Which factors and incentives influence the intention to adopt precision agricultural technologies?

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Abstract:

Precision agricultural technologies (PAT) promise an approach to agricultural production whichboth enhances productivity and minimises environmental herm. Despite promising economic gains from PAT, uptake within Europe is currently low. We explore the factors behind adoption and non-adoption of PAT using a survey of 971 European farmers, focusing on the role of incentives influencing adoption. We examine current non-adopters' intentions for uptake PAT and current adopters intentions to uptake more PAT. We augment past behavioural models applied to PAT uptake by examining the effect of financial and non-financial incentives and attitudes towards payoffs of the technology. We apply a zero-inflated Poisson regression. Results indicate that non-adopters are distinct from adopters and more favourable to financial and non-financial incentives, whereas adopters support incentives around only a limited set of incentives. Attitudinal differences towards certainty of outcome and belief in the payback also emerge between these two groups. These are further explored qualitatively. The results indicate that a gradient of adoption is occurring with specific groups of farmers identifying particular needs but also responding to differing incentives. Recognition of these differences at policy level could lead to cost-effective interventions which maximise uptake, generate returns to farmers and meet policy desires for sustainable agricultural production.

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Abstract

Precision agricultural technologies (PATS) promise an approach to agricultural production which both enhances productivity and minimises environmental herm through recognising the heterogeneity of production units within a farm landscape. The promotion of precision farming is now ubiquitous within policy literature, arguing that the large scale deployment of these technologies will meet future desires around sustainable agricultural production. However, despite promising economic gains from optimal operation of PATS, uptake by farmers, within Europe, is currently low. We explore the factors behind adoption and non-adoption of PATs using a survey of 971 arable farmers in five EU countries, focusing on the role of incentives influencing intended adoption. We examine two groups of adopters, current non-adopters' intentions for uptake PATs and current adopters intentions to uptake more PATs. We augment past behavioural models applied to PAT uptake by examing the effect of financial and non-financial incentives and attitudes towards payoffs of the technology.

We apply a zero-inflated Poisson regression to accommodate the inherent structural differences between of adopters and non-adopters. Results indicate that non-adopters are quite distinct from current adopters and are more favourable to financial and non-financial incentives, whereas current adopters support incentives around only a limited set of incentives. Attitudinal differences towards certainty of outcome and belief in the payback also emerge between these two groups of adoption. These are further explored through examination of qualitative responses of these groups. The results indicate that a gradient of adoption is occurring with specific groups of farmers identifying particular needs but also responding to differing incentives. Recognition of these differences at policy level could lead to cost-effective interventions which maximise uptake, generate returns to candidate farmers and meet policy desires for sustainable agricultural production in the future.

Keywords: precision farming; zero inflated poission regression; arable farming; incentives.

Introduction

Precision farming infers management of the heterogeneity of farm land in order to exploit biophysical resources and conserve the natural capital that is preserved within a farm boundary (Stafford, 2000; Fountas et al., 2005; Reichardt and Jurgens, 2009; Aubert et al., 2012). Precision agricultural technologies (PATs) are a set of technologies aimed at the management of various facets of heterogeneity within agricultural production, negating the spatial and temporal variability within a small spatial unit, typically in-field or single animal, in order to increase profitability, optimize yield and quality, reduce the application of inputs and minimise environmental impacts.

The attraction to policy makers of precision agriculture is that it may allow a step change in productivity to meet food supply demands under land constraints and also enhance environmental management and monitoring (Zarco-Tejada et al., 2014; Schrijver et al, 2016). Agro-ecological narratives towards precision farming focus on sustaining soil quality to maintain and extend productivity potential, whilst simultaneously supporting a range of ecosystems services, and a number of authors argue that precision agriculture is a key pathway for commercial agriculture (Gebbers and Adamchuck, 2010; Telabpour *et al*., 2015). The current policy framework for PATs, and precision farming generally, is diffuse. Schrijver et al. (2016) outlines potential European policies which are affected or may have to change to accommodate adoption of PATs. These include environmental regulations and directives focused on air, carbon and water pollution; regional policy which have capacity for both the integration of broadband and mobile data networks in rural and remote rural regions; and the potential for alternative employment as reductions in labour are expected from PAT adoption. Moreover, a whole tranche of industry wide policies, pertaining to food traceability, data access and storage, as well as intellectual property rights have to evolve if PATs are to become an intrinsic part of the fabric of future European farming. Accordingly, given the potential policy ambitions of PATs it is pertinent to ask what are the limits to current adoption and the particular incentives which may influence further adoption.

Precision agricultural technologies first emerged from yield mapping approaches in the 1980s, measuring the cropping load in field, which were coupled to Global Navigation Systems (GNSS). A yield map would show the productivity within areas of the field and farmers were expected to use this information to dictate future cropping and input provision (Tsoulavis, 2000). Since this time PATs have developed across three differing technological hierarchies (Balafoutis et al., 2017), namely i) guidance technologies, such as controlled traffic farming and machine guidance, ii) recording technologies, such as soil mapping, and iii) reactive technologies, such as variable rate applicators for nitrogen or pesticide. This latter set of PATs are the most advanced and within-field measurements are used to regulate the application of inputs to accommodate identified heterogeneity in the field. These technology hierarchies imply different levels of user engagement and, by implication, the requisite farmer or operator skill and acquired learning needed to operate these technologies. They involve two approaches to user interaction. Embodied knowledge technologies, such as machine guidance, require no additional skills for their operation and Information intensive technologies, such as variable rate application technologies, provide additional information that offer insights for decision making, but also require further investment, in terms of knowledge, software or analytical service support for data analysis, (Griffin et al., 2004;2005; Daberkow et al., 2003; Popp et al., 2002; Miller et al., 2017).

More fundamentally, PATs pose a potential disruption in demand for, and the quality of, farm labour and the knowledge required for farming (Schimmelpfennig, 2016), with consequent wider impacts on the rural economy, but also may affect the identity of the farmer from one who manages land to one of farm technician (Tsoulavis, 2000). Some farmers are embracing these technologies and a dialogue is maturing towards the opportunities for both harvesting significant data from sensor technology and for the aligned services which are offered for interpretation of these data (Kerry et al., 2017; Slyvester-Bradley et al., 2017).

Studies on the adoption of PATs have tended to align with the more technical literature which has focused on farm level benefits accrued from adoption (Schimmelpfennig, 2016). These have focused on improved resource use productivity, reduced input usage and cost, in particular labour, and the wider associated environmental benefits from less intense and targeted application of agrochemicals and nutrients (Godwin *et al.* 2003; Robertson et al., 2007; 2009; Silva et al., 2011; van der Wal, 2014; Smith *et al.* 2013; Eory *et al.* 2015).

A growing wealth of research has examined the behavioural and structural characterisitcs of the adopting farmers, with studies extending the link to the characteristics of the technology itself (Robertson et al., 2007; Pierpaoli et al., 2013). However, these do not draw out fully the needs of the industry nor the response to desires for particular incentives which encourage uptake. Robertson *et al*. (2007) explicitly state that lack of training and technical support are an adoption constraint. Moreover, the cost of these technologies provides a common barrier to adoption, and proxies for this through farm size, higher farm incomes or more specialised activities and a focus on higher value crops have been found to be positively correlated with uptake (Putler and Zilberman 1988; Polling et al., 2010; Cullen et al., 2013; Faber and Hoppe, 2013; Lawson et. al., 2011,Guerin and Guerin, 1994; Montalvo, 2008; Blackmore et al, 2006; Fernandez-Cornejo et al., 2001; Schimmelpfennig, 2016).

Nevertheless, farmer perceptions, knowledge and innovative behaviour have been under-researched within PAT studies but seem to be a critical institutional factor when examining farmer uptake of technologies (see Barnes et al., 2011; Siebert et al., 2007). Robertson et al (2007) and Montalvo (2008) identified knowledge gaps with respect to understanding the return on investment of different technologies, which leads to an inability to economically assess these technologies. For example, a number of studies have found low levels of trust in the technology to be a key driver in determining uptake of PATs, relative to other factors (Bogdanski, 2012; Eidt et al., 2012; Montalvo, 2008). Busse et al. (2014) explored the knowledge gap between different actors involved in PAT adoption, namely the input suppliers, dealers, farmers, scientists and policy makers. In a workshop study of German PAT stakeholders they found a gap in the transfer of knowledge between science and practice and, ultimately, limited communication and collaboration between farmers and technology providers. Moreover the presence of other technologies at the farm level, indicative of innovative behaviour, implies more probability to adopt PATs (Lambert et al., 2014; Castle et al., 2016). Miller et al. (2017) estimated Markov transitions of adoption 'bundles' (namely the number of different PATs on a farm) in a longitudinal dataset of Kansas farmers, finding that current intensive adopters, defined as having three PAT technologies, for example machine guidance, variable rate seeding and precision soil sensing, were less likely to change their adoption profiles, compared to those which had adopted one or two bundles of PATs. Part of this they attributed to the attraction for data service providers to work with information heavy farmers (with more intensive bundles of technologies) as the farm is more likely to continue to provide specific data and therefore become more cost-effective for the data analysts. Accordingly, within farming communities it seems, aside from non-adopters, there may be differences relative to the intensity of adoption of a particular set of technologies and this will have consequences for the targeting of incentives and support by both industry and policy.

It is clear from these latter studies that adoption of PATs may follow a gradient between non-adoption and current adoption. Most studies adopt a General Linear Modelling approach, and apply mainly multinomial logit or multivariate probit regressions. These examine the differences of influencing factors on multiple sets of technologies. To accommodate these multiple bundles of technologies further Lambert et al. (2015) applied a Multiple Indicator Multiple Causation model to accommodate the correlation between individual technologies. More generally several studies have applied a possion count model structure to reflect for the multiple accumulation of PATs across individual farms and seek to explain the differences in the number of PATs adopted through sets of explanatory variables. Paxton et al. (2010) and Castle et al. (2016) adopted a negative binomial regression model to accomodate cotton grower adoption of PATs in, respectively the Southern United States and Nebraska specifically. Isgin et al. (2008) applied both a zero inflated negative binominal (ZINB) and a zero inflated poission (ZIP) model on a random sample of Ohio cotton growers. The poission count model approach focuses on what explains multiple acquisition of discrete technologies but the zero inflated structure allows further accomodation of structural constraints towards adoption. Accordingly it would seem that the decision to adopt PATS, from a baseline of non-adoption, differs from farmers who currently have PATs and wish to adopt more PATs. Specifically, multiple studies identify size as a limiting characterisitic for adoption and this would be unattainable for non-adopting smaller farmers (Fernandez-Cornejo et al., 2001; Schimmelpfennig, 2016). There are also attitudinal constraints in terms of risk aversion that may limit the decision to adopt PATs (Fernandez-Cornejo et al., 2001; Miller et al., 2017).

The purpose of this paper is to explore the effect of incentives on the threshold decision to adopt PATs for current non-adopters and, secondly, to examine the more salient incentives which may encourage higher adoption of PATs for current adopters. We apply a zero inflated model structure to accomodate the differences in these groups. In addition, it would seem that most emprical studies have been applied to the US or Austrailian farming with little representation of European farming systems. Uptake of PATs within Europe is diverse across regions with some countries typified by more intensive cropping activity and more likely to adopt PATs relative to less intensive farming systems. We apply this approach to a large scale survey of European arable farmers conducted to understand both current uptake of PATs and intended uptake of PATs in the future.

2.0 Methodology and Data Collection

Data Collection

A survey was conducted between August 2016 and February 2017 across five European countries (i.e. UK, Germany, Holland, Belgium and Greece). These countries were chosen to represent a diversity of different structural factors (e.g. in terms of farm size and intensity of production) as well provide a diversity of adoption and non-adoption of PATs. The sample was targeted at arable farmers and farm managers that were cultivating wheat (which is the arable crop most widely cultivated in Europe (Eurostat, 2015) or potatoes (which is a high value crop, with a high economic output per ha per year) in the 2015/2016 cropping season. In Greece, cotton farmers were surveyed as a replacement for potatoes, as these are only marginally grown with Southern states but similar PATs are used.

There are no specifically representative databases on PAT uptake within the EU region and, consequently, we had to adopt a multiple sampling approach to create responses within these three categories. Farmers were contacted through trade fairs, machine dealers, agricultural databases and personal contacts. General statistics of responses are shown below.

Table 1. Descriptive statistics of farm sample

	n		Winter Wheat, ha	Spring Wheat, ha	Ware Potatoes*, ha	Seed Potatoes, ha	UAA, ha	Arable Area, ha	Full-Time Employees	Family Members	Part-Time & Seasonal Employees
Belgium	196	mean	6.4	0.1	6.9	0.7	43.4	32.5	0.0	1.4	0.9
		sd	*8.0*	*0.4*	*11.0*	*7.1*	*31.2*	*27.3*	*0.4*	*0.9*	*1.4*
Germany	195	mean	133.2	1.2	11.8	0.9	542.2	442.1	5.0	1.1	2.1
		sd	*249.9*	*8.3*	*41.2*	*5.1*	*889.1*	*721.9*	*10.5*	*1.0*	*4.9*
Greece	200	mean	32.3	26.0	19.1	0.0	84.4	84.2	2.7	1.9	2.4
		sd	*31.4*	*32.9*	*29.7*	*0.0*	*55.0*	*55.0*	*1.4*	*0.8*	*1.8*
Holland	176	mean	34.8	2.1	49.7	6.2	145.3	137.8	1.0	1.3	1.6
		sd	*66.4*	*7.9*	*201.0*	*14.5*	*313.9*	*300.3*	*1.9*	*1.1*	*2.9*
UK	204	mean	57.2	28.7	5.8	5.4	293.7	219.9	1.8	1.3	3.7
		sd	*59.1*	*37.0*	*11.7*	*11.1*	*321.4*	*143.9*	*2.0*	*1.2*	*11.3*

In order to explore current and intended adoption farmers were presented with a suite of 7 common technologies which are available to arable farmers and their definitions (*see appendix A for the full list*), namely:

i) Machine Guidance (+/-2cm),

ii) Machine Guidance (+/-40cm),

iii) Controlled traffic farming,

iv) Variable Rate application for nitrogen,

v) Variable rate pesticide application,

vii) Variable rate seeding/planting, and

viii) Precision physical weeding.

They were then asked whether they a) had no intention of adopting the technology, b) were current adopters of the technology, or c) were planning to adopt this technology in the next 5 years. This allowed some cross tabulation of non-adopters and adopters against intended adoption. These are grouped, for brevity of reporting, into non-adopters, low level adopters (less than 3 current technologies adopted) and high level adopters (3 or more technologies adopted).

Table 2. Distribution of current adoption to intended adoption number of PATS, percentage and total responses

		Intended Adoption			
		No Intention to Adopt (0)	Low Level Intention (1-2)	High Level Intention (3 or more)	Total
Current Adoption	Non-Adoption	41%	30%	29%	382
	Low Level	19%	41%	39%	428
	High Level	16%	63%	21%	161
Total		266	201	190	971

Accordingly, for the sample there are 382 current non adopters, with the majority (158) stating no desire to adopt any PATs in the future. The remainder intend to either adopt 1-2 PATs in the next five years, or have an intention to adopt more than 2 PATs. Similarly, the majority of low level current adopters intend to adopt either 1-2 PATs or more than 2 PATs. Of the high level current adopters around 60% state a desire to adopt 1 to 2 more PATS in the future. Hence, it seems there are a range of communities of PAT adopters, where intentions are dictated by current levels of adoption but which also are composed of incentives. In order to explore this a count regression modelling approach was applied, as the technologies represent count outcomes for the individual farm which runs from 0, namely non-adoption of PATs, to 7, effectively defined as full adoption.

Modelling approach

A zero inflated count model regression structure is preferred as it can handle the non-adopters (those identifying as 0 within the survey) through a different data generation process to the current adopters. The model accommodates two latent groups, namely those who are always non-adopters because of structural or attitudinal barriers, and those who are current non-adopters but are able to adopt in the future. A zero inflated model assumes non-adopters who will either always be non-adopters have an outcome of 0 and a probability of 1 and potential adopters with a not always 0 population, with an outcome of 0 but a *non-0 positive* probability. The zero-inflated model has two parts. The probability of membership of always non-adoption (ψ) of observation i can be written as:

$$\psi_i = F(z_i{}'\gamma)$$

Where z is the vector of explanatory variables, and γ is the vector of coefficients from a logit or probit regression. For those who are not always non-adopters, the positive count outcome is predicted as:

$$P(y_i|x_i) = \frac{e^{-\mu_i}\mu_i^{\gamma_i}}{y_i!}$$

Where μ_i is the conditional mean

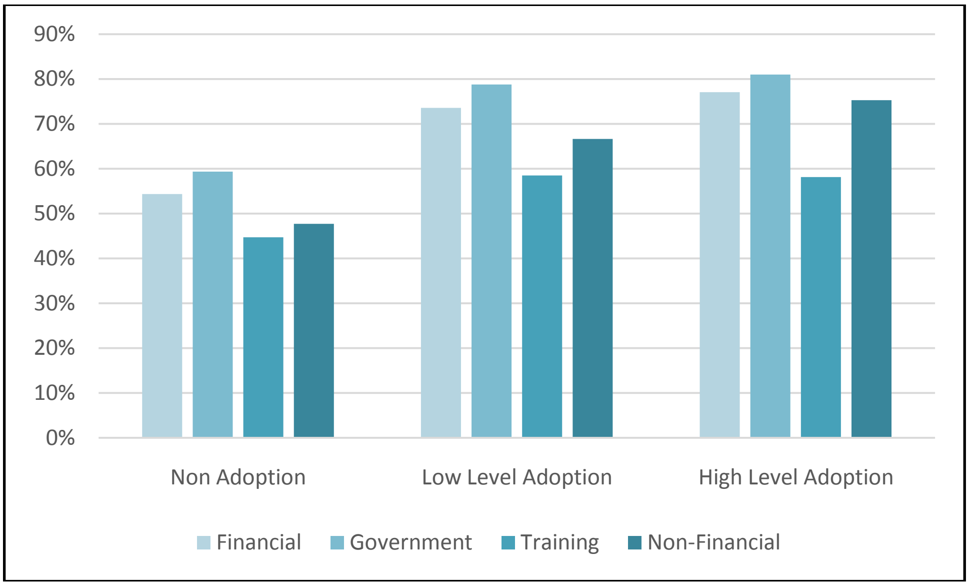
Variable Selection

The list of incentives were developed initially between the researchers and the policy team at the EU Joint Research Centre. These were further refined and extended after discussion with industry members and from piloting the survey within each region. These were presented as individual incentives to the respondents but for ease of presentation in Figure 3 are grouped into four categories:

- *Financial Incentives: "*Confidence that yields would increase"; "Confidence that my costs would reduce": "A 10% reduction in the present cost of the technology"
- *Government Support Incentives:* "Directed subsidy support for uptake of PATS"; "Financial support from tax breaks"; "Government support for soil mapping, by providing ground penetrating radar or intensive soil sampling"
- *Training Support Incentives: "*More technical support from sales people", "More support for training of my staff"; 'More support for training for myself and family'
- *Non-Financial Incentives:* "Improving technology to provide working maps based on soil maps", "more stringent laws on pesticide and nitrogen application"

Figure 1 shows the proportion of positive responses, i.e. those who responded that the incentive would definitely encourage uptake of PATs. These are grouped by their current adoption levels of non-adoption, low-level and high-level adoption.

Figure 1. Grouped incentives by positive response, percentage or total responses by each adoption group



Clearly, the non-adopters are less likely to be encouraged to uptake PATs with these incentives, though financial and government incentives prove the most popular. For both low and high level adopters there are similar levels of response. Again Government and financial incentives seem more popular, however these did not prove to be significantly different between incentives, but across non-adoption and adoption groups.

From literature outlined in the introduction a set of variables were constructed which have been found pertinent to uptake of PATs and these are augmented by both incentive variables and attitudinal variables, shown in table 3.

Table 3. Variables selected and presented at mean/median response

Variable	Median/Mean	Description
Structural and Economic		
AGE	55-59	Operator age in categories
EDUCT	School Only	Education of operator in categories
SIZE	223	Total utilised agricultural area (ha)
SPECZ	0.8	Ratio of arable land to total utilised area (0-1) to represent crop specialisation.
INC	€250,000	Income of farm household in categories
LAB	2	Number of regular labour employed (No).
CURR	1	Level of current technological adoption of the 7 discrete PATS (0-7)
Attitudinal Statements		
ECONATT	agree	'PAT gives too long a payback'. 5-point Likert Altitudinal scale.
ECONCERT	disagree	'I am uncertain towards outcomes'. 5-point Likert Altitudinal scale.
MECHFIT	disagree	'My machinery does not support the technology'. 5-point Likert Altitudinal scale.
SIZEFARM	agree	'My farm is too small'. 5-point Likert Altitudinal scale
Incentives		
IREG	no effect	'Stringent laws on pesticide and nitrogen application'. 3-point scale.
IMAP	definitely increase	'Government support for soil mapping' 3-point scale
ICOST	no effect	'A 10% reduction in the present cost of the technology' 3-point scale
ITECH	no effect	'More technical support from sales people' 3-point scale
ILAB	no effect	'More support for training of my staff' 3-point scale
IFAM	no effect	'More support for training for myself and family' 3-point scale
ISUB	definitely increase	'Directed subsidy support for uptake of PATs 3-point scale
ITAX	definitely increase	'Financial support from tax breaks' 3-point scale
Information		
ADVIS	influence	Advisors; 0: Not an influence; 1: Influence on adoption
OTHFARM	influence	Other farmers; 0: Not an influence; 1: Influence on adoption
CONT	no influence	Contractors; 0: Not an influence; 1: Influence on adoption
REG		A set of dummy variables representing each country with Belgium as the reference value

Structural variables are fairly common within the literature with the earliest studies finding that size and financial ability, through higher incomes, drives uptake (SS). We accommodate various dimensions of these structural variables, in addition the level of current adoption of PATs is seen as a more prevalent predictor of future PAT uptake than related technologies, such as presence of mobile phones (Lambert et al., 2014; Castle et al., 2016).

Increasingly, in other arenas attitudes and perceptions are significant predictors of uptake (Barnes et al., 2016; Toma et al., 2015), but very few studies can be identified in the PAT literature that explicitly explore attitudes (Tay and Brindel, 2012). The lack of trust in the technology in determining uptake has been raised by Montalvo (2012), these are covered by the statements *"Investing in precision agriculture has too long a pay back for the business*" and *''I am too uncertain of the effects of PAT to invest in it*". In addition it may be that size of farm is only a perceived barrier rather than a physical barrier to uptake. Accordingly these are accommodated in the attitudinal question "*My farm is too small to invest in PAT*" and finally, an issue raised by a number of studies is the lack of compatibility of technologies to accommodate these PATs and this is identified through "*My current machinery does not support the technology*". Respondents were given a 5 -point Likert scale to agree or disagree with these statements and Table 4 shows the distribution by the different adoption groups. This shows a greater level of disagreement with the negative statements for both low and high level adopters. For the non-adopters it seems that there is more divergence of opinion with a greater level of uncertainty towards the statements.

Table 4. Distribution of attitudinal statements by non-adopters, low level and high level adopters, pecentage by grouping.

		Non-Adopters	Low Adopters	High Adopters
Investing in precision agriculture has too long a pay back for the business	Strongly Agree	11%	16%	5%
	Agree	29%	39%	25%
	Unsure	43%	19%	27%
	Disagree	9%	23%	39%
	Strongly Disagree	8%	2%	4%
My farm is too small to invest in PAT	Strongly Agree	25%	15%	4%
	Agree	22%	31%	13%
	Unsure	26%	14%	11%
	Disagree	18%	32%	53%
	Strongly Disagree	8%	8%	20%
My current machinary does not suppport the tech	Strongly Agree	19%	9%	3%
	Agree	27%	26%	9%
	Unsure	32%	20%	3%
	Disagree	15%	35%	57%
	Strongly Disagree	6%	10%	29%
My employed labour do not have the training	Strongly Agree	3%	5%	1%
	Agree	8%	17%	11%
	Unsure	65%	34%	16%
	Disagree	14%	34%	48%
	Strongly Disagree	10%	10%	26%
I am too uncertain of the effects to invest in it	Strongly Agree	6%	15%	7%
	Agree	19%	22%	9%
	Unsure	31%	18%	14%
	Disagree	30%	34%	51%
	Strongly Disagree	13%	11%	19%

Results

The zero inflated regression has two parts, a count model which is applied to those adopting the technology, and a binary model which examines the threshold between non-adoption and adoption. Whilst common variables are used between the two models, some flexibility was applied to adjust for differences between the motivations and structural factors for the two groups. For the count model this included their current level of adoption index, as proxy for innovation behaviour, and what influenced their current adoption of PATs, namely other farmers, contractors or advisors. For non-adopters, within the binary model, these were not relevant however a further attitudinal variable could be added to the regression related to their perception of whether the farm size was large enough to accommodate PATS. This is prompted by the bulk of PAT adoption literature indicating a positive relationship between greater size and more likelihood for uptake and, farmers may perceive their farms as too small to invest in PAT (for a review see Tay and Brindel, 2012).

The Zero Inflated Poission (ZIP) model was preferred model by rules of minimising the BIC and AIC against alternative count models (ref Discrete Modelling). A likelihood ratio test found the ZIP favourable over the Zero-inflated negative binomial (ZINB) (LR- 106.380 (p=0.000)). Furthermore a

Voung test also favoured the ZIP over the more parsimonious Poission Regression Model (8.44 (p=0.000)). This strongly infers that the ZIP is the most appropriate model for the data.

The results of the ZIP model are shown in below, presented with raw coefficients (*b*) and expontiated coefficients indicating odds ratios (OR). We focus the discussion on odds ratios as these provide indications of the likelihood of factors which would lead to uptake of more precision agricultural technologies (*Count Model*) or the likelihood of non-adoption of PATs (*Binary Model*).

Table 5 . Zero-inflated Poisson regression coefficients (b) and odds ratios (OR)$^{\phi}$

	Zero Inflated Poission Model					
	Current Adopters			Non-Adopters Model		
	b	P>z	OR	b	P>z	OR
AGE<45						
45-65	0.02		1.02	0.25		1.29
65+	0.16		1.18	1.56	*	4.74
CURR	-0.13	***	0.88			
SIZE	0.00		1.00	-0.03	***	0.97
LAB	0.00		1.00	0.01		1.01
EDUCT	0.04	**	1.05	-0.14		0.87
INC	-0.01		0.99	-0.23	**	0.79
SPECZ	-0.30	*	0.74	-0.29		0.75
ADVIS	0.12	*	1.13			
OTHFARM	0.07		1.07			
CONT	-0.03		0.97			
IREG	0.10	**	1.10	-0.20		0.82
IMAP	0.07		1.08	-0.96	**	0.38
ICOST	0.11	*	1.12	-1.07	**	0.34
ITECH	-0.02		0.98	-0.18		0.84
ILAB	-0.01		0.99	1.28	**	3.58
IFAM	-0.03		0.97	-1.40	***	0.25
ISUB	-0.03		0.97	-0.88	*	0.42
ITAX	-0.07		0.94	1.02	*	2.79
ECONATT	-0.01		0.99	-0.41	*	0.67
ECONCERT	-0.05	*	0.95	-0.27		0.76
MECHFIT	0.01		1.01	0.14		1.16
SIZEFARM				0.07		1.08
BELGIUM						
GERMANY	-0.31	**	0.73	-4.27	*	0.01
GREECE	-0.74	***	0.48	0.69	***	1.99
NETHERLANDS	-0.03		0.97	-0.47		0.63
UK	-0.12		0.89	2.23		9.32

$^{\phi}$ p. * 0.05, ** 0.01,*** 0.001

Count Model

The count model indicates that having higher current levels of PATs on the farm decreases the odds of more intended adoption by a factor of 0.87. Whilst this variable was intended to be a proxy for innovation (Lambert et al., 2014) it may be more reflective of the bounded nature of the technology adopted and saturation of the complementarities of technologies. Specifically Miller et al. (2017) found adoption plateaued at around 3 bundles of PATs which reflects the institutional and technical support structure of data service providers. Increased adoption of these bundles is more likely given the knowledge required and, as an indicator of this, education does have a positive effect on the intention to increase the number of PATs. This reflects agricultural education compared to non-agricultural education, and respondents are more likely, by a factor of 1.04, to adopt more PATS than those without an agricultural education.

Size and income indicators have no significant effect on intended adoption within the count model. Accordingly whilst the threshold for beginning adoption to PATs may be contingent on size and income characteristics, it is a less prevalent characteristic for further adoption. Hence, the current adopters are already of a particular size, compared to the stated non-adopters, and factors such as knowledge of operation are more pertinent. Conversely, those with more specialised arable activities, effectively more land dedicated to arable activities within the farm boundary, decreases the odds of more intended adoption by a factor of 0.82. This may relate to the lack of transferability of machinery between enterprises. Clearly the dominant crop types are cereals and potatoes which traditional require specific specialised equipment. Hence, specialisation of enterprises may be evidence of current technical boundaries restricting further application on the farm.

In terms of influencing adoption of PATs, the use of advisors increases the odds of more PATs, whereas farmer to farmer networks and contractors do not prove significant. This may reflect the knowledge gap, identified by Busse *et al*. (2014), in terms of the innovation supply chain in that advisors provide an accounting and supporting role in encouraging adoption. Moreover, Feder *et al* (1985) identified both farmer extension and field demonstration as important factors in the diffusion of innovation and this may be required for current adopters of the technologies to ensure that the technology fits the farm's current technological structure. The role of farmer to farmer networks has been identified as a potential source of information around technologies (Rogers 1962; Propokny et al., 2008) but this may not be applicable to PATS, as these technologies currently reflect early adopter status within European systems of some of these technologies, given the current cost of implementation.

For those likely to adopt more technologies, the incentive that will have an effect on adoption is more regulation on agrochemical application. This may indicate awareness that these technologies lead to reduced inputs, as it relates to the awareness of some farmers linking agricultural inputs with environmental quality (Barnes et al., 2013; Guillam and Barnes, 2012). In addition a similar positive response is found for a reduction in the cost of the technology. Whilst obviously reflecting the need to support, it may provide some insight into the belief that the investments do not create a high enough return to cover the initial investment despite proven on-farm benefits being found on trial sites (Lawson et. al., 2011; Schimmelpfennig, 2016). Of the attitudinal variables, only the statement '*I am too uncertain of the effects to invest in it'* proved significant with odds less than 1, i.e. more certainty of the outcome would lead to more uptake. This would seem to agree with a number of previous studies who found the level of trust assigned to a technology leads to more uptake (Bogdanski, 2012; Eidt et al., 2012; Montalvo, 2008).

Binary Model

The binary model shows the odds of the independent variables influencing the non-adoption of PATs. Effectively, being a farmer who is over 65 increases the odds of non-adoption of PATs by a factor of 4.7 to that of a farmer under 45. The PAT adoption literature tends to equate younger farmers with those more likely to adopt newer technologies (Mishra et al., 2010; Lambert et al., 2015). The PATs on offer to these farmers are more technically advanced and require a level of engagement and interaction with the results which may appeal to younger farmers against, say the knowledge and the assurity towards the fields heterogeneity of the older farmers.

Another common finding for adoption is related to size proxies and that larger farmers are more likely to adopt (Fernandez-Cornejo, 2001; Castle et al., 2016; Schimmelpfennig, 2016). The odds ratios below 1 confirm this here, i.e. that it is large farms who are less likely to be non-adopters compared to smaller farmers. This is normally coupled with an income measure which is also below 1 and leads to a general view that the larger farms with more household income are more likely to adopt. Nevertheless, few other structural variables seem significant, such as specialisation and educational level. The latter provides a proxy for some aspect of information acquisition. Thus this could be related to the level of awareness these farmers have towards the particular PAT technology.

Only one attitude statement, namely '*Investing in precision agriculture has too long a payback for the business*' is significant. This is a negative statement reflecting economic confidence towards a rate of return and indicates that farmers who are more in agreement would be more likely to be non-adopters. Other attitudinal statements, relating to perceptions towards the size of farm, the ability of machinery to fit the new technology and uncertainty towards the outcomes of the PAT do not seem to predict non-adoption.

Finally, there is a great polarity between the incentives for the non-adopters compared to the current adopters which, for the most part, are significant and below 1 for non-adopters. This means they are likely to influence adoption. The incentives which would encourage adoption are financial "*Confidence that my costs would reduce*"; Government support "*Directed subsidy support for uptake of PATS*" "*Government support for soil mapping, by providing ground penetrating radar or intensive soil sampling*" and training support "*More support for training for myself and family"*. This is in contrast to a strong opinion that "*More support for training of my staff*" would not encourage uptake. This is reflective of the size profile of these non-adopters who do not, on the whole, have a large number of regular staff. In addition, "*Financial support from tax breaks"* did not merit a positive response as this may be again reflect the smaller asset base of these farmers. Accordingly, it seems that for the threshold decision, non-adoption to adoption, there are more incentives which are attractive to these farmers, compared to current adopters which focus on regulation and cost reductions.

Qualitative reasons for adoption and non adoption

Within the survey follow up open questions were asked for reasons towards non-adoption and adoption for farmers to voluntarily respond. For non-adopters concerns around farm physical constraints were stated, specifically they required larger fields to adopt these technologies or saw no need for replacement of their machinery. Moreover, a reason mentioned by a number of farmers was to reduce agro-chemical input, which is also reflected in several mentions around increasing efficiency, and increasing yields. Hence, whilst some of the response to adoption of PAT could be related to literature on environmental behaviours (e.g. Siebert et al., 2006), this seems to be mostly related to profitability concerns where environmental benefits are secondary for these farmers.

What also emerged from the group of non-adopters with no intention to adopt PATS was a belief in their own knowledge of the fields and their ability to farm their fields adequately, for example one German farmer stated:

> *'I do not see the benefits, I can drive yourself straight'* *(Farmer DE128842)*

Moreover a UK farmer stated

> '*I'm not convinced that it's delivering reduced costs. I understand the case for maybe using it with the potatoes but not for grain. Our combine is all laser guided off the header, having a*

*machinery guidance means the only difference is it's using a satellite instead of the laser to guide it so I don't see the point.' (*Farmer UK550)

For the current adopters, arguments promoted for more adoption were for more '*unbiased*' information on the benefits and, conversely, greater reductions in the cost of the technologies. A number of farmers argued for more than a 10% reduction in the cost of the technology. Cost is a common barrier found in previous studies of PAT adoption and clearly links to the wider findings for size being an inhibiting factor to adoption. More information around the benefits can be considered in parallel to the non-adopters' concerns towards understanding the applicability of the PAT systems on a diversity of farming systems, and the needs for both a proven benefit and a higher return on investment to induce more uptake. A dutch farmer stated:

"*Thorough implementation research into the effect on yield; correct prescription maps based on field measurements*" (H505)

Farmers sought some assurity provided by non-industry funded research:

"*scientific proof of returns on investment*" (G128)

"*Proven independent testing*" (U618)

For current adopters with at least 3 technologies, and with an intention to adopt more, their preferences were for more technology development and harmonisation of between equipment manufacturers:

"*Better Internet in the rural area (data transfer, RTK*[1] *reference signals, prescription maps). I am using drone images."* (H2);

"*mechanical sensor-driven techniques, if it works, we do not need the chemical*" (G971).

"*Better communication between different software / management packages. Better substantiated task maps (prescription maps*)"(H424).

Market prices were also a main incentive for more uptake and this links to comments on generating an acceptable return on investment stated by all gradients of current adopters.

"*there is insufficient belief in return on investment*" ("H99")

As well as an awareness of how imprecision currently exists within the PATs adopted

"*As cost of chemicals and fertilizer increases more precision will be needed*." (U419).

A small number of current high adopters identified it was either their curiosity or they perceived themselves as progressive farmers, namely that they felt adoption of PAT was simply part of progress and therefore they were required to adopt this technology.

'………we need to move with the times' (Farmer DE279029)

'Progress and effectiveness, we must move with the times' (Farmer DE37804)

[1] RTK (Real Time Kinematic) is the use of fixed position base stations to enhance the accuracy of GPS systems by transmitting signals that correct positioning errors caused by the Earth's atmosphere.

Standardisation and improved product quality were mentioned by some farmers, specifically the desire to create some uniformity in production, given the variance in soils, and the ability to plough straighter lines, allow more standardisation in production and improved product quality.

> *'to try and even everything out, we have variable soil and with the applications we can even out harvest dates'* (Farmer U34)

> *'It was to even out variation across ground to make more uniformed crops, better targeting of problem areas.'* (Farmer U178)

> *'To try and even out yields across the fields.'* (Farmer U52)

This knowledge of spatial variability has been found to be a factor in driving adoption from a number of studies (Isgin et al., 2008; Khanna, 2001).

Discussion

PATs are becoming more ubiquitous within developed country policy dialogue as a mechanism that could meet both sustainability and food production aspirations. Examining incentives for uptake would seem a logical extension of the desire for understanding on how to support growth on-farm precision agricultural technologies. By including both financial and non-financial incentives towards a set of common technologies we have covered both government and industry initiatives to provide supporting infrastructure for encouraging uptake.

What emerges are differences which are dependant on the gradient of adoption of PATs. Namely, the threshold decision to firstly adopt PATS can be influenced by a wider set of incentives than those currently adopting PATs (some more discussion on incentives).

There are also fundamental issues over the role of the public sector in supporting uptake of PATS. Given the ambition to promote reduced inputs and therefore environmental enhancement then there is an argument for intervention as it promotes public goods, in terms of the protection and maintenance of natural capital. Hence, whilst there seems to be a desire to support uptake there is no regulatory push to adopt PATs, nor any government subsidy in Europe to promote the technology. Schrijver et al. (2016) show the diffuse nature of the policy landscape around PATs and engaging cohesion between technologies, policies and infrastructure would seem a particularly challenging, yet pertinent, problem for engendering a significant uplift in PAT adoption.

Consequently, without support it is purely a commercial decision to adopt and this may explain the focus of statements on returns to investment. Nevertheless, it may be the role of the Government to provide a balance to industry promotion of these technologies through offering demonstration of actual benefits, support for training and, if these benefits are economically justified, potential subsidization for smaller farmers to engage in precision agricultural technologies on farm. In addition the planning transition between non-adoption and adoption is complicated by the role of industry and, in particular, their influence on determining the choice of purchase decision, post-purchase support structures and the creation of scepticism towards the results. Moreover there is some compulsion to 'lock-in' or inhibit further adoption by lack of compatible systems across manufacturers. This lack of complementarity of systems was mentioned by respondents and promotion of standardised systems, through legal infrastructure and R&D support, may be a less direct approach to support adoption of PATs.

We find this is also tied to differences in attitudes towards the technology. Non-adopters perceive PAT to have too long a payback, current adopters not wishing to invest more are more uncertain of the outcomes. Evaluation of the true economic benefits and return to investment is complicated by their application in diverse contexts. Both Castle (2016) and Schimmelpfennig (2016) found that economic returns are dependent on farm related factors and vary dependant on the technology itself, the farm size and whether regular labour are currently employed on the land. This may be a case for Government intervention through the provision of information and field trials demonstrating technologies in these diverse contexts. Consequently this provides some assurances of the return for adoption or, conversely, serve to dissuade farmers given their particular characteristics, which would limit a return.

Accordingly, the main barriers to adoption tend to focus on the high cost element of the initial investment, leading to longer payback periods. Moreover, uncertainty towards the potential for improved profitability to recoup this investment creates a significant barrier towards further adoption. This is in contrast to the adopters who, on the whole, provide a more positive perspective on the technology’s ability to ease the workload and free up time for other tasks on the farm or extend work during critical times.

Whilst we have quantified the main drivers of uptake it is probably the case that softer factors also determine adoption. What emerges from the qualitative analysis is the diversity of responses, both positive and negative, to the technologies. One clear point of dissonance is the lack of a belief that the technology is somehow superior to a farmer's own knowledge for a number of non-adopting farmers. This reflects some of the arguments forwarded by Tsoulavis (2000) that yield mapping is an example of a technology push and has not developed in sympathy for the farmer needs. She argued for more co-creation of technologies and this would seem to be a pertinent avenue for future research studies.

Furthermore, on the margins more intriguing reasons emerge for non-adoption, that it is seen to challenge to the ecological principles of some farmers. This latter reason potentially highlights the issues of farming identity (e.g. Burton, 2004) and those who adopt low input, organic or ecological methods could view precision agriculture as a purely technological, and therefore negative, approach. The literature is lacking in many detailed qualitative studies of uptake of precision agriculture and further work such probably examine the role of these cultural factors of farming and how sophisticated technologies, such as PAT, may create barriers to future adoption.