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Research article

Corn price fluctuations on potential nitrogen application by farmers in the Midwestern U.S.: A survey approach

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Abstract: Research has linked increased fertilizer usage in the past twenty years to large zones of hypoxia and algal blooms in Lake Erie, the northern Gulf of Mexico and other water bodies across the U.S. Given the nature and the scale of these impacts, researchers and policymakers benefit by understanding the drivers behind the increased demand for fertilizer and fertilizer management to help develop strategies to reduce nonpoint source pollution associated with excessive fertilizer applications. The purpose of this paper is to examine the impact of crop price, specifically for corn, on expected demand for nitrogen fertilizer at the farm level. Using survey data, we examine the impact that an increase in expected corn prices could have on potential demand for nitrogen fertilizer given farm characteristics, farm demographics, and farmer behavior, holding land area and fertilizer price fixed. Results indicate that the marginal probability of a farmer increasing nitrogen fertilizer rates when crop prices increase is positive and statistically significant. In addition, we find that this marginal probability increases at a decreasing rate with moderate increases in corn price (up to around 20%) and then decreases at an increasing rate afterwards, while remaining positive. Thus, farmers are likely to increase nitrogen fertilizer applications to corn with future corn price increases.

Keywords: corn; crop price; farmer; fertilizer demand; Kansas; stated choice

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1. Introduction

Advances in plant genetic research over the past fifty years have produced crop varieties designed to be highly responsive to fertilizer application. Coupled with widespread availability of inorganic fertilizers, these varieties have been instrumental in fueling the remarkable growth in per-acre output on farms over the past sixty years [1]. Increased on-farm usage of these fertilizers however, poses a number of potentially serious threats to the environment through runoff into surface (e.g. streams, rivers, lakes, reservoirs, etc.) and groundwater sources. One such threat is hypoxia in bodies of freshwater and the development of algal blooms, which can be highly toxic to aquatic life. Disciplinary and multidisciplinary research has linked increased fertilizer usage in the past twenty years to large zones of hypoxia in Lake Erie, the northern Gulf of Mexico and watersheds throughout the U.S. [2–5]. Given the nature and the scale of these impacts, researchers and policymakers interested in making effective policies to reduce nonpoint source pollution may benefit from an analysis examining the drivers of increased demand for fertilizer, such as fluctuating crop prices.

Input and output prices drive fertilizer demand; however, no clear consensus has emerged as to the extent of these effects. Research by Denbaly and Vroomen [6] found an inelastic own-price demand elasticity for fertilizer, while Heady and Yeh [7] and Carman [8] reported both inelastic and elastic own-price demand elasticities (with variation in estimates occurring by time-period in the former and by region in the latter). More recently, Williamson [9] reported an own-price elasticity estimate of −1.87 for producers who use commercial nitrogen fertilizers exclusively (and −1.67 for other who used both manure and nitrogen fertilizer), suggesting heightened responsiveness on the part of producers to fertilizer prices in recent years. Fewer studies exist that examine fertilizer demand with respect to crop price, and many of them are over a quarter of a century old. Heady and Yeh [7], Gunjal et al. [10], and Choi and Helmberger [11] all report inelastic fertilizer demand elasticities with respect to output prices, though magnitudes vary depending on which crop price is being considered (i.e. demand is particularly inelastic with respect to corn and wheat prices). Sohngen et al. [5] estimated price elasticities of nutrient emissions with respect to input (fertilizer) prices. They find that these elasticities (with respect to nitrogen and phosphorus) are inelastic, but indicate a potentially strong environmental response when considered in the aggregate. They find no significant effect between corn price and nitrogen emissions, but a significant relationship between corn price and phosphorus emissions. A lack of findings in the relationship for nitrogen may be due to the fact that the modelers did not directly consider farmers' expectations. Our study builds on this literature by examining the impact of output prices on fertilizer application using a stated choice approach to examine farmer behavior given the substantial increases in crop prices experienced in the recent past, especially for corn. In addition, the cross-sectional approach taken assumes land and fertilizer prices remain fixed, allowing for a focus on the intensive margin, measured as the likelihood of an increase in nitrogen fertilizer rates.

The purpose of this paper is to examine the impact of corn prices on expected demand for nitrogen fertilizer for corn production at the farm level along the intensive margin. Using survey data, we examine the impact that an increase in expected corn price will have on the potential demand for nitrogen fertilizer applied to corn given farm characteristics, farm demographics, and farmer behavior. We hypothesize that substantial increases in corn price, like those that occurred on and after 2008, can lead to increases in nitrogen fertilizer application rates at the farm level. If this occurs, significant environmental consequences may result if nitrogen fertilizer sources are over-applied (beyond soil and plant capacities) and nitrogen leaching results. We focus on corn due to the rise in corn acreage that resulted from the biofuel expansion across the U.S. and substantial increase in the demand for corn internationally [4]. Our paper provides evidence drawn from a cross-sectional survey of the potential impact that expected corn price increases and other factors may have in driving nitrogen fertilizer application. Results shed light on alternative drivers of nitrogen management that could result in environmental degradation [9].

2. Theoretical model

Consider a profit-maximizing farmer with an expected net returns (above variable costs) or “quasi -profit” function of the form:

$$R_i(P_i, W_i, X_i, \boldsymbol{F}_i) = P_i \times f(X_i, \boldsymbol{F}_i) - W_i \times X_i \quad (1)$$

where $R_i(.)$ is expected net return above variable costs of applying fertilizer to a crop; P_i is expected crop price; $f(X_i, \boldsymbol{F}_i)$ is an expected yield response function that is twice differentiable and concave with respect to X_i; $\boldsymbol{F_i}$ is a vector of variables representing farm management decisions and farm characteristics impacting the expected yield response; W_i is fertilizer input price; and X_i is the amount of fertilizer applied (or rate). The assumptions about $f(X_i, \boldsymbol{F}_i)$ imply that $R_i(.)$ is concave with respect to X_i. The optimal level of nitrogen fertilizer to apply is found by solving the following optimization problem:

$$\max_{X_i} R_i(P_i, W_i, X_i, \boldsymbol{F}_i) = P_i \times f(X_i, \boldsymbol{F}_i) - W_i \times X_i \quad (2)$$

The first order condition for problem (2) is given by $P_i \times \frac{\partial f(X_i, \boldsymbol{F}_i)}{\partial X_i} = W_i$, which indicates the farmer will apply the amount of fertilizer to the crop until the expected marginal revenue product (MRP) of an additional unit of fertilizer is equal to the marginal factor cost (MFC) of a unit of fertilizer application. The optimal level of fertilizer to apply will be given by $X_i^* = X_i^*(P_i, W_i, \boldsymbol{F}_i)$. Note that the optimal level of fertilizer is shaped by the farmers’ expected yield response, which is a function of $\boldsymbol{F_i}$, making the optimal level of nitrogen also a function of $\boldsymbol{F_i}$. Thus, expectations about yield responses to fertilizer application will be shaped by farmers’ circumstances, perceptions and management [12]. For example, farmers who plant legume cover crops may not adjust nitrogen fertilization levels for the following cash crop even though the legume cover crop can help meet nitrogen requirements for the following cash crop. This behavior is due to uncertainty about the expected yield impact of the legume cover crop on the following cash crop and/or as a sort of insurance policy if not enough nitrogen fertilizer is used by the following cash crop [13].

Using comparative statics,

$$\frac{\partial X_i}{\partial P_i} = \frac{\partial R_i / \partial P_i}{\partial R_i / \partial X_i} = \frac{f(X_i, \boldsymbol{F}_i)}{P_i \times \frac{\partial f(X_i, \boldsymbol{F}_i)}{\partial X_i} - W_i} \quad (3)$$

when the expected marginal revenue product from an additional unit of fertilizer (i.e. $MRP_i = P_i \times \frac{\partial f(X_i, \boldsymbol{F}_i)}{\partial X_i}$) is greater than (>) the marginal factor cost of an additional unit of fertilizer (i.e. W_i), $\frac{\partial X_i}{\partial P_i} > 0$. Thus, if crop price increases (decreases) the farmer will increase (decrease) their fertilizer rate. In addition, note that $\frac{\partial^2 X_i}{\partial P_i^2} = -\frac{f(X_i, \boldsymbol{F_i}) \times \frac{\partial f(X_i, \boldsymbol{F_i})}{\partial X_i}}{\left(P_i \times \frac{\partial f(X_i, \boldsymbol{F_i})}{\partial X_i} - W_i\right)^2}$. Assuming that the farmer only applies additional fertilizer when $\frac{\partial f(X_i, \boldsymbol{F_i})}{\partial X_i} > 0$ (i.e. the expected marginal productivity of fertilizer is positive), then $\frac{\partial^2 X_i}{\partial P_i^2} < 0$. This implies that the farmer will increase fertilizer application rates with an increase in crop price at a decreasing rate. While an economically optimal nitrogen rate that would account for the actual nitrogen demand and agronomic yield response by the crop (that may not result in over application of nitrogen) can be determined, the nitrogen rate applied by a farmer will be additionally shaped by the situational context faced by the farmer, their perceptions about their production systems, and management decisions (i.e. the vector of variables $\boldsymbol{F_i}$) [12]. Thus, as in the cover crop example above, famers may over apply nitrogen when cash crop prices increase, potentially resulting in run-off and off-field environmental impacts.

3. Survey and data

Data was collected for this study through a mail survey of Kansas Farm Management Association (KFMA) farm members that produce crops in Kansas. The KFMA provides production and financial information, guidance, and services to farm members (see https://agmanager.info/kfma). In turn, the KFMA collects detailed farm financial and production information about farm members. We were able to access this database to obtain secondary data on farm operator's age, net farm income, number of irrigated acres, crop rotations, farm labor devoted to crop production, and head of cattle. The remainder of the data was collected from a survey of KFMA members.

A mail survey was sent to 1,487 KFMA farm members that produce corn, sorghum, soybeans, and/or wheat in Kansas in April and May of 2013. The survey asked a series of questions about farm demographics, corn and soybean management, adoption of genetically modified crop varieties, conservation practices, farmer perceptions, and a stated choice experiment about fertilizer management. Prior to sending out the survey, the survey was tested with experts in the field and with agricultural students at Kansas State University. Of the farmers contacted, 422 responded to the survey, providing a response rate of 28%. Based on availability of secondary KFMA data, survey completeness, and missing data, 338 surveys were usable for the analyses conducted in this study.[1] Research for the survey and study were reviewed, approved and found exempt by the Institutional Review Board for Human Subjects Research at Kansas State University (#6332).

Of particular interest was a stated choice experiment conducted in the survey examining farmers' response to an increase in crop output prices on fertilizer management. Stated choice approaches have been shown to be able to capture heterogenous responses of respondents to price and cost changes (e.g. [14,15]). The stated choice approach adopted allows for an examination of how farmers may have altered their behavior due to a change in expected crop prices given the circumstances in the year in which the survey was administered. Since the variation in observed expected crop prices

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[1] Of the usable surveys for this study, approximately 93% of the respondents indicated that they currently planted corn, had corn in rotation at the time of the survey on their operation, and/or have recent past experience with planting corn on their operation.

across farmer respondents in cross-sectional data is likely to be low, there is a need for other methods to capture a farmer's response to potential changes in crop prices. A stated choice approach provides a unique way to hypothetically examine such a response, while holding time sensitive variables, like corn acreage and fertilizer prices, constant. That is, given the cross-sectional nature of the study, it is assumed that fertilizer prices and corn acreage remain constant across respondents. The approach though is limited to explaining the likelihood a farmer would increase the amount or rate of fertilizer applied, but not the actual or change in the level of fertilizer applied.

In particular, we were interested in the likelihood that nitrogen fertilizer application rates would potentially increase with an increase in expected corn prices. To elicit farmers' responses to this inquiry, in the survey we asked the following question:

> *Thinking about your overall planting decisions, if* ***expected harvest-time corn prices*** *were to* ***increase by ____ percent*** *relative to other crop prices* ***between February and planting****, how much agreement do you have that you would alter plans in the following way*: *I would apply more Nitrogen fertilizer to my corn if feasible (available and timely).*

It was made clear when asking the above question that the option of increasing nitrogen fertilization was not a result of expanding corn acreage due to a crop price increase, which was assessed separately. The question was asked using a Likert Scale from 1 to 6, with 1 as Strongly Disagree, 2 as Disagree, 3 as Somewhat Disagree, 4 as Somewhat Agree, 5 as Agree and 6 as Strongly Agree. To help simplify the analysis conducted here, the response was recoded as binary with a "0" resulting if the respondent chose options 1 to 3 and a "1" if the respondent chose options 4 to 6. The percentage increase in the expected corn price used in the survey was randomly assigned to each survey respondent from a set of five values: 0, 10, 25, 50, and 100 percent. The motivation for these levels was the large increase in crop prices experienced at the time the survey was administered [4]. In addition, we assumed that farmers respond to expected prices, which would be based on price trends in past growing seasons and on the futures crop price for corn [16]. Crop subsidies were not considered in expected crop price changes.

As stated in the conceptual framework, the economically optimal nitrogen rate response to a change in output crop price is a function of input and output prices, crop management decisions (e.g. crop rotation choice, irrigation, crop nutrient management), farm characteristics (e.g. farm size, geography), and respondent characteristics (e.g. farmer perceptions). Data for these factors was collected in the survey and obtained from the KFMA database. Summary statistics for the binary coded dependent variable and explanatory variables are provided in Table 1.

Table 1. Descriptive Statistics of Dependent and Explanatory Variables.

Variable	Description	Mean	Standard Deviation[a]	2017 Ag Census[b]
	Dependent Variable			
More N	Binary equal to “1” if respondent would increase N rate with an increase in corn price	0.55	0.25	---
	Explanatory Variables			
Region 1[c]	Binary equal to “1” if a respondent is from Northwest Kansas.	0.22	0.17	---
Region 2[c]	Binary equal to “1” if a respondent is from North Central Kansas.	0.16	0.13	---
Region 4[c]	Binary equal to “1” if a respondent is from Southwest Kansas.	0.18	0.15	---
Region 5[c]	Binary equal to “1” if a respondent is from South Central Kansas.	0.10	0.09	---
Region 6[c]	Binary equal to “1” if a respondent is from Southeast Kansas.	0.29	0.21	---
Age	Age of the farmer (years)	56	12	58.1
Crop Acres	Number of crop acres managed (acres)	1686	1510	600
Irrigated Acreage	Number of acres the farmer irrigates. (acres)	141	545	498
Crop Rotation	Binary equal to “1” if the farmer uses a crop rotation with corn.	0.62	0.24	---
Irrigated Corn	Binary variable equal to “1” if the farmer irrigates a portion of their corn crop.	0.21	0.17	---
Cattle	Number of head of cattle. (head)	53	133	44
NFI	Net farm income for the farmer. (in tens of thousands of dollars)	19.99	28.17	17.66
Use GMO	Binary equal to “1” if the farmer uses genetically modified (GMO) corn varieties.	0.80	0.16	---
Soil Test	Binary variable equal to “1” if the farmer conducts soil tests annually.	0.69	0.21	---
Variable Rate	Binary variable equal to “1” if the farmer uses variable rate application of fertilizer.	0.78	0.17	---
No Tillage	Binary variable equal to “1” if the farmer uses no tillage practices for corn.	0.45	0.25	0.29
Insurance	Binary variable equal to “1” if the farmer has crop insurance for corn.	0.77	0.18	---
Soil Perception	Binary variable equal to “1” if the farmer believes their soil quality has decreased over the past 10 years.	0.11	0.10	---
Profit Perception	Binary variable equal to “1” if farmer indicated profitability is more important than environmental stewardship.	0.24	0.18	---

[a] The standard deviation for binary variables is estimated as $p(1 - p)$, where p is the mean.

[b] Source: [17]. [c] Regions are based on KFMA regions (https://agmanager.info/kfma/kfma-map).

Given the cross-sectional nature of this study, input prices and corn acreage were assumed to remain constant for all farmers. Crop management variables included crop rotations with corn, irrigation of corn, use of genetically modified corn varieties, soil testing frequency, use of no tillage practices, and variable rate application of fertilizers. Farm characteristic variables included geography, total crop acreage, total irrigated acreage, number of head of cattle, net farm income, perceptions about soil characteristics, and perceptions about profitability. Additional demographic variables included operator's age. The use of these variables and factors has been supported in prior literature examining fertilizer demand and management [8,18,19].

Comparing the descriptive statistics in Table 1 to averages from the 2017 Agricultural Census reveals the representativeness of the survey respondent pool [17]. Taking account of the survey timeframe, farmer demographics such as age and farm income are in line with 2017 Agricultural Census data for Kansas. KFMA farms though have more crop acres than those in the Census, but this is not unexpected as KFMA farms usually represent medium to large size commercial operations in Kansas, while the Agricultural Census includes a large number of small and hobby farms. Many of the KFMA farms also have less irrigated acreage, on average, but match more closely with the average number head of cattle on-farm.

4. Empirical model

Consider farmer *i* who is determining the optimal level of nitrogen X_i to apply to their corn crop to maximize expected net return above variable costs following problem (2). Given the first order conditions to the problem (where *MRP* = *MFC*), the expected optimal level of nitrogen applied by the farmer is given by $X_i^* = X_i^*(P_i, W_i, \boldsymbol{F}_i)$. Assume that the nitrogen price is fixed in the short-run (i.e. the farmer may have already purchased access to nitrogen fertilizer prior to cash crop planting at a fixed rate), which implies that the MFC_i of fertilizer is fixed. Following condition (3), if expected crop price increases and $MRP_i > MFC_i$, the farmer will increase the amount of fertilizer applied to their crop. If on the other hand, expected crop price decreases and $MRP_i < MFC_i$, then the farmer will decrease the amount of fertilizer applied to their crop.

Given the nature of the data, only the direction of change is observed across survey respondents. Thus, the researcher can view the problem probabilistically. Let Y_i represent a binary random variable equal to 1 if the farmer would increase nitrogen fertilizer application to their corn crop given the stated change in expected corn price and 0 otherwise. Given the reasoning above:

$$\boldsymbol{P}(Y_i = 1|\Delta P_i, \boldsymbol{F_i}) = \boldsymbol{P}(MRP_i > MFC_i|\Delta P_i, \boldsymbol{F_i}) = \boldsymbol{P}(\frac{\partial X_i}{\partial P_i} > 0|\Delta P_i, \boldsymbol{F_i}) \tag{4}$$

where ΔP_i is the change in the expected corn price. Using equation (3) and knowing that at optimality $X_i^* = X_i^*(P_i, W_i, \boldsymbol{F}_i)$, it is assumed that:

$$\frac{\partial X_i}{\partial P_i} = h(\Delta P_i, F) = \boldsymbol{\alpha}_r + \beta_i \Delta P_i + \boldsymbol{\gamma}' \boldsymbol{F_i} + u_i \tag{5}$$

where $\boldsymbol{\alpha}_r$ is a vector of *r* regional effects that capture unobserved geographical, agronomic, climatic and cultural conditions; β_i is an individual specific parameter influencing the impact on nitrogen application from a change in the expected corn price; $\boldsymbol{\gamma}$ is a vector of parameters; and u_i is a zero mean IID random error term. It is assumed that β_i is distributed normal with mean β_0 and standard deviation σ_β. The random parameter assumption for β_i is used to capture heterogeneous expectations and crop price fluctuations across farmers and space, which has been evidenced in the literature for nitrogen management, as well as in cattle and crop markets [20–22].

Substituting equation (5) into condition (4) and assuming u_i follows a logistic distribution, gives:

$$\boldsymbol{P}\left(\frac{\partial X_i}{\partial P_i} > 0 \middle| \Delta P_i, \boldsymbol{F_i}\right) = \boldsymbol{P}(\boldsymbol{\alpha}_r + \beta_i \Delta P_i + \boldsymbol{\gamma}'\boldsymbol{F_i} + u_i > 0 | \Delta P_i, \boldsymbol{F_i})$$
$$= [1 + exp\{-(\boldsymbol{\alpha}_r + \beta_i \Delta P_i + \boldsymbol{\gamma}'\boldsymbol{F_i})\}]^{-1} \quad (6)$$

Equation (6) gives rise to a binary mixed logit model with the addition of a zero mean IID error term [23].

The binary mixed logit model is estimated in NLOGIT using simulated maximum likelihood with 400 Halton draws [24]. Marginal effects of the explanatory variables of interest are estimated as partial average effects with asymptotic standard errors estimated using the delta method [25]. Specification tests were conducted to examine if nonlinear price effects were present. Test results indicated nonlinear terms of ΔP_i were not statistically significant.[2]

5. Results

Binary mixed logit estimation results are provided in Table 2. The pseudo-R^2 for the model was 0.13. The primary hypothesis for the paper was that as expected corn prices increase, application of nitrogen fertilizer will increase. The average partial effect (APE) for a change in the corn price was 0.0022 and it was statistically significant at the 1% level. The APE indicates that for each one percent increase in expected corn price, on average, the marginal probability of increasing the amount of nitrogen fertilizer applied will increase by 0.22%, providing evidence in support of the hypothesis. It should be emphasized that the marginal effect is not a price elasticity estimate. The APE for the crop price change indicates how a one percentage increase in the expected corn price increases the likelihood of applying more nitrogen to a farmer's corn crop, on average. This result is in contrast to the impact of corn price on nitrogen application rate by Williamson [9], who found that corn price did not have a statistically significant impact on nitrogen application rates across a number of different nitrogen fertilizer sources across the Corn Belt and Northern Great Plains.

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[2] Testing for a quadratic term of ΔP_i (using an asymptotic z-statistic) gave a test statistic of −1.16 with an associated p-value of 0.248. Model fit statistics also showed that the logit model was preferred over other functional forms for the transformation function, such as the probit or complementary log-log function formulas based on AIC.

Table 2. Binary Mixed Logit Estimation Results for Empirical Nitrogen Application Response Model.

Variable	Coefficient Estimate	Coefficient Standard Error	Average Partial Effect (APE)	APE Standard Error
Intercept	−1.35*	0.73	---	---
Region 1[a]	1.05*	0.47	0.22**	0.085
Region 2[a]	−0.18	0.47	−0.040	0.010
Region 4[a]	0.36	0.51	0.075	0.11
Region 5[a]	0.67	0.53	0.14	0.10
Region 6[a]	0.58	0.47	0.12	0.097
Age	−0.0094	0.0084	−0.0020	0.0018
Crop Acres	0.00014	0.00011	0.000031	0.000024
Irrigated Acreage	−0.00030	0.00035	−0.000066	0.000077
Crop Rotation	0.38645	0.27	0.085	0.058
Irrigated Corn	0.46	0.29	0.098	0.060
Cattle	0.0023*	0.0013	0.00050*	0.00028
NFI	−0.000000086	0.00000063	−0.00000019	0.00000014
Use GMO	0.41	0.35	0.091	0.077
Soil Test	−0.077	0.21	−0.017	0.046
Variable Rate	0.22	0.24	0.00028	0.052
No Tillage	0.22	0.21	0.048	0.045
Insurance	0.27	0.32	0.060	0.070
Soil Perception	0.90***	0.33	0.18***	0.060
Profit Perception	0.11	0.24	0.025	0.052
Crop Price Change			0.0022***	0.00064
β_0	0.010***	0.0031		
σ_β	0.025***	0.0040		
Fit Statistics				
Log-Likelihood				−206.34
AIC				456.7
Number of Observations				338

Note: *, **, and *** designate statistical significance at the 10, 5 and 1 percent level of significance, respectively. APEs are calculated as the average marginal effect across respondents. APEs for binary variables are estimated as discrete differences. Asymptotic standard errors for APEs are estimated using the delta method [25].

[a] Regions are based on KFMA regions (https://agmanager.info/kfma/kfma-map).

While our model does not indicate the level of the change in the application rate by the farmer, our results provide evidence in support of our hypothesis. From the survey data, farmers on average applied 143 pounds of nitrogen per acre to their corn crop with a range of 45 to 250 pounds per acre. Thus, the impact on application rates will be heterogeneous, varying from one farmer to another due to farm specific management, behavior, and cost considerations. While increased crop prices may increase nitrogen fertilizer use and possible runoff, it could be the case that the level of change in nitrogen fertilizer rates from an increase in the expected corn price has a negligible impact on water quality in the watershed as found by Sohngen et al. [5]. The authors of that study found that annual nitrogen concentrations in five Midwestern watersheds (OH, IN, and MI) are not significantly impacted by changes in corn prices. In addition, other factors will impact fertilizer rates, such as nitrogen fertilizer prices, which are assumed constant in this study. On the other hand, Hendricks et al. [26] found that higher corn prices result in increased corn acreage and greater corn monoculture, increasing nitrogen demand in the Corn Belt. The estimated APE and potential for higher application rates as suggested by the survey data may indicate that an increase in corn price could potentially increase the level of nitrogen applied to the corn crop along the intensive margin (i.e. the expected and perceived marginal benefit due to the higher price is greater than the marginal cost of additional application), as well.

Figure 1 further supports the hypothesis explored here and provides additional insight. First, the APE is positive for all levels of an increase in the crop price for corn examined. Second, the APE changes as the percentage increase in the corn price increases. That is, as the expected corn price increases beyond about 20%, the APE increases, but at a decreasing rate. This aligns with the conceptual framework, where it was hypothesized that $\frac{\partial^2 x_i}{\partial P_i^2} < 0$, and supports prior results from Dhakal et al. [27] (who found - in the case of cotton - that the profit-maximizing level of nitrogen to apply increased at a decreasing rate as cotton price increased, using a stochastic plateau yield function).

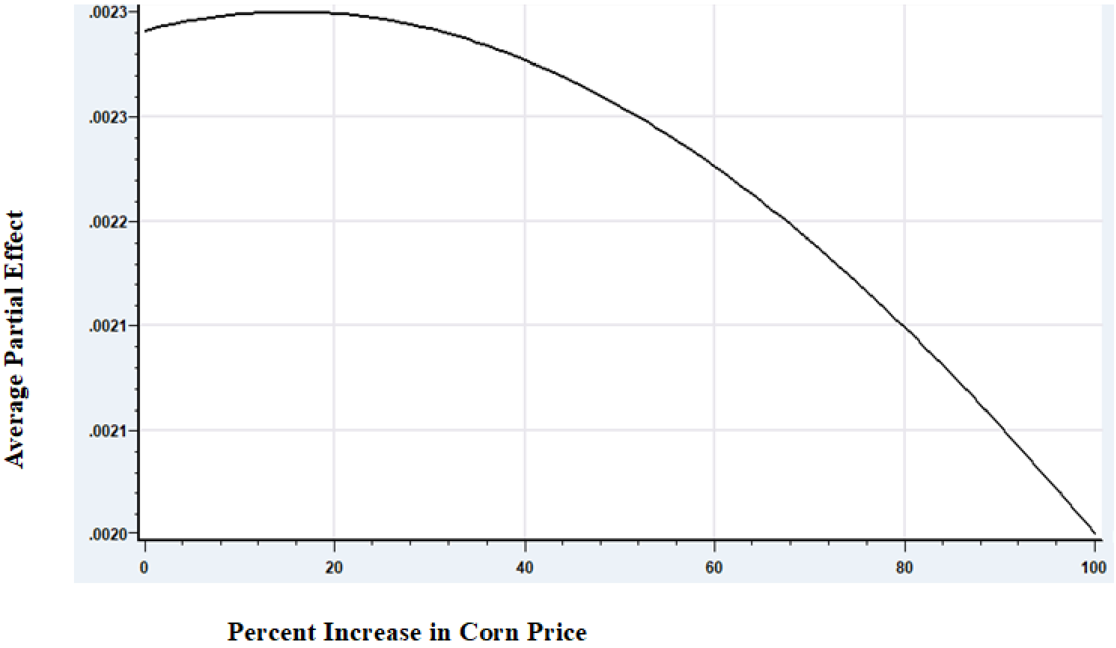

Figure 1. Average Partial Effect of an Increase in Corn Crop Price on the Likelihood of Applying More N Fertilizer.

Other farm characteristics also play a significant role in shaping nitrogen application rates in the presence of an expected corn price increase. If the farmer perceives that their soil fertility has declined over the past ten years, then they will likely increase nitrogen fertilizer application, which may have environmental consequences on crop land that is marginal and near a water body. In addition, farmers that partake in both crop and livestock increased the probability of having higher nitrogen fertilizer rates. Both results were statistically significant. Of interest as well, is that factors such as crop rotation, irrigation, genetics, soil testing, and precision agriculture were not statistically significant factors impacting the likelihood of increasing nitrogen application rates in the presence of an expected corn price increase. These results may be due to the nature and more relative generality of the stated choice approach adopted and a lack of specificity about application to a particular field or cropping situation.

6. Discussion and conclusions

The paper provides an examination of the impact of corn prices on expected demand for nitrogen fertilizer at the farm level using a stated choice approach. Using survey data, we estimate the response of an agricultural producer in Kansas responding to an increase in expected corn prices by examining the likelihood that they would increase their nitrogen fertilizer application rates, conditional on farm characteristics, farm demographics, and farmer behavior. We hypothesized that significant increases in expected corn prices, like those that occurred on and after 2008, can lead to increases in nitrogen fertilizer demand and the likelihood of increases in fertilizer application rates at the farm level. Results indicate that the marginal probability of a farmer increasing their nitrogen fertilizer rate when expected corn prices increase is positive and statistically significant, which is supported by past studies [22,28]. In addition, we find that the probability of increased nitrogen application increases at a decreasing rate. These results lend support to the hypothesis examined. Based on the APE estimated, a 20% increase in corn price would increase the marginal probability of increasing nitrogen application rates by approximately 4.4%. A limitation of this study is that we are unable to determine the change in application rates by farmers, which should be explored in future studies conducted at the farm level. In addition, the probabilities presented here should not be interpreted as changes in application rates. The likelihood of increasing the level of nitrogen applied will also be dependent on farmers' perceptions and situational context. Through interviews with farmers, Reimer et al. [22] found that crop prices play a role in farmers' decisions about nitrogen application rates and management. High crop prices can provide an incentive to increase nitrogen application rates to help boost crop yields. Some farmers interviewed opted for other management options when crop prices changed too, such as changes in nitrogen application methods.

If a significant increase in nitrogen application rates occurs with another significant spike in corn prices it might impact environmental quality as nitrogen fertilizer sources may be over-applied over a more extensive area. Part of this change could occur along the intensive margin (i.e. through application rates) in addition to the extensive margin, as found by Hendricks et al. [24]. Policymakers who are looking to sustain water quality and improve conservation stewardship may have to consider both margins in responding to such market changes. Corn price increases may result in environmental degradation and could undermine potential conservation efforts. Henderson and Lankoski [29] find that policies based on crop price supports and unconstrained input use are not conducive to environmental stewardship and conservation. Thus, robust conservation and environmental stewardship programs (that offer a high enough incentive to efficiently and directly manage nitrogen application and potential leaching and runoff) might help to improve environmental quality. Future research should delve deeper into how farmers' fertilizer decisions react to different crop output markets and how these decisions in turn impact the local environment.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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