental Management 292 (2021) 112826

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

More than two decades of Agri-Environment schemes: Has the profile of participating farms changed?

Paula Cullen [a,b,*], Stephen Hynes [c], Mary Ryan [a], Cathal O'Donoghue [d]

[a] Rural Economy and Development Programme, Teagasc, Athenry, Ireland
[b] Department of Economics, National University of Ireland, Galway, Ireland
[c] Socio-Economic Marine Research Unit, National University of Ireland, Galway, Ireland
[d] College of Arts, Social Sciences & Celtic Studies, National University of Ireland, Galway, Ireland

ARTICLE INFO

Keywords:
Agri-environment schemes
Farmer participation
Agri-environmental policy
Panel data

ABSTRACT

The agri-food sector is under increased pressure from consumers to improve on the sustainability of production processes. Policies that incentivise farmers to improve environmental performance, such as agri-environment schemes (AES), are increasingly important. Understanding the choice to participate in these programmes aids policymakers in designing schemes that meet participation and environmental goals. While a number of studies have investigated the decision using cross-sectional data on one or multiple locations, very few have used longitudinal data to investigate the impact of institutional changes over time. Using Ireland as a case study, this paper uses a nationally representative panel of data spanning 23 years to model the impact of scheme and policy changes on the type of farms participating in AES. This paper argues that environmental issues surrounding intensive farms (such as the loss of nutrients and sediment to water and greenhouse gas emissions) are not being optimally addressed in scheme design and further development of such programmes is needed to reduce negative environmental impacts.

1. Introduction

Farmers' actions influence the environmental sustainability of land use practices. With growing policy emphasis on improving the levels of biodiversity, water quality and climate stability and in many cases attempting to reverse man-made damage through ecosystem restoration, agriculture is increasingly under the spotlight. Land used for agricultural purposes makes up 38% of global terrestrial area and contributes to environmental degradation (FAO, 2018). Thus, there are strong policy efforts to improve the environmental performance of agriculture by changing farmer behaviour in relation to farm management practices. Agri-environment schemes (AESs) have become a leading policy mechanism in the European Union (EU) in changing farmer environmental behaviour (Batáry et al., 2015). However the environmental improvement attributed to AESs has been brought into question in a number of studies (e.g. Bertoni et al., 2020; Finn and Ó hUallacháin, 2012; Kleijn and Sutherland, 2003). With greater subsidiarity being assigned to EU member states (MS) under the 2020 reform of the Common Agricultural Policy (CAP), it is timely to develop a better understanding of scheme participation along with reasons for successes and failures in past scheme design.

Improved understanding of participation choices of farmers in light of differences in scheme characteristics and policy changes, both environmental and agricultural, would aid policymakers in making decisions on AESs in the future. Studies investigating participation in schemes have predominantly focused on single schemes (Lastra-Bravo et al., 2015), or multiple schemes in different locations (Siebert et al., 2006). There has been little research conducted using longitudinal (panel) data. To the best of the authors' knowledge this is limited to two studies (Hynes and Garvey, 2009 and Murphy et al., 2014), that focused on a single AES scheme. Panel data, as used in the two referenced studies, is data collected from the same data points (such as an individual or farm) repeatedly over time. Analysis with panel data has a number of benefits over cross-sectional data, including the greater degrees of freedom and sample variability which improves the efficiency of estimates (Hsiao, 2007). It also allows researchers to analyse the process of change over time particularly at an individual level, which cannot be gleaned from cross-sectional data alone (Andreβ et al., 2013).

This paper aims to extend these studies by examining a time-series of data, using Ireland as a case study country, in which a range of AESs

* Corresponding author. Hardiman Building, National University of Ireland, Galway, Ireland.
E-mail address: paula.cullen@nuigalway.ie (P. Cullen).

https://doi.org/10.1016/j.jenvman.2021.112826
Received 12 June 2020; Received in revised form 21 April 2021; Accepted 17 May 2021
Available online 23 May 2021

were implemented over the last 25 years. These AESs differed both in relation to the targeting of environmental outcomes and the determination of payments, providing a unique opportunity to analyse differing characteristics. This study builds on the previous panel data analyses and extends it by examining a much longer time-period with multiple varying schemes. It investigates the types of farmers that participated in the different AESs and considers the changing agricultural policy context in general and the impact this may have had on the participation decision. In what follows, section 2 provides a description of AESs in Ireland. Section 3 then presents the literature on AES participation choice and is followed by a description of the data and methodology used in Section 4. Section 5 presents the results of the panel analysis. The results are discussed and some concluding comments are provided in the final section.

2. Agricultural policy in Ireland from 1996 to 2018

2.1. Agri-environment schemes

The implementation of AES became compulsory for EU Member States in 1992 under EC Regulation 2078/92. Member States, including Ireland, have since implemented a number of AESs with numerous objectives and design changes over time, in response to changes in international and national environmental goals and also in response to criticisms of past schemes.[1] Throughout the EU these schemes have been action-based with payments for measures undertaken (Cullen et al., 2018). The first national AES in Ireland, the Rural Environmental Protection Scheme (REPS), began in 1994. REPS had four iterations (REPS1, REPS2, REPS3, REPS4) with the last of the five-year contracts ending in 2014.[2] With the help of agricultural extension agents, farmers were required to submit a whole-farm five-year plan detailing the agri-environment measures selected. Along with 11 compulsory basic measures, the latter two iterations of REPS also required farmers to undertake at least two optional measures from a predefined list. The scheme paid farmers for undertaking measures on a per hectare basis, with the iterations having differing rates of graduated payments; the highest payments were for the first 20 ha, with different rates of declining payments for additional hectares across different iterations of the scheme. This led to farm size being a strong determining factor in a farmer's decision to participate (Hynes and Garvey, 2009).

Livestock density also determined eligibility as scheme entry was conditional on meeting requirements of the Nitrates Directive with organic nitrogen (N) levels of less than 170 kg per hectare for all bar the final scheme iteration, where extra measures were required under a Nitrates Derogation[3] for farms above this level. Thus, livestock density was a limiting factor for farms with high stocking densities. The fourth iteration of REPS was popular with participants across all farm systems. This was likely due both to the opening of the scheme to derogation farms and the legal requirement for all farms to meet a number of scheme conditions, whether participating in the scheme or not, under the Nitrates Directive (Murphy et al., 2014).

The Agri-Environment Options Scheme (AEOS) replaced REPS in 2010. It differed from REPS in that payments applied to individual measures at set rates, rather than across the whole farm (see appendix B for a list of AEOS measures). Entry was prioritised for farms with certain features such as those with land designated as a Special Areas of Conservation or Special Protection Area. However, very few farms were ineligible, possibly due to lower uptake rates. One key difference which has been seen as a reason for the perceived failure of AEOS in terms of participation numbers was the lack of advisory input in both the design and implementation stages (Cullen et al., 2018). Farmers were not required to consult advisors to submit applications or to choose the measures to be undertaken. Another difference that likely influenced participation was the reduction in payment levels compared to the previous REPS scheme (McGurk et al., 2020).

The Green Low-Carbon Scheme (GLAS) which replaced AEOS in 2015 attempted to address some of the issues of previous schemes (see appendix B for a list of GLAS measures). Entry into GLAS was by a three-tier system based on farms' 'Priority Environmental Assets'. The highest tier included those with Natura 2000 sites, important farmland birds, commonages, High Status waterbodies and rare breeds. The second tier included those with Vulnerable Water Areas and those choosing to undertake 'Priority Actions' which were: minimum tillage, catch crops, low emission slurry spreading and wild bird cover. The third tier applied to the remaining farms. This targeting of areas with existing environmental need or value was an attempt to address the issue of a lack of additionality, seen as a problem in previous schemes (Finn and Ó hUallacháin, 2012). However, it is hypothesised in this study that this would also still result in extensive farms being more likely to participate as they are more likely to have the features targeted (Hypothesis 1). Linked to this, a number of studies have also suggested that extensive farms are more likely to participate as they may have to make the least changes as the schemes fit with their existing practices (Hynes and Garvey, 2009; Murphy et al., 2014; Wilson and Hart, 2000; Defrancesco et al., 2008). Payments under GLAS were limited to €5,000 annually per farm except in exceptional circumstances such as the presence of multiple priority assets. In this scheme, advisors were again involved in the application and design process.

2.2. Agricultural policy changes

As the AESs have evolved, a number of EU agri-food policy changes have occurred that may also have influenced participation in schemes. Over the last 25 years increasing emphasis has been placed on the sustainability of farming, including environmental sustainability (Bertoni et al., 2012). The reform of CAP in 2003 resulted in the decoupling of subsidy payments from production. The new payments known as 'single farm payments' were subject to 'cross-compliance' conditions, some of which were environmental in focus.

In 2006 Ireland implemented its first National Action Programme under the Nitrates Directive. This limited the amount of livestock manure applied to the farm each year, set time periods for organic manure (slurry) spreading and set capacity levels for manure storage. All farmers were obliged to follow the programme as the whole of Ireland was designated as a Nitrates Vulnerable Zone. Given that farms now had to abide by these restrictions anyway, this in effect removed a number of barriers to AES entry. In 2007 the EU granted Ireland a Nitrates Directive derogation allowing eligible farmers to exceed the Nitrates Directive threshold for livestock manure applied to the farm each year. The number of farms availing of this has been steadily increasing, reaching a level of almost 7000 farms in 2018; the majority of these are dairy farms (DAFM, 2019). The derogation granted to Ireland was time limited, however the derogation is reviewed periodically and extensions have since been granted. The fourth iteration is set to expire at the end of 2021. Farmers with a derogation are required to reapply on an annual basis and have to meet a number of environmental conditions including using low emission slurry spreading equipment, conducting soil testing and participation in an environmental training course. AESs have been adapted to allow 'derogation farms' at the higher rate of organic nitrogen output per hectare to be eligible to apply for scheme participation.

In recent years Ireland has been increasing the productivity of the agricultural sector with goals to increase the primary output of agriculture by 30% under Food Harvest 2020 (DAFF, 2010) and 65% under Food Wise 2025 (DAFM, 2015). While there is a strong focus on

[1] The objectives of the Irish AESs can be found in Appendix A.

[2] For greater detail on the differences in the four iterations of REPS see Murphy et al. (2014).

[3] The Irish Department of Agriculture, Fisheries and the Marine operates the Nitrates Derogation (SI 65 2018). Ireland's nitrates derogation enables farms to stock at higher stocking rates, above 170 kg livestock manure nitrogen/ha, subject to additional environmental conditions.

'sustainable intensification' within these strategies, this targeted growth contrasts with other environmental policy goals of reducing greenhouse gas emissions, runoff to waterways and improving biodiversity. Such productivity targets could result in less participation in AES as these Government strategies potentially open up other higher income opportunities, while the constraints on management under an AES act as a barrier to accessing such opportunities.

The removal of milk quotas in 2015, coinciding with the opening of the GLAS AES in Ireland, may also have impacted on scheme participation choices. During the quota period, dairy farmers were limited to a maximum quota of annual milk production. With the abolition of the quota system many farmers availed of the post-quota expansion opportunity. Quota removal resulted in a 35% increase in milk production and a 21% increase in dairy cow numbers between 2014 and 2018 (Eurostat, 2020a, 2020b, 2020b). This expansion suggests increased competition for land that might be targeted for inclusion under AESs and higher opportunity costs, which we hypothesise, would lead to a drop in participation levels of dairy farms (Hypothesis 2).

3. Analyses of AES participation

A broad range of literature has explored why farmers choose to voluntarily participate in agri-environment schemes. Common recurring factors include profit-maximisation (Gasson, 1973; Willock et al., 1999), farm and farm characteristics (Defrancesco et al., 2008; Hynes et al., 2008; Lastra-Bravo et al., 2015; Murphy et al., 2014), contract structure (Ducos et al., 2009; Wilson and Hart, 2000), and farmer attitudes (Ahnström et al., 2017; Greiner, 2015; Pannell et al., 2006). Predominantly this research is conducted using cross-sectional data focusing on a single AES or multiple AESs occurring with spatial disparity (Lastra-Bravo et al., 2015; Siebert et al., 2006; Uthes and Matzdorf, 2013). While Hynes and Garvey (2009) and Murphy et al. (2014) both conducted panel studies, the analysis was limited to one scheme in each case. Riley (2016) examined the change in farmers attitudes using interviews with the same farmers ten years apart.

A number of farm characteristics have been studied in relation to the participation choice. Farm size is often found to influence participation in AESs, however, the findings in this regard have been mixed. While some studies have found that farms in AESs are larger on average (Hammes et al., 2016; Lynch and Lovell, 2003; Murphy et al., 2014; Wilson and Hart, 2000), others found the opposite (Capitanio et al., 2011; Vanslembrouck et al., 2002) and some studies found no significant effect (Ducos et al., 2009; Mathijs, 2003). It is possible that the variation in results may be due to differences in the structure of both the schemes and the farms being studied but it may also be due to a non-linear relationship between farm size and participation. This non-linearity is hypothesised, especially in the case of Ireland, to be due to scheme design with the cost of entry restricting the likelihood of small farms entering the schemes and payments per hectare reducing for large farms (Hypothesis 3). This relationship is tested in this study through use of quadratic terms on farm size.

Productivity has been found to have differing impacts on AES participation. Dupraz et al. (2003) for example found that farms with high productivity potential would be less likely to participate and Hynes and Garvey (2009) found farms with more productive soil types would also have a lower likelihood of participation. In contrast, Murphy et al. (2014) found that gross output per hectare (market based outputs only) was positively associated with participation when included in a regression alongside family farm income (calculated as farm revenue including subsidy payments minus costs) which was negatively associated. Their suggestion was that this means business-minded extensive farmers with lower farm incomes are more likely to join REPS. These income variables are included in this research to see if this is true across multiple schemes. As an extension to this it is hypothesised for this research that the reliance of farms on the market for income, versus subsidies, may reduce their participation due to lack of experience in applying for subsidies (Hypothesis 4). Another key determinant of participation in AES that has been found in previous studies is participation in previous AESs resulting in a higher likelihood of continued participation in schemes after the first experience (Murphy et al., 2014; Wossink and van Wenum, 2003).

The afore-mentioned studies (excluding Hynes and Garvey (2009) and Murphy et al. (2014)), use cross-sectional data to understand the participation decision, thereby limiting analyses to understanding participation in the context of one scheme and location, or multiple schemes in differing locations. However, analysis of schemes in different locations could be complicated if farmers in such areas vary across other more qualitative factors that have been found to influence participation. Such factors include perceptions of farming, attitudes towards the AES under study and opinions on conservation in their areas (Burton et al., 2008; Cullen et al., 2020; Dessart et al., 2019; Herzon and Mikk, 2007). Without access to this information this study includes farmer characteristics which may relate to their attitudes and have been found to be important in past research. For example, age in the past has been found to be significant with younger farmers found to be more likely participants than older farmers in a number of studies (Barreiro-Hurlé et al., 2010; Hynes and Garvey, 2009; Peerlings and Polman, 2008; Polman and Slangen, 2008). Whether or not a farmer has a child is also included as a measure of whether there is a possible successor. Mixed results related to the influence of succession planning among farmers has been found in the past with some studies finding a positive impact on participation (Karali et al., 2014; Murphy et al., 2014), others negative (Defrancesco et al., 2008; Giannakis, 2014), while others did not find an effect (Peerlings and Polman, 2009; Polman and Slangen, 2008). Higher education levels were found to be associated with higher rates of participation in AESs by Peerlings and Polman (2009) and Wilson and Hart (2000), while Defrancesco et al. (2008) found no association.

The studies reviewed above all examined actual farmer behaviour. There have also been a number of stated preference studies that examined AES participation and farmer willingness-to-accept payment to participate in AES (Beharry-Borg et al., 2013; Espinosa-Goded et al., 2010; Hynes et al., 2011; Hynes and Campbell, 2011; Putten et al., 2011; Trenholm et al., 2017; McGurk et al., 2020). A common finding in these studies was that there is considerable heterogeneity among the farming population in terms of potential AES participation.

In summary, while the literature has been wide ranging on the topic of participation in AESs, there has been little work that takes an intertemporal perspective; spanning farmer participation over time and across policy (scheme) changes. Based on past literature and policy changes, this study aims to fill this gap using an extended panel data approach to test four hypotheses:

1) Extensive farms are more likely to participate than intensive farms across all schemes but especially in the case of GLAS due to targeting.
2) The removal of milk quotas has a negative influence on dairy farm participation over time.
3) There is a non-linear relationship between farm size and participation.
4) Greater dependence on subsidies versus market income increases the likelihood of participation in AESs.

4. Methodology and data

4.1. Methodology

A standard neoclassical model is used as the theoretical framework for this analysis. Using panel data information on participation of farmers in AESs from 1996 to 2018, we treat the choice of farmers to participate as a utility maximisation problem. In any given year, *t*, the choice of a farmer, *i*, to participate or not participate is determined by the relative utility associated with each option. The utility derived from participating is:

$$U_{Pit}(I_{it} + S_{it} - C_{it}, E_{it}; Z_{it}) \quad (1)$$

where the utility from participation, U_{Pit}, is a function of family farm income,[4] I_{it}, plus the payment for the scheme, S_{it}, minus the opportunity cost of participation, C_{it}, as well as effort of participation, E_{it}. Z_{it} is a vector of the farm and farmer characteristics that affect utility. The utility derived from non-participation in a scheme is given by:

$$U_{NPit}(I_{it}, 0; Z_{it}) \quad (2)$$

where utility of non-participation, U_{NPit}, is a function of family farm income and farm and farmer characteristics that affect utility. Effort is equal to zero as they are not undertaking actions related to scheme participation. We assume that when a farmer i, makes the decision to participate in an AES they receive a greater utility from participating than not. This results in a decision function as follows:

$$Y_{it} = U_{NPit}(I_{it}, 0; Z_{it}) - U_{Pit}(I_{Pit} + S_{it} - C_{it}, E_{it}; Z_{it}) \quad (3)$$

While we cannot directly observe the utility amounts and therefore do not know the value of Y_{it} we can observe the participation choice. This discrete choice is given by:

$$Y^*_{it} = \begin{cases} 0, if\, Y_{it} > 0 \\ 1, otherwise \end{cases} \quad (4)$$

where 1 represents participation and 0 represents non-participation in an AES. Hence the decision function can be rewritten as:

$$Y^*_{it} = U_{NPit}(I_{it}, 0; Z_{it}) - U_{Pit}(I_{Pit} + S_{it} - C_{it}, E_{it}; Z_{it}) = X_{it}\beta + \varepsilon_{it} \quad (5)$$

where X_{it} is a vector that gathers the determinants of Y^*_{it}, β is a parameter vector and ε_{it} is a random component.

To estimate this model a standard random effects logit estimator is employed. The individual-specific effect is a random variable that is uncorrelated with the explanatory variables. Due to the possibility of endogeneity with components in such as family farm income, the possibility of fixed effects, (where there is a correlation between the individual farm effect and one or more of the X variables), must be accounted for. This is achieved by including the mean farm income over the examined period in each regression as an additional variable. This approach follows the work of Hynes and Garvey (2009) and Murphy et al. (2014) where using mean income is expected to capture unobserved farm or farm management characteristics. This is a version of the Mundlak-Chamberlain random effects model (Mundlak, 1978). A disadvantage of random effects models is that random effects estimates may be biased if one fails to control for omitted variables. However the advantage of being able to estimate the effects of time-invariant variables using this modelling approach is an important consideration with a farm level dataset where many of the key explanatory variables tend to remain unchanged for long periods (e.g. system and size of farm).

4.2. Data

The data used for this analysis are from the Teagasc National Farm Survey (NFS), an annual survey conducted by the Irish Agriculture and Food Development Authority, Teagasc, as part of its data-collection commitments to the Farm Accountancy Data Network of the European Union. NFS data from the years 1996–2018 inclusive are used to investigate the type of farmer who participates in an AES over time and to identify any variation between different schemes and across time. The NFS is an unbalanced panel that is nationally representative of farm size and system based on the Census of Agriculture undertaken by the Central Statistics Office. Approximately 1000 farms are surveyed each year with farms staying an average of 7.33 years in the panel. Once a farm is at least 2 years in the panel it can be used in the estimation of the random effects logit model. Table 1 shows the comparative summary statistics for all Teagasc NFS farms that are also separated into NFS AES participant (REPS, AEOS or GLAS) and non-participant farms for the variables included in the regression. The figures displayed are averages for farms in each group across all years.

Ireland's dominant farm systems (using EU farm typology based on standard output as set out in Commission Decision 78/463) are associated with grass-fed livestock production. For the purpose of this analysis, farm systems are split between dairy, cattle, sheep and tillage, based on the dominant enterprise on the farm. Cattle farms make up the biggest group in the NFS sample with 41% of farms. Dairy follows with 37.6%, with sheep and tillage farms representing the smaller groups at 12.6% and 8.8% respectively. Other systems such as poultry, horse and pig farms are excluded due to low numbers. AES participants over the period are more likely to be cattle and sheep farmers at 47.5%, and 19% respectively compared to 37.7% and 9.4% for non-participants. The average farm size is 54 ha with approximately 1.33 livestock units per hectare. The stocking rate is determined by applying coefficients to each type and age category of livestock, then aggregating these and dividing by the utilisable agricultural area (e.g. a dairy cow is one livestock unit per hectare (LU/ha)). On average, AES participant farms are smaller than non-participants, averaging 51 ha, and are less highly stocked at 1.27 LU/ha compared to 55.4 ha and 1.40 LU/ha.

Family farm income is calculated as revenue, including subsidies such as direct payments, minus costs. AES payments are excluded from the subsidies in this calculation to prevent an endogeneity issue. All monetary values were adjusted to 2016 levels based on the consumer price index (CPI) as reported by the Central Statistics Office. Average family farm income in the sample was €29,607. This broke down as €21,291 for AES participant farms and €33,700 for non-participant farms. Household income (which includes off-farm income) is not collected in the survey so cannot be considered. Used as a measure of productivity of land, average gross output per hectare across the entire sample was €1,770 (Brennan et al., 2016). AES participants are on average less productive with €1,580 per hectare gross output compared to €1,870 per hectare for non-participants. The proportion of income from the market (the alternative being subsidies) is included as a measure of financial sustainability (Brennan et al., 2016).[5] On average across the country, 69% of farmers' income comes from the market.

Table 1
Comparative summary statistics for all farms in the NFS and AES farms in NFS (1996–2018).

Variable	All NFS	NFS AES participants	NFS Non-participating farms
Total no.	23,789	7,857	15,928
Dairy (%)	37.6	25.1	43.9
Cattle (%)	41.0	47.5	37.7
Sheep (%)	12.6	19.0	9.4
Tillage (%)	8.8	8.5	8.9
Farm size (ha)	53.9	50.8	55.4
Livestock units per hectare	1.33	1.20	1.40
Family farm income (000€)	29.6	21.3	33.7
Gross output per ha (000€)	1.77	1.58	1.87
Proportion of income from market (%)	69.1	62.7	72.2
Farmer age (years)	52.7	52.3	52.9
Children (% of farms with children)	42.8	46.9	40.7

[4] Family farm income is calculated by deducting all farm costs (direct and overhead) from farm gross output (Teagasc, 2019).

[5] Subsidies include the direct payment and other payments from the EU or State that the farmer received.

There is less reliance on market income among AES participants at 62.7% on average compared to 72.2% for non-participants (excluding AES payments from subsidies). Hence, AES participants are more reliant on subsidies for income than their non-AES counterparts.

In terms of farmer characteristics, participant farmers are similar in age, 52.2 years versus 52.9 for participant and non-participant farmers respectively. Participant farmers are more likely to have children at home - 46.9% versus 40.7% for non-participant farmers.

Table 2 disaggregates this information into the periods when each of the schemes was in place. A number of changes occurred over the three different periods in which the large-scale AESs were running. Inflation adjusted family farm income increased on average across all farms from €28,000 in the REPS period to €42,000 in the GLAS period. Average real incomes also increased for AES participants from €20,000 to €22,000 to €32,000 in REPS, AEOS and GLAS respectively. However, participants in each of the AESs still have lower incomes compared to the national average.

There is a noticeable difference in the percentage of participants who are dairy farmers across the schemes with REPS having the highest at 28%. Dairy farmers only make up 10% of AEOS participants in the NFS and 13% of GLAS participants, compared to the average of approximately one third of all NFS farms in each period. The level of sheep farmers as a proportion of total participants peaked during the AEOS period, making up 35% of AEOS participants compared to 17% in REPS and 23% in GLAS. The size of scheme participant farms varied over the three periods, compared with the average farm size of all NFS farms. REPS farms were smaller than average, while AEOS and GLAS farms were larger than the average NFS farm.

In all three scheme periods, the stocking rate of participant farms was lower on average than across 'all farms', ranging from a difference of 0.1 livestock units per hectare in REPS to 0.3 livestock units per hectare in AEOS. Gross output per hectare has increased across the three time periods after adjusting for inflation. On average gross output per hectare was €1,596 for REPS farms over the period and this had increased to €2,041 for GLAS farms in the later period. Participants had lower gross output per hectare than the national average in all three periods.

5. Results

Before presenting the participation models we first examine the temporal change in participation numbers over the reference period, in total and by farm system and size. Participation levels across schemes differed greatly. As can be seen in Fig. 1, based on the NFS weighted panel participation in schemes peaked in the last REPS period (REPS4) before REPS participation began declining as the 5-year contracts ended. AEOS by comparison was seen as less successful due to the low uptake rate, topping out at just over 10% of NFS farms. GLAS by comparison, reached its participation goal of 50,000 farms, which translates to a 35% participation rate on NFS farms. This scheme was closed for new applicants in December 2016.

Examining participation levels by farm system shows differences in trends across time (Fig. 2). Across the period under investigation, sheep and cattle farms had higher participation rates than dairy and tillage farms. This converged in 2011, the first year of AEOS entry, during which participation levels were low. From then on, sheep farm participation levels increased while dairy farm levels dropped markedly. While tillage participation levels were consistently lower than cattle participation levels throughout the GLAS period they were much closer to each other in the years 2016 and 2017. In total, just over 30% of NFS tillage farms participated in the GLAS scheme.

Fig. 3 shows the average AES payments received by farms between 1996 and 2018, categorised by farm size. During the REPS period there was a substantial difference in the level of payment by farm size, the difference reaching nearly €6000 between the highest and lowest size categories in the mid-2000s. Since the payments for REPS ceased in 2014, the average payment for schemes in each size category is much closer, with a gap of just over €1000 between the top and bottom category. This narrowing is likely due to the change in payments from the area based system in REPS to a measure based system in AEOS and GLAS.

To gain a clearer picture of the pattern of behaviour observed in the preceding graphics, a number of random-effects logit panel models of participation in AESs were conducted. The results of four such models estimated using the NFS data from 1996 to 2018 are displayed in Table 3. Model 1 presents the results of a random effects logit model where the dependent variable is equal to 1 if the farmer is a REPS, AEOS or GLAS participant in a given year, and 0 otherwise. The next three columns show the results of a random-effects logit on each of the three periods of agri-environment schemes in Ireland separately. The REPS period runs from 1996 until the end of the last contracts in 2014, the AEOS period runs from 2011 to 2017 and GLAS from 2015 to 2018. A likelihood ratio test rejected the hypothesis that there was an absence of correlation in residuals over time in all models suggesting that a panel rather than pooled regression is preferred. Odds ratios are reported for the models coefficients. Odds ratios greater (less) than 1 indicate farmers are more (less) likely to be participants in the schemes when there is a positive change in the explanatory variable. An increase of 0.01 in the coefficient represents a 1% increase in the odds of participating in the scheme for a one unit increase in the explanatory variable.

A number of farm characteristics are significant in the analysis. The farm system was included in the model with the base system being dairy, a relatively intensive category compared to the other systems. Across all four models, cattle and sheep farms were more likely to be participants than dairy farms. In the extreme case in the GLAS model, this increased to 43 times more likely for cattle and 72 times more likely for sheep farms. This agrees with findings of other studies that less intensive systems are more likely to participate in schemes (Bertoni et al., 2012; Wynn et al., 2010; Baylis et al., 2008; Hejnowicz et al., 2016; Hynes and Garvey, 2009). Tillage farms had significantly different participation levels in GLAS, in which they were more likely to participate than the base case - dairy farms.

Farm size and the quadratic term of farm size were both significant. The significance of the quadratic term indicates a non-linear relationship between AES participation and farm size. The results of all the models and the fact that the turning points (where the curve is at the maximum or minimum depending on whether the coefficients are above or below one) are well above the average farm size (see Table 4) suggest that as farm size increases, the likelihood of participation increases but at a decreasing rate.

A similar result was found for the stocking rate in three of the models (the complete time period AES, the REPS and the GLAS models) with a positive coefficient on stocking rate and a negative coefficient on its quadratic term. However, the turning point in the models differs. In the AES and REPS models the turning point is below the average stocking rate suggesting that stocking rate has a negative association with most farms (farms stocked above 0.8 livestock units per hectare), while the turning point for the GLAS model (4) is at the average stocking rate. This suggests that a below average stocking rate is associated with a higher likelihood of participation, while those who have an above average stocking rate would be less likely to participate. Stocking rate in the AEOS regression had a linear functional form and was found to be significantly negatively related to participation. A 0.5 livestock unit per hectare increase in stocking rate is associated with a farmer being 41% less likely to participate in a scheme. This is consistent with other studies.

Economic factors were also found to be significant in the participation decision in the majority of cases. Economic variables in the AEOS model showed the least significance with gross output per hectare being the only significant variable with an increase of €1000 associated with a farmer being twice as likely to participate in a scheme. Increases in gross output per hectare were positive and significant for REPS participation and GLAS participation respectively with farms 2.6 times and 13 times

Table 2
Summary statistics for REPS, AEOS and GLAS participants in NFS and for all NFS farms.

	REPS period (1996–2014)		AEOS period (2011–2017)		GLAS period (2015–2018)	
	Participants	All	Participants	All	Participants	All
	6,542	20,387	433	5,942	914	3,402
Dairy (%)	27.6	37.9	10.5	33.1	13.6	36.1
Cattle (%)	46.5	40.8	48.7	43.4	54.2	41.7
Sheep (%)	17.3	12.4	35.3	14.0	23.4	14.1
Tillage (%)	8.6	8.9	5.5	9.5	8.9	8.2
Farm size (ha)	48.0	52.7	71.3	60.0	70.1	61.2
Livestock units per ha	1.29	1.32	1.10	1.40	1.19	1.42
Family farm income less AES payments (000€)	20.43	27.80	22.17	36.88	32.21	40.47
Gross output per ha (000€)	1.596	1.722	1.281	1.958	1.563	2.067
Proportion of income from market (%)	62.4	68.3	65.9	72.9	64.0	74.0
Age	51.9	52.3	54.0	55.0	54.7	55.1
Children (%)	49.2	44.6	37.2	35.5	35.4	32.1

Source: NFS (1996–2018). Monetary values have been adjusted to the year 2016 using the CPI.

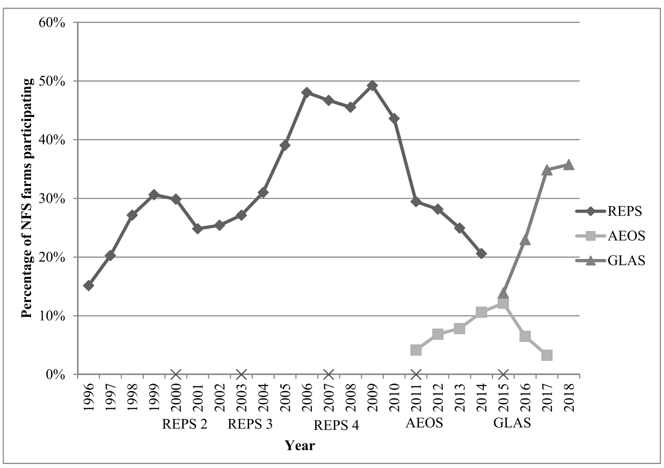

Fig. 1. Participation in agri-environment schemes for NFS farms 1996–2018.

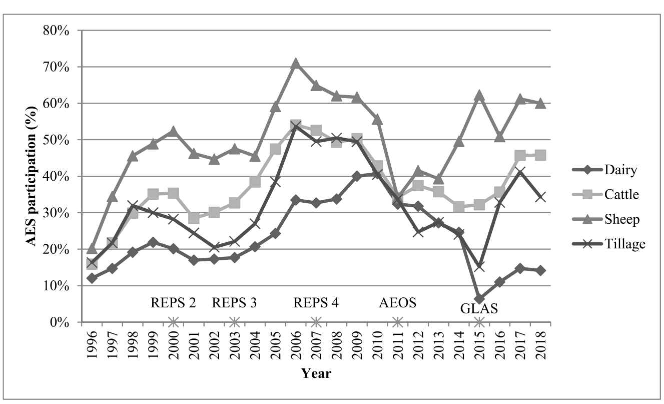

Fig. 2. Percentage of NFS farms that are AES participants by system 1996–2018.

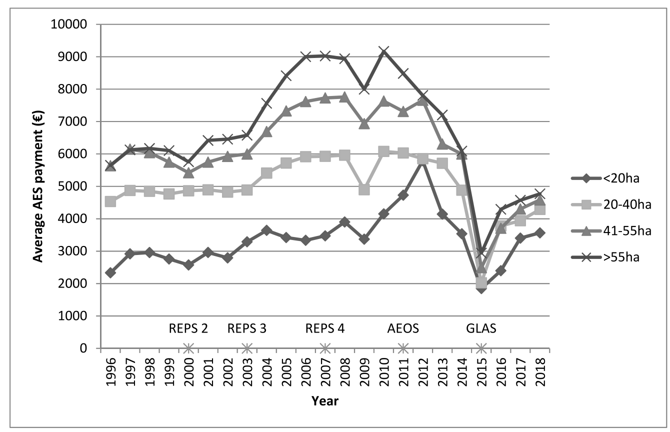

Fig. 3. Average AES payments (€) by farm size 1996–2018.

more likely to participate in a scheme for every €1000 gross output increase.[6] This is in line with the results found by Murphy et al. (2014). With stocking rate already accounted for, this is indicative of productivity being positively associated with participation. Murphy et al. (2014) suggested this could be explained by extensive farmers looking to optimise profits therefore maximising production as well as joining an AES.

Family farm income by comparison, was negatively associated with participation in the AESs. An increase in income of €1000 leads to a likelihood of the farmer being an AES participant dropping by between one and two per cent. Market orientation or the inverse of farmers' reliance on subsidies is found to be negatively significant on the participation decision for the complete time period AES participation model (Column 2 in Table 3) and in the individual REPS and GLAS models. Mean family farm income was significant in all but the AEOS model suggesting that there are individual level effects at play.

In general, farmer characteristics were significant in the model. Age is negatively associated with participation with each year leading to a drop in the likelihood of participation of between 1 and 4%. However, age is not significant in the GLAS model. This agrees with the findings of Wilson (1997) and Wynn et al. (2010). The presence of children in the household increased the likelihood of participation in the complete time

[6] Prior to 2009 gross output per hectare was higher for non-participants in the NFS. From 2009 onwards the opposite is the case. Due to the fact that the highest number of participating farms in the NFS are seen during the 2005–2009 period the overall average gross output per hectare is less for participating farmers that for non-participating farmers, as shown in the summary statistics of Table 1.

Table 3
Results of random effects logit models of participation in agri-environment schemes.

	(1)	(2)	(3)	(4)
	All AES participation	REPS participation	AEOS participation	GLAS participation
Farm characteristics				
Farm system (base: Dairy)				
Cattle	1.883***	1.431***	12.89***	43.74***
	(0.188)	(0.153)	(10.04)	(31.35)
Sheep	3.392***	2.205***	66.75***	71.66***
	(0.418)	(0.289)	(56.30)	(60.44)
Tillage	1.388**	1.188	0.552	50.20***
	(0.183)	(0.169)	(0.500)	(43.22)
Farm size (ha)	1.006***	1.012***	1.016**	1.028***
	(0.00136)	(0.00237)	(0.00648)	(0.00851)
Farm size squared	0.99999*	0.99997***	0.99999*	0.99998***
	(1.85e-06)	(7.71e-06)	(6.35e-06)	(8.57e-06)
Stocking rate	2.475***	2.356***	0.173***	91.88***
	(0.456)	(0.478)	(0.0797)	(96.82)
Stocking rate squared	0.569***	0.596***		0.204***
	(0.0367)	(0.0427)		(0.0675)
Family farm income (000's)	0.984***	0.981***	0.992	0.986*
	(0.00175)	(0.00215)	(0.00719)	(0.00726)
Proportion of income from market	0.986***	0.979***	1.002	0.819***
	(0.00203)	(0.0218)	(0.00276)	(0.0140)
Gross output per hectare (000's/ha)	2.502***	2.811***	2.036**	12.97***
	(0.161)	(0.212)	(0.690)	(4.383)
Mean family farm income (000's)	0.995**	0.993**	0.993	0.979**
	(0.00221)	(0.00271)	(0.0105)	(0.0104)
Farmer				
Age	0.990***	0.990***	0.965**	0.989
	(0.00255)	(0.00279)	(0.0148)	(0.0151)
Children	1.382***	1.413***	0.837	2.491**
	(0.0815)	(0.0914)	(0.305)	(0.947)
Participation				
Lagged participation	29.17***	41.12***		
	(1.703)	(2.828)		
Past REPS participation			2.253**	7.583***
			(0.847)	(3.050)
Past AEOS participation				51.58***
				(31.50)
Period dummies	Yes	Yes	No	No
Constant	0.0743***	0.0962***	0.00225***	0.426
	(0.0204)	(0.0285)	(0.00318)	(0.763)
Observations	19,977	16,679	3,397	3,216
Number of individual farms	2,511	2,378	1,125	1,020

Standard error in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4
Turning points for quadratic terms in regressions.

	AES participation	REPS	AEOS	GLAS
Farm size (ha)	870	208	723	585
Stocking rate (LU/ha)	0.804	0.829	–	1.423

period AES, the REPS and the GLAS models. This corresponds with past work by Wilson (1996) and Lynch and Lovell (2003) among others who found the same. Others have found conflicting results (Potter and Lobley, 1992; Wossink and van Wenum, 2003).

A lagged participation dummy variable representing whether a farmer was an AES participant in the previous year was included in the first and second model to account for path dependence. Due to the shorter periods involved in the AEOS and GLAS models, collinearity between current and previous year participation meant that it was not appropriate to include lagged participation. Dummies were also included for whether the farmer had participated in a previous scheme. AES period dummies were included in the first model for the periods of the four REPS iterations and the AEOS and GLAS periods. The REPS participation model included period dummies for each of the REPS periods. Period dummies were not included in the AEOS or GLAS models as the schemes did not differ greatly over their lifetime. As previously discussed, mean income across all years is included in each model to account for fixed effects as a variant of the Mundlak-Chamberlain model.

Across the models we see the importance of path dependence and past participation in schemes as a predictor of current participation. The path dependence indicated by the odds ratio of participation in the previous year is expected due to the five-year duration of AES contracts and has been a consistent finding in past studies (Hynes and Garvey, 2009; Murphy et al., 2014). In the models for AEOS and GLAS, dummy variables were used to represent past participation by the farmer in REPS for the AEOS model and in REPS and AEOS for the GLAS model. Past scheme participation was significant for both AEOS and GLAS. A farmer who participated in REPS was 2.3 times as likely to be an AEOS participant and 7.6 times as likely to be a GLAS participant than those who did not participate in REPS. Past AEOS participants were 51.6 times as likely to participate in GLAS as those who did not participate.

6. Discussion and conclusions

The aim of this study was to examine agri-environment scheme participation against a backdrop of changes in scheme characteristics and agricultural policy. While previous work has looked at the success of schemes in isolation or comparing schemes in different locations, the novelty of this analysis lies in the use of a nationally representative data across a twenty-three-year time period, spanning three different agri-environment schemes. This enabled us to provide a more nuanced view of changes in farm participation relative to scheme design and agricultural policy than previous cross-sectional approaches in the literature.

The analysis shows that extensive farm systems, cattle and sheep, are more likely than intensive farm systems (dairy and tillage), to be AES participants across all of the period, confirming the first hypothesis of this study. High participation among extensive farmers has been raised as a concern in previous studies due to the possible lack of additionality that such farms could provide (Baylis et al., 2008; Hejnowicz et al., 2016; Hynes and Garvey, 2009). However, this analysis provides greater insight into contributory factors, primarily scheme design and agricultural policy. In terms of scheme design, firstly, in relation specifically to the environmentally targeted, capped (GLAS) scheme, which was partly introduced to counter the lack of additionality argument, the payment caps continued to hamper the incentive to participate for large farms whose costs may not be met by the limited payment. Secondly, the targeted environmental assets such as Natura 2000 areas and Pristine or High water quality areas are mostly found in extensively (rather than intensively) farmed locations (Kleijn et al., 2012). Thirdly, while entry opportunities existed for intensive farms in areas with vulnerable water quality, farmers were required to undertake low emission slurry spreading, a measure with a relatively high capital cost which is only partly grant-aided. It could be argued that the extensive farms entering the AES over the time period under review are unlikely to have intensified even without an AES. Nevertheless participation is likely to have led to better environmentally educated farmers and a reduction in environmentally damaging practices. To give a definitive answer to the question to whether there is additionality from participation in AES schemes standardized baseline assessments would need to carried out – something that has been argued for since the start of EU agri-environmental schemes (Hynes et al., 2008).

These factors are also related to the second hypothesis that milk quota removal would result in lower participation of dairy farms. The removal of milk quotas and other policy measures meant to increase agricultural productivity under the Irish Government's Food Harvest 2020 and Food Wise 2025 strategies, presented dairy farmers with an opportunity to expand production and increase profits. This meant that any land devoted to AES measures had a higher opportunity cost than previously, representing an added deterrent to participation (Udagawa et al., 2014). The results of the random-effects logit suggest that this hypothesis is true as the odds of other farm systems participating compared to dairy farms has increased over time, especially in the GLAS period that corresponds to the removal of milk quotas.

The third hypothesis, that farm size has a non-linear relationship to participation was confirmed by the regression results showing that there is a quadratic relationship. The likelihood of participation increases with farm size at a decreasing rate. Scheme design factors likely contribute to this. For example, in REPS there were size limits for per hectare payments while under GLAS a cap of €5000 per farm was set, which may have been below the level of payments received by farms in the earlier AES scheme REPS. It is possible this helps to explain differing results relating to size in past research if similar payment structures were in place (Capitanio et al., 2011; Ducos et al., 2009; Hammes et al., 2016; Lynch and Lovell, 2003; Mathijs, 2003; Murphy et al., 2014; Vanslembrouck et al., 2002; Wilson and Hart, 2000).

Increases in the proportion of income obtained from the market versus subsidies is associated with a decline in the likelihood of participation in a scheme. Flipping this finding suggests that farmers who choose to participate are already in receipt of a number of other different payments under CAP, suggesting the validity of the fourth hypothesis, namely that subsidy exposure increases participation. It is likely to be the case that farms with strong market orientation are less likely to need extra income from other sources such as AESs and thus are less likely to participate. Additionally, those who are in receipt of other subsidies may be more aware of AESs through their interaction with the system and have the experience and connections with advisors to more easily apply and participate in a scheme, thereby facing lower transaction costs of participating and less fear of 'form-filling' (Cullen et al, 2018, 2020, 2018).

As mentioned previously, a key concern of early schemes remains, namely that extensive farms are the most likely to participate, with consequential concerns for additionality. Depending on the environmental goal of schemes, which in the case of GLAS included reducing carbon emissions, this could be detrimental to inducing the hoped-for impacts. Intensive livestock farms are seen to have a higher risk of nutrient losses to water and absolute carbon emissions (Lynch et al., 2016), while extensive farms have been found to have the most important environmental features from an ecosystem perspective due to less intrusive past land-use and other spatial factors (Matin et al., 2020). This suggests that if policymakers want greater participation from intensive farms, they may need to either make changes to scheme design (such as the targeting of tillage farmers in GLAS) or use other tools to improve environmental performance such as regulation, taxation (such as the strict regulation on water quality under the Resource Management Act 1991 in New Zealand (Cassells and Meister, 2001)). Alternatively, policies could be focused on incentivising specific measures to reduce negative externalities, that also have benefits for intensive farmers, i.e. 'win-wins' such as improved slurry management (Cullen et al., 2020).

The results presented here provide a deeper understanding of how changes in scheme design and agricultural policy impact on the participation decision. Understanding the implications of AES structures is particularly important in the design of schemes post CAP 2020. The targeting of entry to GLAS which was based on environmental assets in largely undisturbed landscapes is likely to have resulted in less-than-optimal participation of intensive farms. With the European Union aiming to be climate neutral by 2050 under the European Green Deal, addressing the impact of agriculture on climate change will need to be a focus of future agricultural environmental policy. The European Green Deal also calls for systemic solutions for restoring biodiversity and ecosystem services, and for delivering tangible benefits for biodiversity. Future agri-environmental programmes could therefore have a greater focus on ecosystem restoration, particularly where the restoration measures can also act as nature-based solutions to reduce the impacts of climate change. This would require the targeting of relevant ecosystems in particular locations that can fulfil such a role (Meyer et al., 2015; van der Horst, 2007).

The EU Biodiversity Strategy for 2030 also calls on Member States to integrate biodiversity and ecosystems into school, higher education curricula and professional training. While education has always played an important role in EU agri–environmental schemes that role should be increased under future programs not just for the participants but also for the farm advisory services administering the schemes. The 2030 Strategy also contains an EU Nature Restoration Plan that will involve a proposal for legally binding EU nature restoration targets. Future agri-environment schemes would be an obvious avenue for fostering the cooperation of land managers in achieving the terrestrial targets but ensuring that the necessary ecosystem types are covered will require the 'correct' landowners are participating in the schemes. Finally, while extensive farms have a role to play in the protection of priority environmental assets, higher intensity farms also have a critical role to play. Broadening the spatial scope of new schemes and improving buy-in of intensive farms in win-win measures to reduce emissions to air and water and to protect biodiversity will be needed to make progress in achieving agri-environmental targets in the future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by a Teagasc Walsh Fellowship.

Appendix A. Scheme objectives

Table A1
Objectives of Irish AESs

REPS	AEOS	GLAS
The establishment of farming practices and production methods which reflect the need for environmental conservation and protection.	To promote biodiversity, encourage water management/ quality and combat climate change.	To encourage actions at farm level that promote biodiversity, protect water quality, and help combat climate change
The protection of wildlife habitats and endangered species of flora and fauna.	To contribute to positive environmental management of farmed Natura 2000 sites and river catchments in the implementation of the Birds Directive, Habitats Directive and Water Framework Directive.	To contribute to positive environmental management of farmed Natura 2000 sites and river catchments in the implementation of the Birds Directive, Habitats Directive and Water Framework Directive
The production of quality food in an extensive and environmentally friendly manner.		To promote and sustain attitudinal change amongst farmers.
		To achieve a balanced and effective environmental programme over the period of the RDP.

Appendix B. Scheme measures

Table B1
AEOS measures

Objective	1.Mandatory (Priority Environmental Action)	2.Complementary Actions	3.Additional Actions
Contribute to Halting Biodiversity Decline	At least one of the following undertakings MUST be selected: Species rich grassland Traditional hay meadows Establishment & Maintenance of Habitats Wild Bird Cover (grassland farms only) Where only one of these is selected at least one additional option from column 2 must be selected.	Riparian Margins Conservation of Animal Genetic Resources Traditional Orchards Tree Planting Coppicing hedgerows Laying Hedgerows Traditional Stone wall maintenance	Planting of new hedgerows Arable Margins Green Cover Establishment from a sown crop Use of new technologies for slurry spreading Minimum Tillage Alternative water source for bovines
Contribute to maintaining water quality	At least one of the following undertakings MUST be selected: Riparian Margins Alternative water source for bovines Where only one of these is selected at least one complementary option from column 2 must be selected	Species rich grassland Traditional hay meadows Arable Margins Green Cover Establishment from a sown crop Minimum Tillage Use of new technologies for slurry spreading	Traditional Orchards Planting new hedgerows Wild Bird Cover (Grassland farms only) Tree Planting Establishment & Maintenance of Habitats Conservation of Animal Genetic Resource Coppicing hedgerows Laying Hedgerows Traditional Stone wall maintenance
Contribute to combating climate change	At least one of the following undertakings MUST be selected: Arable Margins Green Cover Establishment from a sown crop Minimum Tillage Where only one of these is selected at least one additional option from column 2 must be selected.	Riparian Margins Planting new hedgerows Tree Planting Species rich grassland Traditional hay meadows Use of new technologies for slurry spreading	Establishment & Maintenance of Habitats Coppicing hedgerows Laying Hedgerows Traditional Orchards Alternative water source for bovines Traditional Stone wall maintenance Conservation of Animal Genetic Resources

Table B2
GLAS measures

Core	An approved agricultural planner must prepare the GLAS application Nutrient Management Planning Training in environmental practices and standards
Measures	Arable margins Bat boxes Bird boxes Catch crops Conservation of solitary bees Coppicing hedgerows Environmental management of fallow land Farmland birds Farmland habitats Laying hedgerows Low-emission slurry spreading Low-input permanent pasture Minimum tillage

(*continued on next page*)

Table B2 (*continued*)

Planting new hedgerows
Planting a grove of native trees
Protection of archaeological sites
Protection of water courses from bovines
Rare breeds
Riparian margins
Traditional hay meadow
Traditional orchards
Traditional stone wall maintenance
Wild bird cover

Credit author statement

Paula Cullen: Conceptualization, Writing – original draft, Data curation, Methodology, Formal analysis. Stephen Hynes: Conceptualization, Writing – review & editing, Funding acquisition. Mary Ryan: Conceptualization, Writing – review & editing, Project administration, Funding acquisition. Cathal O'Donoghue: Conceptualization, Writing – review & editing, Funding acquisition.

References

Ahnström, J., Höckert, J., Bergea, H.L., Francis, C.A., Skelton, P., Hallgren, L., Ho, J., Bergea, H.L., Hallgren, L., Ahnström, J., Höckert, J., Bergea, H.L., Francis, C.A., Skelton, P., Hallgren, L., 2017. Farmers and nature conservation: what is known about attitudes, context factors and actions affecting conservation? Renew. Agric. Food Syst. 24, 38–47. https://doi.org/10.1017/S1742170508002391.

Andreß, H.J., Golsch, K., Schmidt, A.W., 2013. Applied Panel Data Analysis for Economic and Social Surveys. Applied Panel Data Analysis for Economic and Social Surveys. https://doi.org/10.1007/978-3-642-32914-2.

Barreiro-Hurlé, J., Espinosa-Goded, M., Dupraz, P., 2010. Does intensity of change matter? Factors affecting adoption of agri-environmental schemes in Spain. J. Environ. Manag. 53, 891–905. https://doi.org/10.1080/09640568.2010.490058.

Batáry, P., Dicks, L.V., Kleijn, D., Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. Conserv. Biol. 29, 1006–1016. https://doi.org/10.1111/cobi.12536.

Baylis, K., Peplow, S., Rausser, G., Simon, L., 2008. Agri-environmental policies in the EU and United States: a comparison. Ecol. Econ. 65, 753–764. https://doi.org/10.1016/j.ecolecon.2007.07.034.

Beharry-Borg, N., Smart, J.C.R., Termansen, M., Hubacek, K., 2013. Evaluating farmers' likely participation in a payment programme for water quality protection in the UK uplands. Reg. Environ. Change 13, 633–647. https://doi.org/10.1007/s10113-012-0282-9.

Bertoni, D., Cavicchioli, D., Pretolani, R., Olper, A., 2012. Determinants of agri-environmental measures adoption: do institutional constraints matter? Environ. Econ. 3, 8–19.

Bertoni, D., Curzi, D., Aletti, G., Olper, A., 2020. Estimating the effects of agri-environmental measures using difference-in-difference coarsened exact matching. Food Pol. 90, 101790. https://doi.org/10.1016/j.foodpol.2019.101790.

Brennan, N., Ryan, M., Hennessy, T., Cullen, P., Dillon, E., Ireland, I., 2016. Going beyond FADN: the use of additional data to gain insights into extension service use across European Union Member States. Stud. Agric. Econ. 118, 145–153. https://doi.org/10.7896/j.1630.

Burton, R.J.F., Kuczera, C., Schwarz, G., 2008. Exploring farmers' cultural resistance to voluntary agri-environmental schemes. Sociol. Rural. 48, 16–37. https://doi.org/10.1111/j.1467-9523.2008.00452.x.

Capitanio, F., Adinolfi, F., Malorgio, G., 2011. What explains farmers' participation in rural development policy in Italian southern region? An empirical analysis. New Med. 10, 19–24.

Cassells, S.M., Meister, A.D., 2001. Cost and trade impacts of environmental regulations: effluent control and the New Zealand dairy sector. Aust. J. Agric. Resour. Econ. 45, 257–274. https://doi.org/10.1111/1467-8489.00142.

Cullen, P., Dupraz, P., Moran, J., Murphy, P., O'Flaherty, R., O'Donoghue, C., O'Shea, R., Ryan, M., 2018. Agri-environment scheme design: past lessons and future suggestions. EuroChoices 17, 26–30. https://doi.org/10.1111/1746-692X.12187.

Cullen, P., Ryan, M., O'Donoghue, C., Hynes, S., HUallacháin, D., Sheridan, H., 2020. Impact of farmer self-identity and attitudes on participation in agri-environment schemes. Land Use Pol. 95, 104660. https://doi.org/10.1016/j.landusepol.2020.104660.

DAFM, 2019. Public Consultation - 2019 Nitrates Derogation Review.

DAFM, 2015. Food Wise 2025 A 10-year Vision for the Irish Agri-Food Industry.

DAFM, 2010. Food Harvest 2020: a Vision for Irish Agri-Food and Fisheries.

Defrancesco, E., Gatto, P., Runge, F., Trestini, S., 2008. Factors affecting farmers'participation in agri-environmental measures: a northern Italian perspective. J. Agric. Econ. 59, 114–131. https://doi.org/10.1111/j.1477-9552.2007.00134.x.

Dessart, F.J., Barreiro-Hurlé, J., Van Bavel, R., 2019. Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. Eur. Rev. Agric. Econ. 46, 417–471. https://doi.org/10.1093/erae/jbz019.

Ducos, G., Dupraz, P., Bonnieux, F., 2009. Agri-environment contract adoption under fixed and variable compliance costs. J. Environ. Plann. Manag. 52, 669–687. https://doi.org/10.1080/09640560902958248.

Dupraz, P., Vermersch, D., Henry De Frahan, B., Delvaux, L., 2003. The environmental supply of farm households: a flexible willingness to accept model. Environ. Resour. Econ. 25, 171–189. https://doi.org/10.1023/A:1023910720219.

Espinosa-Goded, M., Barreiro-Hurlé, J., Ruto, E., 2010. What do farmers want from agri-environmental scheme design? A choice experiment approach. J. Agric. Econ. 61, 259–273. https://doi.org/10.1111/j.1477-9552.2010.00244.x.

Eurostat, 2020a. Collection of cow's milk. https://ec.europa.eu/eurostat/databrowser/view/tag00037/default/table.

Eurostat, 2020b. Number of dairy cows. https://ec.europa.eu/eurostat/databrowser/view/tag00014/default.

FAO, 2018. World Food and Agriculture - Statistical Pocketbook 2018 (Rome).

Finn, J.A.A., Ó hUallacháin, D., 2012. A review of evidence on the environmental impact of Ireland's Rural Environment Protection Scheme (REPS). Biol. Environ. 112, 1–24. https://doi.org/10.3318/BIOE.2011.19.Biology.

Gasson, R., 1973. Goals and values of farmers. J. Agric. Econ. 24, 521–542. https://doi.org/10.1111/j.1477-9552.1973.tb00952.x.

Giannakis, E., 2014. Modelling farmers' participation in agri-environmental schemes in Greece. Int. J. Agric. Resour. Govern. Ecol. 10, 227–238. https://doi.org/10.1504/IJARGE.2014.064005.

Greiner, R., 2015. Motivations and attitudes influence farmers' willingness to participate in biodiversity conservation contracts. Agric. Syst. 137, 154–165. https://doi.org/10.1016/j.agsy.2015.04.005.

Hammes, V., Eggers, M., Isselstein, J., Kayser, M., 2016. The attitude of grassland farmers towards nature conservation and agri-environment measures—a survey-based analysis. Land Use Pol. 59, 528–535. https://doi.org/10.1016/j.landusepol.2016.09.023.

Hejnowicz, A.P., Rudd, M.A., White, P.C.L., 2016. A survey exploring private farm advisor perspectives of agri-environment schemes: the case of England's Environmental Stewardship programme. Land Use Pol. 55, 240–256. https://doi.org/10.1016/j.landusepol.2016.04.005.

Herzon, I., Mikk, M., 2007. Farmers' perceptions of biodiversity and their willingness to enhance it through agri-environment schemes: a comparative study from Estonia and Finland. J. Nat. Conserv. 15, 10–25. https://doi.org/10.1016/j.jnc.2006.08.001.

Hsiao, C., 2007. Panel Data Analysis—Advantages and Challenges 1–22. https://doi.org/10.1007/s11749-007-0046-x.

Hynes, S., Farrelly, N., Murphy, E., O'Donoghue, C., 2008. Modelling habitat conservation and participation in agri-environmental schemes: a spatial microsimulation approach. Ecol. Econ. 66 (2–3), 258–269.

Hynes, S., Campbell, D., 2011. Estimating the welfare impacts of agricultural landscape change in Ireland: a choice experiment approach. J. Environ. Plann. Manag. 54, 1019–1039. https://doi.org/10.1080/09640568.2010.547691.

Hynes, S., Campbell, D., Howley, P., 2011. A holistic vs. an attribute-based approach to agri-environmental policy valuation: do welfare estimates differ? J. Agric. Econ. 62, 305–329. https://doi.org/10.1111/j.1477-9552.2010.00287.x.

Hynes, S., Garvey, E., 2009. Modelling farmers' participation in an agri-environmental scheme using panel data: an application to the rural environment protection scheme in Ireland. J. Agric. Econ. 60, 546–562. https://doi.org/10.1111/j.1477-9552.2009.00210.x.

Karali, E., Brunner, B., Doherty, R., Hersperger, A., Rounsevell, M., 2014. Identifying the factors that influence farmer participation in environmental management practices in Switzerland. Hum. Ecol. 42, 951–963. https://doi.org/10.1007/s10745-014-9701-5.

Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E.D., Clough, Y., Díaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovács, A., Marshall, E.J.P., Tscharntke, T., Verhulst, J., 2012. On the relationship between farmland biodiversity and land-use intensity in Europe. Proc. R. Soc. B Biol. Sci. 276, 903–909. https://doi.org/10.1098/rspb.2008.1509.

Kleijn, D., Sutherland, W.J., 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? J. Appl. Ecol. 40, 947–969. https://doi.org/10.1111/j.1365-2664.2003.00868.x.

Lastra-Bravo, X.B., Hubbard, C., Garrod, G., Tolo, A., Tolón-Becerra, A., 2015. What drives farmers' participation in EU agri-environmental schemes?: results from a qualitative meta-analysis. Environ. Sci. Pol. 54, 1–9. https://doi.org/10.1016/j.envsci.2015.06.002.

Lynch, J., Hennessy, T., Buckley, C., Dillon, E., Donnellan, T., Hanrahan, K., Moran, B., Ryan, M., 2016. Teagasc National Farm Survey 2015 Sustainability Report. Athenry, Co. Galway, Teagasc. https://www.teagasc.ie/media/website/publications/2017/2015-sustainability-report.pdf.

Lynch, L., Lovell, S.J., 2003. Combining spatial and survey data to explain participation in agricultural land reservation programs. Land Econ. 79, 259–276.

Mathijs, E., 2003. Social capital and farmers' willingness to adopt countryside stewardship schemes. Outlook Agric. 32, 13–16. https://doi.org/10.5367/000000003101294217.

Matin, S., Sullivan, C.A., Finn, J.A., Ó hUallacháin, D., Green, S., Meredith, D., Moran, J., 2020. Assessing the distribution and extent of high nature value farmland in the republic of Ireland. Ecol. Indicat. 108 https://doi.org/10.1016/j.ecolind.2019.105700.

McGurk, E., Hynes, S., Thorne, F., 2020. Participation in agri-environmental schemes: a contingent valuation study of farmers in Ireland. J. Environ. Manag. 262, 110243. https://doi.org/10.1016/j.jenvman.2020.110243.

Meyer, C., Reutter, M., Matzdorf, B., Sattler, C., Schomers, S., 2015. Design rules for successful governmental payments for ecosystem services: taking agri-environmental measures in Germany as an example. J. Environ. Manag. 157, 146–159. https://doi.org/10.1016/j.jenvman.2015.03.053.

Mundlak, Y., 1978. On the pooling of time series and cross section data. Econometrica. https://doi.org/10.2307/1913646.

Murphy, G., Hynes, S., Murphy, E., O'Donoghue, C., 2014. An investigation into the type of farmer who chose to participate in Rural Environment Protection Scheme (REPS) and the role of institutional change in influencing scheme effectiveness. Land Use Pol. 39, 199–210. https://doi.org/10.1016/j.landusepol.2014.02.015.

Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F., Wilkinson, R., 2006. Understanding and promoting adoption of conservation practices by rural landholders. Aust. J. Exp. Agric. 46, 1407–1424. https://doi.org/10.1071/EA05037.

Peerlings, J., Polman, N., 2008. Agri-environmental contracting of Dutch dairy farms: the role of manure policies and the occurrence of lock-in. Eur. Rev. Agric. Econ. 35, 167–191. https://doi.org/10.1093/erae/jbn022.

Peerlings, J., Polman, N., 2009. Farm choice between agri-environmental contracts in the European Union. J. Environ. Plann. Manag. 52 (5), 593–612.

Polman, N.B.P., Slangen, L.H.G., 2008. Institutional design of agri-environmental contracts in the European Union: the role of trust and social capital. NJAS - Wageningen J. Life Sci. 55, 413–430. https://doi.org/10.1016/S1573-5214(08)80029-2.

Potter, C., Lobley, M., 1992. The conservation Status and potential of elderly farmers: results from a survey in england and wales. J. Rural Stud. 8, 133–143.

Putten, van I.E., Jennings, S.M., Louviere, J.J., Burgess, L.B., 2011. Tasmanian landowner preferences for conservation incentive programs: a latent class approach. J. Environ. Manag. 92, 2647–2656. https://doi.org/10.1016/j.jenvman.2011.06.002.

Riley, M., 2016. How does longer term participation in agri-environment schemes [re]shape farmers' environmental dispositions and identities? Land Use Pol. 52, 62–75. https://doi.org/10.1016/j.landusepol.2015.12.010.

Siebert, R., Toogood, M., Knierim, A., 2006. Factors affecting European farmers' participation in biodiversity policies. Sociol. Rural. 46, 318–340. https://doi.org/10.1111/j.1467-9523.2006.00420.x.

Teagasc, 2019. Teagasc National Farm Survey 2018 Results.

Trenholm, R., Haider, W., Lantz, V., Knowler, D., Haegeli, P., 2017. Landowner preferences for wetlands conservation programs in two Southern Ontario watersheds. J. Environ. Manag. 200, 6–21. https://doi.org/10.1016/j.jenvman.2017.05.055.

Udagawa, C., Hodge, I., Reader, M., 2014. Farm level costs of agri-environment measures: the impact of entry level stewardship on cereal farm incomes. J. Agric. Econ. 65, 212–233. https://doi.org/10.1111/1477-9552.12043.

Uthes, S., Matzdorf, B., 2013. Studies on agri-environmental Measures : a survey of the literature. Environ. Manag. 51, 251–266. https://doi.org/10.1007/s00267-012-9959-6.

van der Horst, D., 2007. Assessing the efficiency gains of improved spatial targeting of policy interventions; the example of an agri-environmental scheme. J. Environ. Manag. 85, 1076–1087. https://doi.org/10.1016/j.jenvman.2006.11.034.

Vanslembrouck, I., Van Huylenbroeck, G., Verbeke, W., 2002. Determinants of the willingness of Belgian farmers to participate in agri-environmental measures. J. Agric. Econ. 53, 489–511. https://doi.org/10.1111/j.1477-9552.2002.tb00034.x.

Wilson, G.A., 1997. Factors influencing farmer participation in the environmentally sensitive areas scheme. J. Environ. Manag. 50, 67–93. https://doi.org/10.1006/jema.1996.0095.

Willock, J., Deary, I.J., Edwards-jones, G., Gibson, G.J., Mcgregor, M.J., Sutherland, A., Dent, J.B., Morgan, O., Grieve, R., 1999. The role of attitudes and objectives in farmer decision making: business and environmentally- oriented behaviour in Scotland 50. J. Agric. Econ. 50 (2), 286–303.

Wilson, G.A., 1996. Farmer environmental attitudes and ESA participation. Geoforum 27, 115–131. https://doi.org/10.1016/0016-7185(96)00010-3.

Wilson, G.A., Hart, K., 2000. Financial imperative or conservation concern? EU farmers' motivations for participation in voluntary agri-environmental schemes. Environ. Plann. 32, 2161–2185. https://doi.org/10.1068/a3311.

Wossink, G.A.A., van Wenum, J.H., 2003. Biodiversity conservation by farmers: analysis of actual and contingent participation. Eur. Rev. Agric. Econ. 30, 461–485. https://doi.org/10.1093/erae/30.4.461.

Wynn, G., Crabtree, B., Potts, J., 2010. Modelling farmer entry into the environmentally sensitive area schemes in scotland. J. Agric. Econ. 52, 65–82. https://doi.org/10.1111/j.1477-9552.2001.tb00910.x.