Unfolding the Bias in Farm Nitrogen Management[1]

Sandip Agarwal

Department of Economics

Iowa State University

email: sandip@iastate.edu

Keri L. Jacobs

Department of Economics

Iowa State University

Quinn Weninger

Department of Economics

Iowa State University

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1 Introduction

Biochemical flows in the form of nitrogen and phosphorous have emerged as a dreadful threat to our ecosystem that needs immediate attention from scientists and governments. These flows have been ranked as the area with highest risk and uncertainty in the terms of imposing limitations to human development and destabilizing the earth's system [1]. The artificial Nitrogen fixation has been mostly attributed to its increased usage as fertilizers in agricultural activities. The increased anthropogenic use of Nitrogen in agriculture has been linked to the development of dead-zones in water bodies, which are huge regions of very low (or no) concentration of dissolved oxygen in water (known as hypoxia or anoxia) that warrant any life in these regions [2] [3].

The contamination of water from the discharge of agricultural nutrients in the water bodies is a non-point source of pollution which makes it even more difficult to held a single individual or a firm accountable for the damage it does to our eco-system. There is a unanimous consensus among economists and policy makers that a reduction in the outflow of nutrient loading will significantly improve the distressed situation. But there is no consensus about how the nutrient flow can be reduced. The reduction in nutrient flows can be made either through a reduced amount of nitrogen usage on the agricultural fields or through adoption of efficient farming practices that would allow minimal nitrogen leaching from the fields. Nutrient Best Management Practices (that includes Rate-Timing-Method recommendation) have been developed in order to put one of these methods in action [2]. The corn-belt and Northern plains dominate in terms of cropland not meeting this management criteria. For almost half of the all acres planted, corn does not meet one of the above criteria and hence in need of some type of improvement in Nitrogen management. Corn has the smallest percentage of treated acres meeting all the three criteria [5]. But whether it is a recommendation about the nitrogen rates or any farm management practice, it will meet with limited success if it is not adopted by farmers. Adoption by farmers typically hinge on their be-

[2] Please refer to [4] to get an idea about the approach followed to provide nitrogen recommendations by ISU Extension

liefs and expectations about the alternative recommendation regarding farm management practices including nitrogen management that might be contrary to their long held heuristic. Therefore, it is critical to know about the subjective decision process that underlies their farm management. In this paper we make an attempt to understand the subjective beliefs of farmer surrounding the nitrogen management decision on their field.

The present paper is organized as follows. Section 2 of the paper provides a brief review about the background of the research to familiarize the readers with the context. In this section we also motivate the need for the measurement of subjective beliefs and how it can be successfully done. Section 3 outlines and describes the survey methodology and the data collection procedure for measuring the key beliefs about the subjective Expected Yield. Section 4 estimates the Objective and the Subjective model of nitrogen conditional expected yield so as to comment upon bias in the beliefs, if it exist. Section 5 present the results of the paper by comparing the subjective marginal product of nitrogen to the objective model used as a benchmark for comparison. Chapter 6 concludes by outlining the implications of present research in ag-policy and provides a direction for future research.

2 Background

One of the biggest water problems in Iowa is nitrate pollution in streams, rivers and water supplies. In the last couple of years, the regional drinking water facility in Des Moines saw record nitrate levels well above the EPAs allowable limit of 10 milligrams per liter in both of its source waters, the Raccoon and Des Moines Rivers. The water facility department runs the worlds largest nitrate removal facility to remove the pollutants. Subsequently, under intense pressure from the Hypoxia Task Force on the Environmental Protection Agency built in 2008, Iowa drafted the Iowa Nutrient Reduction Strategy in 2013 as "a science and technology-based framework to assess and reduce nutrients to Iowa waters and the Gulf of Mexico [6]." The strategy has set target levels of 45% and

29% reductions in Nitrogen and Phosphorus loading respectively through incentives and voluntary adoptions of Nitrogen Best Management Practices. On the contrary, the officials from the water facility claim that voluntary approach that is in place is defunct and farmers have never accepted this responsibility. The water utility wanted the farmers to be held accountable for it, need it be through a lawsuit, which they filed against Calhoun, Sac and Buena Vista counties. Following this different farmers groups have vehemently opposed the antagonistic, regulatory and lawsuit approach of the city utility service.

Efforts to date, however, have centred on programs that rely on voluntary participation by farmers to implement best management practices. For these actions to be effective, more must be done to understand the nutrient management practices currently used by midwest farmers. Agronomists and agricultural economists have studied fertilizer decision-making and provided recommendations and policy advice in this context. However, when each farmer is undertaking their agricultural decisions in an uncertain environment, it becomes extremely important to account for the unobserved decision process of the farmers. Observed outcomes that are ex-post to the decision made might indicate a very different situation ex-ante under which the decision was made. In any framework of decision making under uncertainty, the choices are made based on subjective beliefs and expectations. Based solely on the observed choice data, it is impossible to comment on the decision process unless an assumption about the expectations and beliefs is made. Researchers have resorted to rational expectations that have made identification of the decision process possible. Inferring decisions from observed choice data (or even experimental data) could be compatible with many plausible sets of beliefs and assumptions that are held subjectively by the farmers. This questions the appropriateness of the assumption of rational expectations in models of decision-making that also introduces the researcher's bias by assuming that the researcher and the decision-maker share the same information set [7].

On the one hand, where nitrogen has been used as a productive input, farmers have also used it as an instrument to manage risk and uncertainty in agricultural fields [8, 9]. Given this dual nature of nitrogen management, it is very difficult to separate the two aspects and understand motivation behind the nutrient decision management that has driven the choice of nitrogen on fields. Among the major uncertainties affecting nitrogen management decisions, the ones that have caught widespread attention are the uncertainty about the form of the production function, availability of nitrogen in the soil and the weather uncertainty [8]. Economists have put forward several explanations behind over-application of nitrogen from the perspective of a farmer. Overestimation of marginal product of nitrogen has been advocated as one of the possible causes of over application of nitrogen [8]. We measure if farmers overestimate the benefit of nitrogen.

In our paper we measure subjective beliefs about the yield and potential subjective nitrogen crop response farmers associate with in their field. Our research goal is to exploit recent advances in the field of behavioural economics to investigate subjective beliefs surrounding the nitrogen management practice and find evidence of bias, if any, by comparing the subjective beliefs of crop yields and nitrogen-crop response with a benchmark model of objective yield. We try to identify the decision process of farmers by measuring their subjective beliefs instead of imposing restrictive assumptions on the expectations process. Our work is an attempt to contribute to the largely inconclusive literature on desirability of nutrient applications by looking at the effect of nitrogen on the yields both from an objective and a subjective standpoint. Better nitrogen management decisions through improved design of nutrient management plans will ultimately address water quality problems affecting our ecology and the agricultural industry as a whole.

3 Data and Methodology

In order to investigate if there exists any evidence of bias in the subjective beliefs about the marginal product of nitrogen, we compare estimated subjective marginal product of nitrogen as perceived by farmers with an objective benchmark of marginal product of nitrogen. The subjective belief about the marginal product of nitrogen is estimated from the elicited expectations of yield by the farmers through a web-based survey. To model the objective benchmark of marginal product of nitrogen, we used data from nitrogen experiments conducted by the Iowa State University Research and Extension.

3.1 Objective Yield Model

We define *Objective* yield model[3] as the one which approximates the agronomic relationship between the nitrogen and the yield. It draws from controlled experiments by using data on the experimental nitrogen trial study conducted on the research farms at the Iowa State University. The nitrogen trial experiment data is recorded for four farms, Ames, Sutherland, Kanhawa and Nashua, which are located in different soil regions of Iowa ad across Soybean-Corn (SC) and Corn-Corn (CC) rotation [4]. The level of Nitrogen application treatment were 0, 60, 120, 180 and 240 lbs./acre for Ames and 0, 40, 80, 120, 160, 200 and 240 lbs./acre for rest of the three farms. For the Ames farm we have the data from the year 1999-2013 (2000 onward for SC).The data series for Sutherland farm is from the year 2000-2013 (2001 onward for SC). For both Kanwha and Nahsua we have a shorter time series of 2005-2013 (2006 onward for Kanawha CC). Figure 1, lends support to much of the research on increasingly negative crop yield skew, as nitrogen application increases[5] [11][9][12].

We model the objective nitrogen conditional yield using a Generalized Linear Model (GLM) [13][14]. GLM is an alternative to the normal distribution based econometric modelling. The point of departure of the Generalized Linear Models from the Classical Linear Regression Model is that it uses a statistical distribution that fits the data best instead of relying on the normal distribution. GLM has three components:

1. ***Response Distribution*** or "Error Structure" is the random component of the GLM model where distribution of the dependent variable is chosen from an exponential family.

[3] In order to get a concise view of statistical modelling of crop yield, please refer to [10]

[4] We are extremely thankful to Dr. John Sawyer at Iowa State University for providing the experimental data on nitrogen study led by him from the the ISU research farms

[5] The histograms are produced for 0, 120 and 240 lbs./acre only using both SC and CC rotations, but even if they are plotted separately the story remains same.

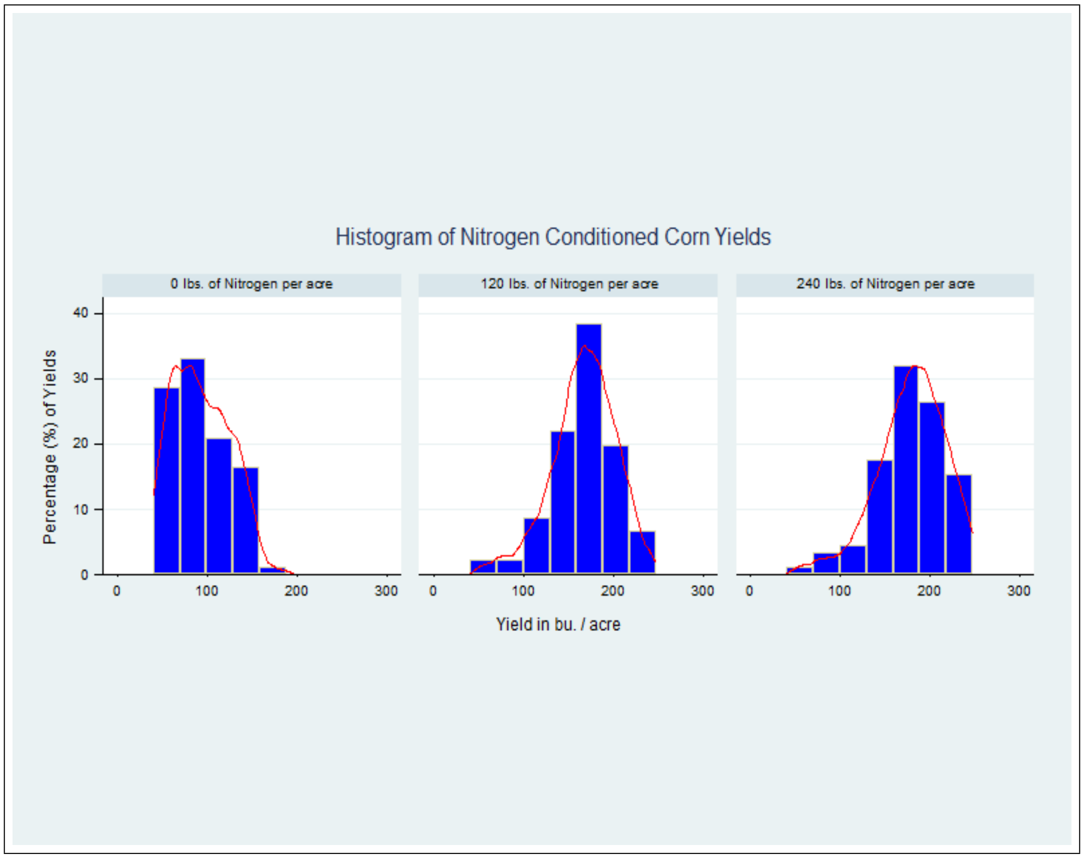

Figure 1: Distribution of Corn Yields conditional on Nitrogen

2. ***Linear Predictor*** is the linear combination of the set of explanatory variables. This tells us how the location of the response distribution changes with a change in the explanatory variable.

3. ***Link function*** gives the relationship between the linear predictor and mean of the distribution. The link function must be monotonic and differentiable.

The parameters of the GLM are estimated using the Maximum Likelihood estimation (MLE) technique. We assume a standard Beta distribution as our response distribution and the link function used is the logit link. This is more popularly known as Beta regressions [15][6]. The choice of Beta distribution has been motivated by the pattern of skewness in the histogram as it can capture positive, zero and negative skewness of a distribution. Secondly, the corn yields lie in a non-negative

[6]The Beta Regressions have been used as an alternative to model proportions as the standard beta distribution is defined over a random variable defined over the domain $(0, 1)$. But any bounded random variable can be assumed to beta distributed by normalizing its domain to $(0, 1)$

bounded domain, which is also a desirable property of the Beta distribution [9].

The pdf of a Beta distribution on the bounded interval $[0, 1]$ is defined as

$$f(y) = \frac{(y)^{p-1}.(1-y)^{q-1}}{B(p,q)}$$

such that $0 < Y < 1$, whereas $p > 0$ and $q > 0$ are the two shape parameters. $B(p, q)$ is the Beta function. the mean and the variance of the beta distribution are given by

$$E(y) = \frac{p}{p+q}$$

$$V(y) = \frac{pq}{(p+q)^2(p+q+1)}$$

The set of explanatory variables are used to define the linear predictor. The linear predictor for mean is given by $\eta = X\beta$ where X is the explanatory variables and β is the coefficient vector of the unknown parameters. We also model the dispersion parameter to be dependent on the explanatory variables [16] . Therefore, we also define a linear predictor for the dispersion parameter. This is given by $\phi = Z\delta$ where Z is the explanatory variables and δ are the unknown parameters to be estimated.

We also define the two link function, one for the mean and other for the dispersion parameter. Th mean link function is a logistic link so that it is written as

$$\eta = g(E(y)) \Leftrightarrow E(y) = g^{-1}(\eta) \Leftrightarrow g^{-1}(\eta) = (1 + \exp(\eta)^{-1})^{-1}$$

and the link function for the dispersion parameter is a log link

$$Z\delta = h(\phi) \equiv \ln \phi \Leftrightarrow \phi = \exp(Z\delta)$$

Likewise, X, $Z(\neq X)$ is a set of explanatory variables (in my case I have set $Z = 1$) for the dispersion parameter. The function h is also differentiable and monotonic. Using the dispersion parameter, the variance function is written as

$$V(y) = \frac{E(y)(1-E(y))}{1+\phi}$$

3.2 Subjective Yield Model

The *Subjective* Yield Model is based on the survey data which includes the beliefs and expectations about yield conditional on other relevant farming variables. We conducted an internet survey among the farmers of a co-operative in central Iowa during the growing season of 2014 in the month of June to elicit and capture their beliefs regarding nitrogen management on their farms. Before we actually designed and sent out the survey, we met with a group of farmers to discuss parts of survey and incorporated the feedback of the focus group which helped us in designing the survey to connect better with farmers' responses. The survey completion took approximately 25-30 minutes. The growing season is a busy season for farmers with high opportunity cost of time. An unconditional monetary reward of $50 was paid to the farmer for completing the survey in lieu of their time.

The survey was structured into four sections. The first and last section included general questions and demographics. The second and third section asked questions related to two different fields respectively. We wanted farmers' response to be very specific to a particular field and its management because it is not unlikely that same farmer adopts different management practices across fields. In order to reduce ambiguity in their response regarding the field they have in mind while answering the question, we prime the field as the *Best Producing Field* in the second section and randomize across an *Average Performing Field* or a *Typically Under-Performing Field* in the third section.

Section 1 asked questions about total acres of land on which the respondents are responsible for making nitrogen decisions and what part of that is owned or leased. These questions were intended to get an idea about the scale of operation and land ownership pattern. Nutrient management information sharing decisions were asked, if they make decision jointly with others. The percentage of time spent in farming reflected the intensity of their involvement in farming if it was their primary occupation. The last section of the survey concluded with some demographic questions, sources of nitrogen management advice, and their attitude towards it.

Sections 2 and 3 are related to fertilizer management on their fields with different productivity. Each farmer answered the same set of questions twice, firstly for their *Best Performing field* and secondly for one of their *Average Performing field* or *Under-Performing Field.* Some basic characteristics of the field in context were recorded. It included the county location of the field, Corn Suitability Rating (CSR)[7], size of the field in acres, and acres of field classified Highly Erodible Land (HEL)[8]. Crop rotation was recorded for the current year and previous two years (i.e. 2012 through 2014).

We move ahead in the survey with questions on their beliefs and perception. We ask the farmers to rate the fertility of their field (on a 5-point adequacy scale). Because it is difficult to give an estimate of nitrogen concentration in the soil, we asked them to report their best estimate of the nitrogen required in their field to achieve their expected yield. We also asked the farmers to report the precision level of their nitrogen estimate as symmetric confidence intervals of 5%, 10%, 20%, and 50% around the reported nitrogen estimate in lbs./acre rather than percentages. To get detailed information about their each nitrogen application, respondents were asked to select months of commercial nitrogen application. Corresponding to each selected month of nitrogen application, respondents were asked to report the N-P-K ratio[9] of the used fertilizer, method of fertilizer application and quantity of nitrogen in pounds per acre.

We measured farmers' beliefs and expectations about the yield. Conditional on their nitrogen scheduled reported for their field in context, respondents were asked to elicit their *Expected Yield* *($E[Y|N]$)* in bu./acre. The elicited $E[Y|N]$ was used as an anchor to begin with thresholds, two on either side of $E[Y|N]$, 75% and 90% of $E[Y|N]$ as the lower thresholds, and 110% and 125% of $E[Y|N]$ as the higher thresholds. Corresponding to each threshold, *Chances out of 100* [7] format was used to elicit cumulative subjective probability of $E[Y|N]$ less than and greater than the

[7]CSR is an index of corn productivity of a field used in Iowa. Higher the CSR higher is the productivity on a scale of 0-100

[8]HEL is an index of soil erosion

[9]N-P-K ratio is very standard branding of fertilizers that summarizes the proportion of Nitrogen, Phosphorus and Potassium in the fertilizer used

lower and the higher thresholds respectively. In answering the *Chances out of 100* question, the respondents were provided with a pointer and a scale from 0-100 (with the pointer set at 0) to slide and choose their response [10]. Figure 2 provides a snapshot of the page from the survey that elicited cumulative subjective probabilities.

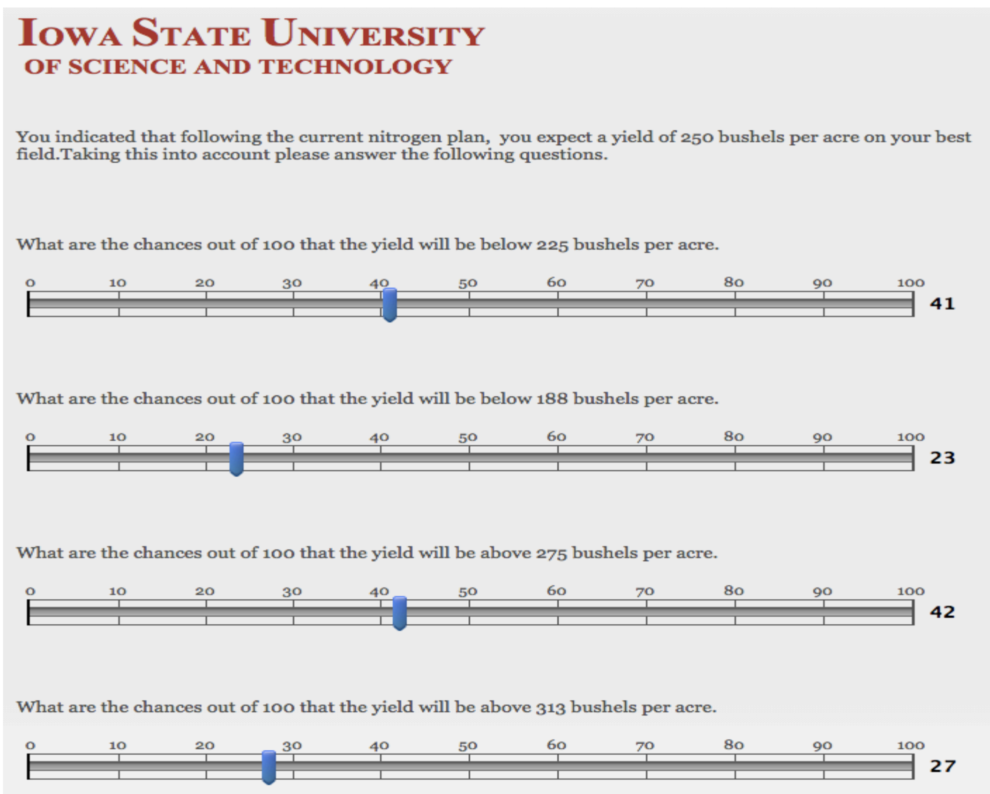

Figure 2: Survey Page for Eliciting Subjective Probabilities

We also asked respondents to report their perceived mapping of yields conditional on the nitrogen and rainfall variable. With a reminder about their reported nitrogen usage in their last nitrogen application, they were asked to report expected yields (in bu./acre) if instead of the quantity of

[10]To maintain coherency of the responses, so that the reported values are consistent with the axioms of probability, a warning message was displayed for the first time, if there was inconsistency in the response

nitrogen use reported, they used 115%, 130%, 85% and 75% of the amount of Nitrogen used in their last application through the survey as depicted in Fig 3. We also sought information about the expected planting date and conditional upon the expected planting date, their expected pollination dates by choosing from a grid of dates closest to the date they expected.


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We would now like you to describe how yield might change if you were to apply different amounts of nitrogen fertilizer. You indicated that you plan to apply 180 pounds/acre in your May, 2014 application.

Suppose instead you applied 207 pounds per acre at the May, 2014 application. How many bushels per acre would your best field now yield?

bushels per acre

Suppose instead you applied 234 pounds per acre at the May, 2014 application. How many bushels per acre would your best field now yield?

bushels per acre

Suppose instead you applied 153 pounds per acre at the May, 2014 application. How many bushels per acre would your best field now yield?

bushels per acre

Suppose instead you applied 135 pounds per acre at the May, 2014 application. How many bushels per acre would your best field now yield?

bushels per acre

Figure 3: Survey Page for Eliciting Nitrogen Conditioned Subjective Expected Yield

We model the subjective yields using a Mixed Linear Model (MLM) [17][18]. Given the data collection strategy, our survey employs a hierarchical data collection methodology involving three levels. The highest level or at level 3 are the randomly sampled farmers denoted by k. The next level is the field level, j, where the respondents answer for *Best Performing Field* and a second field, either an *Average* or *Under-Performing Field*. At the lowest level, i indexes the different rates of nitrogen application around the reported Nitrogen application. At this level, the measured Expected Yield is farmer specific and field specific, corresponding to the amount of additional (could be above or below the reported level 2 Nitrogen) nitrogen applied in their last month's application. The dependent variable Expected Yield is measured at this lowest level which is conditional Expected Yield for k^{th} farmer for j^{th} field corresponding to the i^{th} level of Nitrogen application in their last month's application. The yield equation is modelled as below:

$$Y_{ijk} = \beta_{0k} + \beta_{1k} X_{ijk} + \beta_2 Z_{jk} + \beta_3 S_k + \beta_4 (X_{ijk} \times Z_{jk}) + \beta_5 (X_{ijk} \times S_k) + \beta_6 (Z_{jk} \times S_k) + \beta_7 (X_{ijk} \times Z_{jk} \times S_k) + \epsilon_{ijk}$$

such that $(\beta_{0k}, \beta_{1k}) \sim N(\bar{\beta}, \Sigma)$ with $\bar{\beta} = \begin{pmatrix} \bar{\beta}_0 \\ \bar{\beta}_1 \end{pmatrix}$ and $\Sigma = \begin{pmatrix} \sigma_0^2 & u_{01} \\ u_{10} & \sigma_1^2 \end{pmatrix}$ and $\epsilon_{ijk} \sim N(0, {\sigma_\epsilon}^2)$

Therefore the yield equation can be written as:

$$Y_{ijk} = \bar{\beta}_0 + \bar{\beta}_1 X_{ijk} + \beta_2 Z_{jk} + \beta_3 S_k + \beta_4 (X_{ijk} \times Z_{jk}) + \beta_5 (X_{ijk} \times S_k) + \beta_6 (Z_{jk} \times S_k) + \beta_7 (X_{ijk} \times Z_{jk} \times S_k) + \delta_{0k} + (\delta_{1k} \times X_{ijk}) + \epsilon_{ijk}$$

such that $(\delta_{0k}, \delta_{1k}) \sim N(0, \Sigma)$ with $\Sigma = \begin{pmatrix} \sigma_0^2 & u_{01} \\ u_{10} & \sigma_1^2 \end{pmatrix}$ and $\epsilon_{ijk} \sim N(0, {\sigma_\epsilon}^2)$

Y_{ijk} is the dependent variable of the model. The independent variables are at three levels i, j and k. S_k, Z_{jk} and X_{ijk} are the vector of variables at the three different levels, at the lowest being X indexed by ijk and at the highest being S indexed by S_k. The model equation also includes several interaction terms among the variables at different levels. The MLM model described above is estimated using a Maximum Likelihood (ML) or a Restricted Maximum Likelihood (REML) procedures.

4 Results

The Objective and the Subjective yield models are estimated as described in the earlier section. The regression results of the objective yield model are tabulated in Table 1 in the Appendix. Corn Yield (in bu./acre) is the dependent variable. We bound the domain of yields by a lower bound of 10% of the standard deviation of the site-rotation specific yields from the lowest yield (at 0 lbs./acre of nitrogen), and 25% of the standard deviation with the highest yield (for 240 lbs./acre of nitrogen) as the upper bound[11]. In Table 1 in the Appendix the name of each site is an independent dummy variable indicating whether the observation belongs to that particular field. Similarly, *Rotation* is a dummy variable indicating corn-corn rotation with a value of 1 and 0 for soybean-corn rotation. *Nitrogen* is the amount of nitrogen applied on the fields either in multiples of 40 or 60 lbs./acre within the range of 0 to 240 lbs./acre. Since we have time series data and with constant technological improvements, we have accounted for annual trend in the model to capture it. The reduced model as estimated in table 1 includes quadratic terms of nitrogen and trend variable, though higher polynomials[12] were rejected in favour of a quadratic model.

From table 1 in the appendix we can see that CC rotation starts at lower average yields compared to the SC rotation, but the productivity of nitrogen is higher for the CC rotation. A negative coefficient of the quadratic nitrogen terms indicates toward diminishing marginal productivity of nitrogen. A quadratic trend indicate an increasing average yield over the years. The productivity of nitrogen, too, has increased over the years captured by the interaction of trend and nitrogen variable. We have plotted the marginal product of nitrogen from the experimental data which we call the *Objective* nitrogen productivity in fig 4 and fig 5 respectively by the solid blue line and the dashed line provides 95% confidence interval for the objective marginal product of nitrogen.

The estimated subjective model is tabulated in table 2 through a mixed linear regression model.

[11]The bound was required so as to transform the yield variables on $(0, 1)$, domain of the standard beta distribution. Such a method has been adopted earlier in the literature in modelling yield as beta distributed variables [9]

[12]We used Chebyshev polynomials of nitrogen and trend so as to stable estimation at the end points[19]

The fixed effects in the model estimate the average effect of the independent variable across farmers, where as the estimated random parameters in the model through δ_{0k} and δ_{01} capture the heterogeneity in farmers belief about the subjective expected yield. Average Performing Field or Under-Performing Field are the dummy variables for the field type that the response is recorded, with *Best Producing Field* as the benchmark. *Size of the Field* and *Land* are the farm size and total farming land operated of which *% of Owned Land* is a proportion of farmed land owned by farmers rather than leased or farmed under any other arrangement. Planting and pollination dates are expected dates in incremental units of 15 days. N is the total amount of nitrogen applied by a farmer in their given field whereas ΔN is the change in nitrogen application around the reported nitrogen application, N. Education is a dummy variable for higher education which is a dummy for undergraduate degree and beyond. *Advice* is a dummy variable, which is the primary source of advice for the farmers regarding nitrogen management which are ISU Extension, a professional agronomist at a consulting firm, or other farmers. *Advice - Specific Field* is the dummy if they received nutrient management advice specifically for the field in context.

The regression result shows that on an average expected yield is significantly lower by 13 bu./acre. For the under-performing field on an average across farmer, productivity of nitrogen is lower for nitrogen application after planting and even lower for the fall application. Experienced farmers expect lower yields at their reported level of nitrogen compared to less experienced farmers. Farmers who seek advice from agronomists at a professional consulting firm believe that at the applied level of nitrogen, marginal productivity of nitrogen is substantially higher than the farmers who seek advice from the agronomists at the co-op. On the contrary, for farmers whose primary source of advice is ISU Extension, marginal productivity of nitrogen at the total amount of nitrogen applied is lower than all other farmers. Farmers who have taken a second opinion regrading their nutrient management tend to have reported lower expected yields than who do not. Marginal productivity of nitrogen around the applied nitrogen is lower for the average performing field and even lower for the under-performing field. For a delay in the planting dates, expected yield is lower by around 7 bu./acre for every 15 days and 6 bu./acre for every 15 days of delay in pollination. From the mixed model of Expected Yield, we estimate the marginal productivity of nitrogen using the delta method.

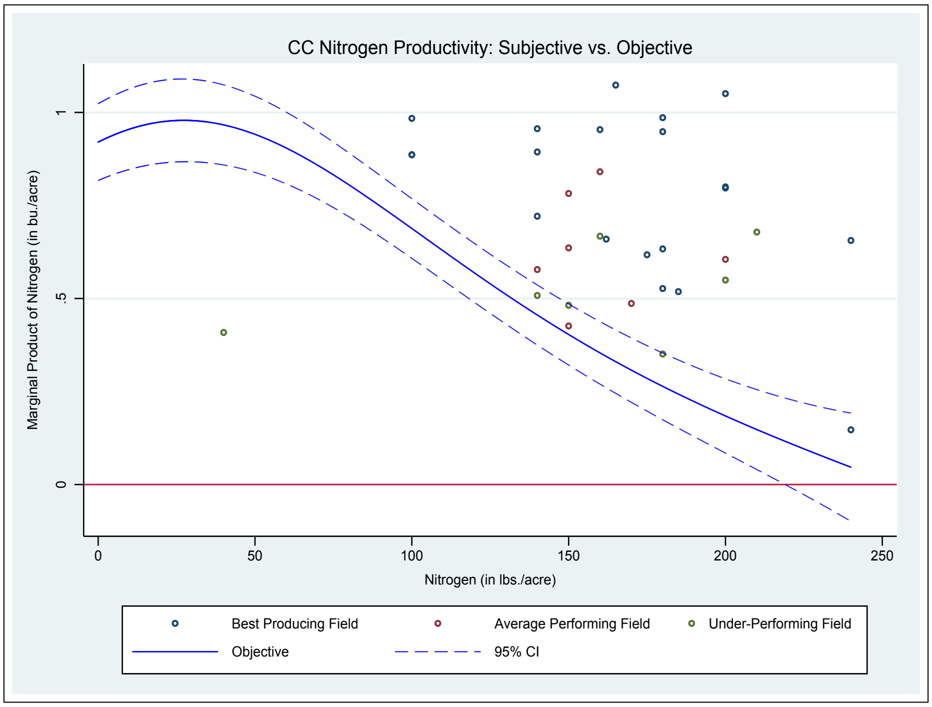

Figure 4: Nitrogen Productivity for CC rotation

We plot the *Subjective* marginal product of nitrogen from both the CC and SC rotation[13] in Fig 4 and Fig 5 respectively. It is a well-known fact that the soil nitrogen concentration is a big uncertainty in crop production, which could significantly limit the yields if not available in adequate amount. Therefore, to comparing the expected yield across different fields and region with varied characteristics might be unfair. Hence, instead of comparing the expected yield, we compare the marginal productivity of nitrogen. We can see that for both the SC and CC yields, marginal productivity of nitrogen is higher and relatively even higher for CC rotation. This belief of higher marginal product of nitrogen is portrayal of upward bias in the perceived marginal product of nitrogen [20].

In estimating the marginal product of nitrogen we have made all possible efforts to control for the

[13]For subjective models, CC refers to those fields which grew only corn in their last growing season and SC to those who grew any crop other than corn including soybeans

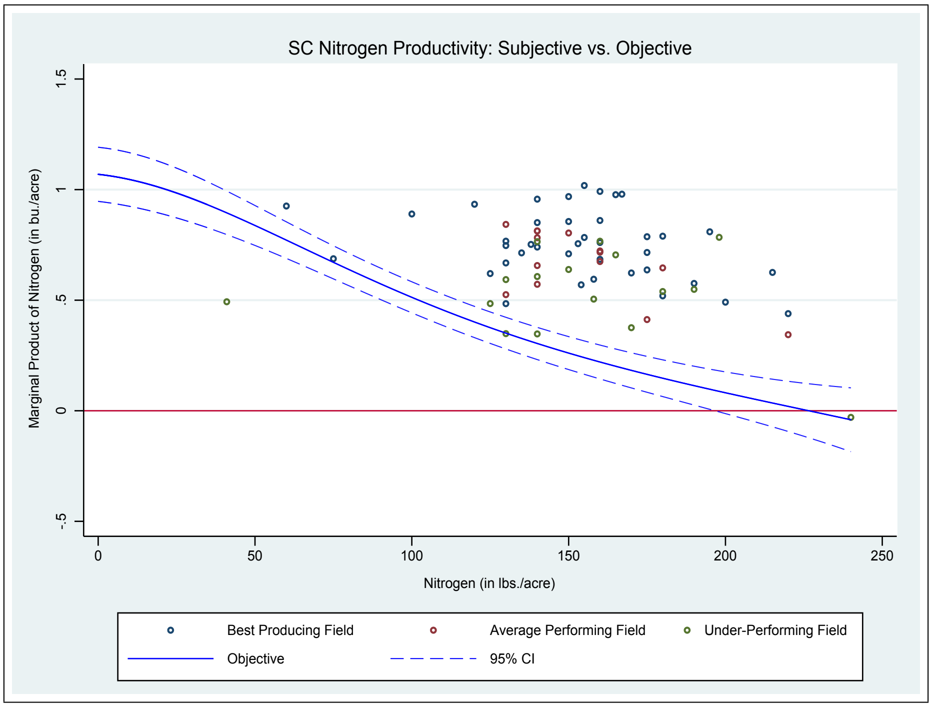

Figure 5: Nitrogen Productivity for SC rotation

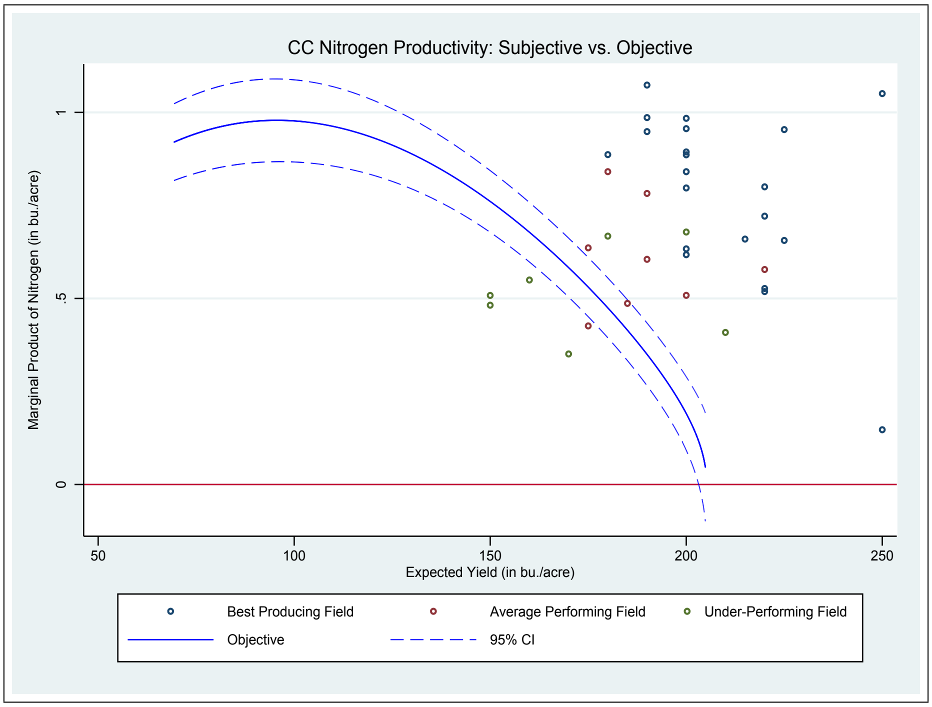

Figure 6: Nitrogen Productivity for CC rotation

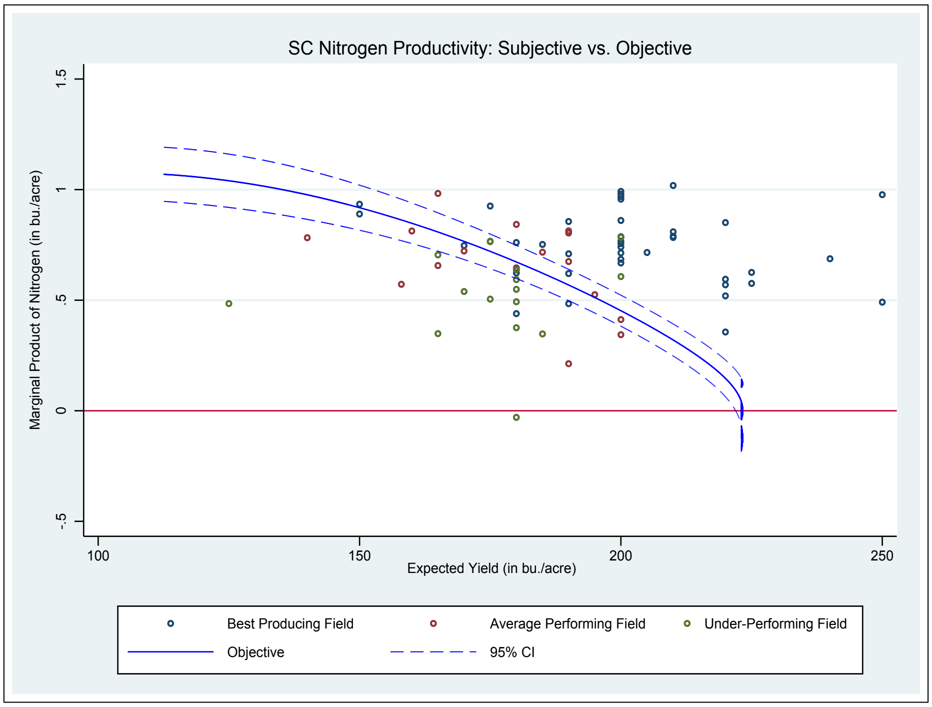

Figure 7: Nitrogen Productivity for SC rotation

heterogeneity in the external environment but the concern is that the amount of nitrogen already in the soil might be influencing the productivity of nitrogen. The farmers associated with the upward bias could be the ones with low nitrogen concentration in the soil or such that . In order to make an adequate comparison, instead of using nitrogen as a scale, we compare the subjective marginal product of nitrogen on the expected yield-marginal product plane. In Fig 6 and Fig 7, we plot the marginal product of nitrogen that is associated with the expected yield. This warrants a more comparable method to evaluate the subjective marginal product of nitrogen vis-a-vis the objective benchmark. We find similar results as earlier that most farmers are upwardly biased in their subjective belief about their marginal product of nitrogen. This is more pronounced for the fields under CC rotation and the ones which are the *Best Producing Field*. The figures depicting the bias also tells us that the perceived bias in the marginal productivity of nitrogen is more for the *Best producing Field*.

5 Conclusion

The evidence of upward bias in farmers' beliefs about productivity of nitrogen is rather a sneak peek into the black box of nutrient management by farmers under uncertainty. It rather invites several questions on the agricultural policies without knowing much about the subjective decision process of farmers. The biggest contribution of our research is that it makes the least (almost no categorical) assumption about farmers' expectations and their beliefs about nitrogen management in their farms. Based on a minimalist assumption about the beliefs of farmers, found that farmers perceive marginal productivity of nitrogen to be higher than it is warranted. We also find that the perceptions are somehow more biased for relatively high yielding fields. The results from our research have created a hole in the black-box of farmers' decision making process under uncertainty, but much still remains to be unknown. Further research effort directed towards it need to be put together to identify farmer's decision processes for better provision of agri-environmental good and services.

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6 Appendix

Table 1: Objective Model: Generalized Regression Model with Beta Distribution

Link function: Logit		
Mean: Independent Variables	Coef.	Std. Err.
Ames	0.614***	0.056
Sutherland	0.496***	0.065
Kanawha	0.414***	0.063
Nashua	0.187***	0.052
Ames × *Rotation*	-0.416***	0.068
Sutherland × *Rotation*	-0.523***	0.074
Kanawha × *Rotation*	-0.416***	0.078
Nashua × *Rotation*	-0.303***	0.060
Ames × *Nitrogen*	0.665***	0.060
Sutherland × *Nitrogen*	0.356***	0.065
Kanawha × *Rotation*	0.409***	0.069
Nashua × *Rotation*	0.657***	0.057
Nitrogen × *Rotation*	0.238***	0.052
$Nitrogen^2$	-0.255***	0.022
Trend	0.290***	0.047
$Trend^2$	-0.116***	0.036
Nitrogen × *Trend*	0.240***	0.059
Dispersion Parameter: Independent Variables		
Ames	3.270***	0.121
Sutherland	2.504***	0.149
Kanawha	2.998***	0.138
Nashua	3.541***	0.142
Sutherland × *Rotation*	0.520***	0.200
Nitrogen	-0.494***	0.089
Trend	0.329**	0.144

*** 1 %, ** 5 % and * 10 % level of significance

Table 2: Subjective Model: Mixed effects Model of Farmer Yield

$Independent\ Variable : Expected\ Yield$	Coeff.	Std. Err.
$Average\ Performing\ Field$	-13.145^{***}	2.169
$Under-Performing\ Field$	3.359	6.145
$\%\ of\ Owned\ Land$	-0.337^{**}	0.169
$Nitrogen\ Decision\ Sharing$	31.314^{***}	11.068
$Experience$	1.229^{***}	0.469
$Education$	-9.015^{*}	5.510
$Land\ (in\ acres)$	-0.003	0.002
$Advice-ISU\ Extension$	62.245^{***}	16.716
$Advice-Professional\ Agrnomist$	-120.405^{***}	36.067
$Advice-Other\ Farmers$	15.447^{**}	6.439
$Advice-Specific\ Field$	9.634^{***}	3.766
$Size\ of\ Field\ (in\ acres)$	0.101^{***}	0.02
$Corn\ Suitability\ Rating\ (CSR)$	0.54^{***}	0.145
$Percentage\ of\ HEL\ land\ in\ field$	-0.047	0.041
$Conservation\ Tillage$	-7.604^{**}	3.17
$Planting\ date$	-6.85^{***}	2.314
$Pollination\ date$	-5.749^{***}	1.784
$S-C\ Rotation$	39.714^{***}	11.561
$C-C\ Rotation$	33.995^{***}	11.57
$N \times S-C$	-0.193^{***}	0.063
$N \times C-C$	-0.184^{***}	0.062
N	0.581	0.127^{***}
N^2	$-0.001 \times 10^{-1***}$	$0.001 \times 10{-}1$
$N \times Fall \times Under-Performing\ Field$	-0.154^{***}	0.047
$N \times After\ Planting \times UnderPerforming\ Field$	-0.103^{**}	0.045
$N \times Percentage\ of\ Owned\ Land$	0.002^{*}	0.001
$N \times Nitrogen\ Decision\ Sharing$	-0.145^{**}	0.061
$N \times Experience$	-0.010^{***}	0.003
$N \times ISU\ Extension\ Advice$	-0.384^{***}	0.1
$N \times Professional\ Agronomist\ Advice$	0.722^{***}	0.207
ΔN	0.771^{***}	0.044
ΔN^2	-0.003^{***}	0.004×10^{-1}
$\Delta N \times Average\ Performing\ Field$	-0.143^{***}	0.046
$\Delta N \times Under-Performing\ Field$	-0.247^{***}	0.058
$\Delta N \times \%\ of\ HEL\ Land$	0.001^{*}	0.006×10^{-1}
$\Delta N \times Land$	-0.519×10^{-4}	$0.0036^{*} \times 10^{-2}$
$Constant$	120.061^{***}	27.185
Random-effects Parameters	Estimate	Std. Err
$Var(\delta_{0k})$	0.041	0.012
$Var(\delta_{1k})$	376.7	82.659
$Cov(\delta_{0k}, \delta_{1k})$	-1.966	0.799
$Var(\epsilon_{ij})$	147.18	10.463

*** 1 %, ** 5 % and * 10 % level of significance