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Effects of Farmers' Yield-Risk Perceptions on Conservation Practice Adoption in Kansas

Steven M. Ramsey, Jason S. Bergtold, Elizabeth Canales, and Jeffery R. Williams

When considering adoption or intensification of existing conservation practices, farmers have unique, subjective views of the associated risks. These individual risk perceptions could have important implications for conservation adoption or intensification. As a result, traditional policy approaches to encourage conservation agriculture may be inefficient. This study examines conservation adoption, with special consideration given to yield-risk perceptions. We present a conceptual model of perceived yield risk and estimate bivariate probit models using survey data. Results indicate that positive practice perceptions, particularly with respect to soil fertility, and opportunities for on-farm trialing may encourage adoption.

Key words: bivariate probit, conservation agriculture, yield risk

Introduction

Risk is an important component of agricultural production and plays an important role in farmers' production decisions, particularly the adoption of new or intensification of existing conservation efforts on-farm (Aimin, 2010). In some cases, risk can have a larger effect than cost factors (Sattler and Nagel, 2010). The introduction or intensification of on-farm conservation efforts can create (perceived) risks due to technological uncertainty (Knowler and Bradshaw, 2007) or through various direct, indirect, and opportunity costs such as establishment, hindered establishment of the succeeding cash crop, and forgone cash-crop income, respectively, for cover crops (Snapp et al., 2005). These changes can result in shifts in net returns that may not be known *a priori*. Thus, risk is an important aspect in farmers' adoption decisions.

Risk perceptions will be unique to individual farmers. Regardless of the statistical or objective measure of risk for a given scenario, farmers form their own perceptions. Menapace, Colson, and Raffaelli (2013), for example, found that farmers' subjective probabilities of crop loss from weather events varied based on farm and farmer characteristics. Thus, attempting to anticipate risk behaviors using an objective risk measure may produce misleading results. Risk perceptions may also differ based on the decision context (Bontempo, Bottom, and Weber, 1997). That is, risk perceptions—for the same farmer—will be a function of characteristics specific to the farmer and to the practice. Farmers may also adjust their perceptions to favor their current management practices, as suggested

Steven M. Ramsey is an assistant professor in the Department of Agricultural Economics and Agricultural Business at New Mexico State University. Jason S. Bergtold is a professor in the Department of Agricultural Economics at Kansas State University. Elizabeth Canales is an assistant professor in the Department of Agricultural Economics at Mississippi State University. Jeffery R. Williams is a professor in the Department of Agricultural Economics at Kansas State University.
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by Lee, Brown, and Lovejoy (1985), who found farmers' subjective income distributions to be more optimistic than objective distributions constructed by the authors.

Producer-specific risk measures have been commonly used as an explanatory factor in conservation-adoption models. Based on interviews with Indiana farmers, Reimer, Weinkauf, and Prokopy (2012) concluded that risk characteristics are a barrier to adoption of conservation practices. To assess the impact of conservation practice characteristics on adoption, the farmer interviews were transcribed and analyzed to identify risk characteristics such as uncertainty regarding effectiveness or planting dates (conservation tillage) and termination and competition (cover crops) (Reimer, Weinkauf, and Prokopy, 2012). Risk characteristics were identified as barriers to adoption for conservation tillage, grassed waterways, filter strips, and cover crops by 44%, 4%, 7%, and 9% of farmers, respectively. Kim, Gillespie, and Paudel (2005) found that cattle producers who self-identified as risk averse were less likely to adopt cover/green-manure crops, watering systems, or rotational grazing. Wilson, Howard, and Burnett (2014) used farmer-specific risk aversion and risk perceptions to examine the potential for reducing nutrient loads going into Lake Erie. Risk perceptions in the study were based, in part, on the average response to a series of statements regarding negative consequences to categories such as human health, the United States as a whole, and people worldwide, in addition to risks to farm profits and viability. Arbuckle and Roesch-McNally (2015) found that Iowa farmers were less likely to adopt cover crops as the perceived risk of doing so increased, as measured by the average response to seven Likert scale statements regarding potential cover-crop risks. In a separate but related series of interviews, the authors found that "issues of complexity, and compatibility with their current production system(s) lead to perceived risks, particularly concerns about potential negative yield impacts" (p. 426). Such findings show that perceptions can have a significant impact on conservation efforts.

Crop yields are a primary channel through which farmers may perceive risks from conservation adoption, yet little research has been done to highlight the connection between farmer-specific yield-risk perceptions and conservation adoption. Conservation practices, such as no-tillage (e.g., Williams, Roth, and Claassen, 2000), crop rotation (e.g., Williams et al., 2012), cover crops (e.g., Bergtold et al., 2019), and variable-rate application of inputs (e.g., Schimmelpfennig, 2016) can impact cash-crop yield and variation. Results from Singer, Nusser, and Alf (2007) indicate that a perceived yield advantage increased the likelihood that a farmer had ever used cover crops, though the authors note that these findings were "suggestive but inconclusive" (p. 355). This inconclusiveness potentially results from a joint relationship between perceived yield impacts and adoption. How a farmer perceives the riskiness of a practice prior to adoption will influence the adoption decision, which then reinforces or alters these pre-perceptions. Bergtold et al. (2012) appear to acknowledge this and examine yield-risk perceptions conditional on having used cover crops in the past 3 years. Of those farmers who had used cover crops in the previous 3 years, the authors report 37% perceived a yield gain from using the practice.

Accounting for risk perceptions and understanding the factors that shape them is important if education, extension, outreach, and programmatic efforts to promote conservation adoption are to be successful. For example, understanding how risk perceptions affect adoption could help increase participation in programs designed to intensify on-farm conservation, such as the Conservation Stewardship Program operated by the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (U.S. Department of Agriculture, 2017). This may lead to increased additionality as farmers intensify existing or adopt new conservation practices (Mezzatesta, Newburn, and Woodward, 2013).

This study examines farmer adoption of a bundle of in-field conservation practices, with special consideration given to yield-risk perceptions. The practices examined are continuous no-till, conservation crop rotation, cover crops, and variable-rate application of inputs. These practices were selected on the premise that their adoption represents an intensification of on-farm conservation efforts. Continuous no-till, for example, would be an intensification for farmers who commonly utilize no-till for corn and soybean production but switch to reduced tillage when producing wheat in rotation (Canales, 2016). In contrast to past research (e.g., Wilson, Howard, and Burnett, 2014; Arbuckle and Roesch-McNally, 2015), this study employs a more targeted view of risk perceptions by focusing on farmers' perceived yield risk for each practice. Crop yields are a major source of income risk and can be an important barrier to the adoption of conservation practices (e.g., conservation tillage in Reimer, Weinkauf, and Prokopy, 2012). For the purposes of this study, yield risk can be thought of as increased crop-yield variability or low-yield frequency. An increase in the latter can be viewed as an increase in "downside risk," which would correspond to a left-skewed yield distribution (Chavas, 2004). Understanding how risk perceptions impact conservation adoption and the factors that shape them can help in the design of successful conservation policies.

This study uses survey-response data from Kansas farmers regarding their current use of four practices and their beliefs about how each practice will impact yield risk. Whereas previous literature has treated yield-risk perceptions as exogenous, this study models the joint process between yield-risk perceptions and current use of a practice using bivariate probit models.

Conservation Practices

Continuous No-Till

The USDA's Natural Resources Conservation Service (NRCS) defines no-till as "limiting the amount, orientation and distribution of crop and plant residue on the soil surface year around" (U.S. Department of Agriculture, 2013d). In general, no-till limits soil disturbance to direct seeding and nutrient injection (Hill, 2001). Under continuous no-till, the no-till system is maintained for all crops throughout a rotation cycle.

No-till benefits include increased soil organic carbon, soil microbial biomass, reduction of wind and water erosion, and enhanced nutrient cycling (Lal, 1999; Paustian et al., 2000; Campbell et al., 2001; Zibilske, Bradford, and Smart, 2002; Kladivko, 2001; Kushwaha, Tripathi, and Singh, 2001; Blanco-Canqui et al., 2009; Wang et al., 2011). Soil moisture preservation can also be improved (Blevins et al., 1983; Daniel et al., 1999). No-till systems will also likely decrease production costs compared to more conventional tillage systems (Kaval, 2004). However, no-till can cause planting delays due to slowed soil warming (DeJong-Hughes and Vetsch, 2007) or increased incidence of diseases (Anaele and Bishnoi, 1992; Bockus and Shroyer, 1998). No-till has been associated with both reduced (Williams, Roth, and Claassen, 2000; Ribera, Hons, and Richardson, 2004) and increased yield risk (Larson et al., 2001; Varner, Epplin, and Strickland, 2011). Previous research on the impacts of tillage on yields suggests that location and other management decisions, such as rotations, are important factors for crop-yield impacts. The importance of location is due primarily to precipitation, as conservation tillage is generally expected to perform better in semiarid regions due to increased soil moisture at planting (Williams, Llewelyn, and Mikesell, 1989). Given that annual rainfall increases moving from west to east across Kansas, continuous no-till would be expected to produce more favorable results in the east.

Conservation Crop Rotation

Generically, a crop rotation is a sequence of different crops on the same field. A conservation crop rotation (CCR) can be defined as a rotation with the purpose of simultaneously reducing erosion, maintaining or increasing soil health and organic matter, and improving soil moisture efficiency (U.S. Department of Agriculture, 2013b). To qualify as a CCR under NRCS guidelines, at least two different crops must be included. Additional criteria usually apply depending on the proposed purpose of the CCR (e.g., providing food and habitat for wildlife or sod-based rotations to reduce water-quality degradation). Improvements in soil moisture efficiency may be particularly important for producers in drier climates, such as western Kansas. Over the long term, CCRs can help to mitigate pests or weed pressure and improve soil health and productivity (Blackshaw et al., 1994;

West and Post, 2002; Cathcart et al., 2006; Karlen et al., 2006). Some studies have shown yield increases and yield-variability reductions from the use of crop rotations (Helmers, Langemeier, and Atwood, 1986; Williams et al., 2012). Across five management-rotation schemes in east-central Nebraska experimental plots, Helmers, Langemeier, and Atwood (1986) found corn yields from continuous corn to be lower than the other four trials, all of which included some form of rotation. Continuous-soybean yields were less than soybean yields in four out of five other trials involving rotations, and sorghum yields were higher in a sorghum–soybean rotation compared to continuous sorghum. Using data from experimental plots in southwest Kansas, Williams (1988) found continuous-wheat and continuous-sorghum yields—using conventional tillage—to be lower than yields in wheat–fallow, wheat–sorghum–fallow, and sorghum–fallow rotations using both conventional and conservation tillage. However, the reported standard deviations for both continuous-wheat and continuous-sorghum yields were also found to be lower than their rotational counterparts.

Cover Crops

A cover crop is a brassica, small grain, grass, legume, or mixture of these grown between regular cash-crop production periods to provide soil protection and improve soil quality (Singer, Nusser, and Alf, 2007). Cover crops are used to control erosion, improve soil moisture efficiency, and improve overall soil health (U.S. Department of Agriculture, 2013c). Some cover crops may reduce production costs through decreased weed pressure or fertilizer requirements (Snapp et al., 2005). Legume cover crops in particular, which can provide nitrogen to the following cash crop, may produce cost savings. However, cover crops can reduce water available to the following cash crop. This may be a significant drawback in areas such as western Kansas where water is a limiting factor (Lu et al., 2000; Biederbeck and Bouman, 1994).

Anticipating yield impacts from cover crops may be more difficult than for the other practices due to the number of factors that may play a role (e.g., cover-crop variety, preceding or subsequent cash crops, local climate, timing of establishment and termination). Schlegel and Havlin (1997), for example, found sorghum and wheat yields in west-central Kansas to decrease following hairy vetch (a legume) when compared to a traditional fallow–cash crop system. However, the field trials were conducted in an area where nitrogen was not a limiting factor, but water was. As a result, cash-crop yields did not benefit from soil fertility improvements but suffered from decreased soil water. Additionally, the authors found that cash-crop yield reductions increased the closer termination dates were to cash-crop planting due to further reductions in soil water. In a similar study, Blanco-Canqui, Claassen, and Presley (2012) assessed the impacts of no-till cover crops on yields in a wheat–sorghum rotation in south-central Kansas. When used as a summer cover crop, grown between wheat harvest and sorghum planting, the authors found sunn hemp and late-maturing soybeans generally increased both wheat and sorghum yields relative to a no-cover-crop system. The authors also note, however, that increases in crop yields tended to decrease at higher rates of nitrogen application. Bergtold et al. (2019) indicated that the impact of cover-crop adoption on crop-yield risk will likely be farmer dependent but could reduce long-term yield risk if continued use stabilizes crop yields over time. On the other hand, farmers may face short-term yield risks when adopting cover crops into their cropping systems due to adverse weather (e.g., drought) or market conditions (e.g., high input costs).

Variable-Rate Application of Inputs

Variable-rate application (VRA) varies input amounts spatially based on field requirements, with the objective of maximizing economic efficiency (Sawyer, 1994). By avoiding over-applications, VRA can improve surface and ground water quality by reducing runoff and nutrient leaching (Khanna and Zilberman, 1997). Variable-rate technologies have not seen widespread adoption: Only 33% of sampled Kansas farmers were using some form of variable-rate technology as of 2016 (Griffin et al., 2017). Schimmelpfennig and Ebel (2011) attributed this to uncertainty surrounding VRA benefits, perhaps due to significant investment costs and profitability that is often site-specific, varying according to the characteristics of the field (Biermacher et al., 2009). Another potential factor in slow adoption is that additional precision agriculture technologies, such as yield and soil mapping, are necessary to realize VRA benefits. This is supported by evidence that, compared to other precision agriculture technologies, VRA is less likely to be adopted as a standalone practice than to be bundled with other technologies (Schimmelpfennig, 2016; Griffin et al., 2017). When bundled with technologies such as yield and soil mapping, however, VRA may produce positive yield impacts by avoiding the under-application of inputs, though it is generally held that yield and profitability outcomes for VRA require a sufficient degree of variation in soil fertility (Schimmelpfennig, 2016; Thrikawala et al., 1999). Thrikawala et al. (1999), for example, estimated that variable-rate application of nitrogen could result in increased or decreased corn revenues compared to a constant rate of application. Results found by the authors were dictated by the distribution of soil fertility—as measured by available nitrogen—within a field. Variable applications performed better in simulated fields with higher mean and coefficient of variation of available nitrogen. The optimal nitrogen rate, and thus the resulting revenues, in the study were based on first-order profit-maximization conditions.

Conceptual Model of Perceived Yield Risk

Yield risk can be quantified in terms of means, variances, and other statistical measures. While these measures can be obtained from sources such as government or academic institutions, a disparity likely exists between risk evaluations made by researchers and by typical farmers (Kellstedt, Zahran, and Vedlitz, 2008). In fact, some researchers have questioned the use of purely economic approaches to risk assessment, given other social and cultural influences (Short, 1984; Tucker and Napier, 1998). This disparity makes the use of statistical measures as representative of farmer risk perceptions potentially problematic. For example, researchers may label individuals choosing a risky option as risk-seeking, when in fact their behavior is based on their subjective risk perception and may actually be “perceived-risk averse” (Bontempo, Bottom, and Weber, 1997). Thus, in many instances, an approach that focuses on perceived risk and allows for heterogeneity in risk perceptions may be valuable.

Modeling individual risk perceptions is complex, largely due to the uncertainties regarding the underlying psychological process by which risk perceptions are formed. Risk perceptions are likely a function of culture and environment, the individual’s background and experiences, and contextual characteristics (e.g., Tucker and Napier, 1998; Knowler and Bradshaw, 2007; Greiner, Patterson, and Miller, 2009). Moreover, perceptions may be changed over time by new knowledge or experiences. These complexities make the formulation of a conceptual model and subsequent selection of variables a nontrivial task.

The conceptual framework for practice adoption is based on expected utility theory and assumes that a farmer’s adoption decision, and the practice’s perceived yield risk, may be shaped by multiple dimensions. Assume farmer i has an expected utility function of the form $V_a(\boldsymbol{x},\boldsymbol{y},R(\boldsymbol{x},\boldsymbol{z}))$ for $a = 0,1$, where $a = 1$ represents the state in which a farmer adopts; $a = 0$ is the state in which a farmer does not adopt; $R(\cdot)$ is a perceived-risk-of-adoption function; $\boldsymbol{x}$ is a vector of variables impacting $V_a(\cdot)$ and $R(\cdot)$; $\boldsymbol{y}$ is a set of variables impacting only $V_a(\cdot)$; and $\boldsymbol{z}$ is a set of variables that impact only $R(\cdot)$. The function $R(\cdot)$ maps the farmer’s subjective risk assessment for a conservation practice. We assume that higher values of R indicate weaker perceived risk and that $V_j(\cdot)$ is increasing in R. A farmer will adopt a conservation practice if $\Delta V = V_1(\boldsymbol{x},\boldsymbol{y},R(\boldsymbol{x},\boldsymbol{z})) - V_0(\boldsymbol{x},\boldsymbol{y},R(\boldsymbol{x},\boldsymbol{z})) \geq 0$. A primary objective is the incorporation of individual-specific yield-risk perceptions into the adoption decision, but given the nature of the data, it is also necessary to account for the impact that current practice use has on perceived risk.

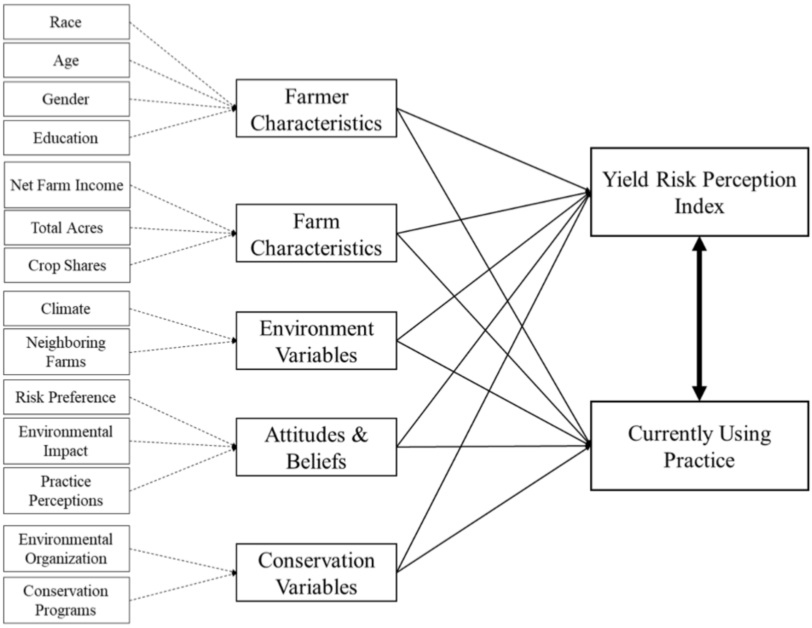

Figure 1. Yield Risk Model Conceptual Framework

Studies often assume that risk perceptions can be explained along a set of key dimensions. van der Linden (2015), for example, noted that research on climate-change risk perceptions typically assumes influence from four key dimensions: sociodemographic, cognitive, experiential, and sociocultural. Hung and Wang (2011) proposed that perceived risk from a nuclear plant was a function of compensation effects, social trust, socioeconomic characteristics, local context, and hybrid psychometric dimensions. Despite differing terms for the individual dimensions, similarities exist in what they intend to capture, such as knowledge about the topic, respondent demographics, and respondent world views. This study follows van der Linden's "key dimension" approach. As seen in Figure 1, along with current use of a practice, yield-risk perceptions are assumed to be a function of five key dimensions: farmer characteristics, farm characteristics, environment variables, attitudes and beliefs, and conservation variables. Though the conceptual model allows for variables that only affect adoption ($\boldsymbol{y}$) or only affect risk perceptions ($\boldsymbol{z}$), for the variables available for this study, a case can be made that each of them may affect both adoption and risk perceptions. Thus, all variables are included in the $\boldsymbol{x}$ vector. Examples of variables ($\boldsymbol{y}$) that could impact utility but not subjective risk assessment could include farmers' operational goals and household attributes, while variables ($\boldsymbol{z}$) that could directly impact farmers' subjective risk assessment and only indirectly impact utility could include interest rates or market volatility. Some of these factors would require a temporal model, which is beyond the scope of this study.

Farmer characteristics capture influences from demographic sources and a farmer's background, such as age, ethnicity, gender, and education. Evidence from the literature regarding the impact of these variables on risk perceptions is inconclusive. Kellstedt, Zahran, and Vedlitz (2008) stated that past research indicates higher socioeconomic status, including education, leads to lower levels of perceived climate-change risk. However, van der Linden (2015) noted that, while there is some support for this view, many studies find little to no correlation between age or education and risk perceptions regarding climate change. Tucker and Napier (1998) found that farmer characteristics, such as education, had no significant impact on the perceived risk of farm chemicals. Bergtold et al. (2012) found that farmer characteristics such as education, years farming, and off-farm income did not significantly increase the likelihood of a cover-crop adopter experiencing a perceived yield benefit; however, for farmers that did perceive a positive yield benefit, factors such as education level and years of farming experience decreased the magnitude of the perceived benefit. While these factors may not be statistically significant at times, van der Linden (2015) warranted their inclusion as control variables to aid in assessing the net influence of other factors. Risk-perception studies often find what is termed the "white male effect," referring to the fact that women and racial minorities tend to exhibit higher levels of perceived risk (Kellstedt, Zahran, and Vedlitz, 2008). Due to low variability in the data (99.2% white and 98.4% male), race and gender were not included as variables in this study.

Farm characteristics capture the influence of farm-level factors. Many of these capture economic influences and are commonly included in economic assessments of risk (Knowler and Bradshaw, 2007). Two of the variables are farm acres and net farm income (NFI). Farmers operating more acres may hold a "more-to-lose" view, leading to greater perceived risk, or they may see more acres as a way of spreading risk. Higher NFI is expected to reduce perceived yield risk. Higher NFI may allow a farmer to take on more risk than one whose operation is not performing at the same level. Higher NFI may also indicate a more diversified operation (e.g., crops and livestock), thus lowering the perceived risk of any given practice. The third component is the share of acres devoted to corn, sorghum, soybeans, and wheat. These are included to capture cropping-system (and rotation) influences. As mentioned previously, a farmer who has wheat in rotation, for example, may perceive continuous no-till to be yield-risk increasing if they currently manage wheat using reduced-tillage practices.

Environment variables represent a farmer's physical and social environment. Physical environment could include climate variables, soil characteristics, etc. We use regional dummies to capture these and other unavailable spatial factors. The social environment, which we use as a proxy for influence of social networks and of practice adoption in the local area, is examined through neighboring farms' usage of soil conservation practices. When a farmer adopts a conservation practice, his experience may add to his neighbors' knowledge. However, even if a neighboring farm's specific successes or failures with a practice go unnoticed, risk perceptions may still be impacted if the increased usage is noticed. Here, increased usage may signal nonadopters that yield risk is lower than originally thought. Thus, as more farmers adopt a given practice within an area, there could be a corresponding effect on yield-risk perceptions. Tucker and Napier (1998) suggested that family, peers and informal social networks can impact risk assessments and conservation adoption. Manson et al. (2016) also found social networks to be an important factor in conservation practice adoption, but the impact depends upon the strength of ties between agents (e.g., farmers and local organizations) in the network. It should be understood that the survey used in this study did not collect explicit data on social networks and their complexities. The variable only captures neighbors' usage of soil conservation practices. Thus, insignificance of this variable does not necessarily imply that social networks, flow of information through these networks, or more complex spatial dynamics are not at work in shaping risk preferences or conservation practice usage. We acknowledge that social network dynamics and flows of information through social networks are complex and difficult to model in this context and are thus beyond the scope of this study.

Attitudes and beliefs represent cognitive factors. Tucker and Napier (1998) argue that cognitive factors, such as awareness and sensitivity to environmental issues, will impact farmers' risk assessments of conservation practices. Theoretical foundations for including cognitive factors emphasize that sensitivity to adverse and/or beneficial impacts from adopting new technologies is associated with cognitive characteristics, such as memory and aptitude, which may provide the ability to process more complex risk information (Tucker and Napier, 1998). Increased cognitive awareness of issues surrounding a practice will then impact its perceived riskiness. Factors assessed in this study include a farmer's self-reported level of risk aversion; perceptions of practice impacts on soil erosion, soil fertility, production costs, weed pressure, and insect pressure; and belief regarding the consequences of their cropping decisions for the local environment. We expect more risk-averse individuals to assign higher risk to a practice, perhaps based on emotion or worldview. However, if farmer risk assessments are completely objective, the level of risk aversion may not exert any influence. Farmers who hold “positive” practice perceptions (e.g., regarding benefits to soil erosion and fertility) are expected to hold more favorable yield-risk beliefs. There is no *a priori* expectation regarding the belief about local-environmental impacts. As with risk aversion, for a completely objective farmer this may have no impact. However, if perceived impacts on the local environment evoke positive or negative emotions and emotions impact yield-risk perceptions, a causal relationship may exist.

Conservation variables capture a farmer’s experience with and knowledge regarding conservation and conservation practices. Knowledge is proxied by membership in an environmental organization. Tucker and Napier (1998) suggested that access to risk information from different sources will influence cognitive factors and risk assessment. Thus, membership in an organization that focuses on the types of conservation practices examined here (e.g., Nature Conservancy, Kansas Alliance of Wetlands and Stream, National Sustainable Agriculture Coalition) should impact yield-risk perceptions. For other types of environmental organizations, the implied relationship is less clear. However, farmers involved with any environmental organization may be more inclined to seek information on conservation practices than their nonmember counterparts, and so a relationship may still hold. Knowler and Bradshaw (2007), in a review of conservation agriculture adoption, showed that membership in environmental organizations may increase the adoption of conservation agricultural practices. A farmer’s knowledge about these practices can also be impacted through other means as well, such as extension services; local, state, or federal government conservation resources; or membership in other types of organizations. Moreover, it may be that farmers involved in environmental organizations have a more natural inclination toward conservation and are thus more likely to adopt. In this sense, membership in these organizations may, to some extent, capture a farmer’s underlying value system with respect to the natural environment, and so an argument could be made for placement within the attitudes and beliefs dimension, as well.

Conservation assistance is captured through a variable that indicates whether a farmer has participated in any of the Conservation Reserve Program (CRP), Conservation Stewardship Program (CSP), Environmental Quality Incentives Program (EQIP), or a Kansas state-level conservation program. Participation in conservation programs is expected to lead to lower perceived yield risk, primarily because participation in these programs may provide technical information needed to effectively implement new conservation practices, subsequently reducing any potential negative impact on crop yields (Knowler and Bradshaw, 2007).

The final component of the conceptual model is a bilateral relationship between current use of a conservation practice and its perceived impact on yield-risk. For farmers already using a conservation practice, their perceived yield risk has likely been impacted by their experiences. However, a farmer’s initial level of perceived yield risk likely impacted the decision to adopt in the first place. Because we use cross-sectional data, we treat this empirically as a joint-determination process, represented in Figure 1 by the two-way connection between yield-risk perceptions and current use. Many of the same variables impacting yield-risk perceptions also impact the adoption decision, as seen in the literature (see Pannell et al., 2006), indicated in Figure 1 by the connection from each of the dimensions to current use of the conservation practice.

Data

Data for this study come from a survey administered during a series of workshops spanning 10 locations across Kansas from December 2013 to March 2014. Workshop locations were selected to capture differences in climate, landscape, and farm make-up. Locations included the towns and cities of Salina, Great Bend, Colby, Dodge City, Wellington, Pratt, Hiawatha, Topeka, Manhattan, and Parsons. Prior to administering the survey, it was field tested with three focus groups held in Manhattan, Salina, and Wellington.

A sample of farms was obtained from the Kansas Farm Management Association (KFMA) database, which includes approximately 2,300 farms across Kansas that produce crops and livestock.

Table 1. Summary Data for Dependent Variables

Variable	Description	N	Average
NTR	= 1 if respondent "strongly agrees" or "agrees" that continuous no-till will reduce yield risk, and 0 otherwise.	242	0.58
CCRR	= 1 if respondent "strongly agrees" or "agrees" that conservation crop rotation will reduce yield risk, and 0 otherwise.	242	0.64
CCR	= 1 if respondent "strongly agrees" or "agrees" that cover crops will reduce yield risk, and 0 otherwise.	242	0.28
VRAR	= 1 if respondent "strongly agrees" or "agrees" that variable-rate application will reduce yield risk, and 0 otherwise.	240	0.41
NTCURR	= 1 if respondent is currently using continuous no-till, and 0 otherwise.	248	0.61
CCRCURR	= 1 if respondent is currently using conservation crop rotations, and 0 otherwise.	248	0.61
CCCURR	= 1 if respondent is currently using cover crops, and 0 otherwise.	248	0.32
VRACURR	= 1 if respondent is currently using variable-rate applications, and 0 otherwise.	248	0.26

Notes: Own survey, 2013–2014. Number of observations changes across variables due to incomplete survey responses. Nonresponses for the current-use variables were recoded as 0.

Table 2. Adoption Statistics by Perceived-Yield-Risk Group and Practice

	Practice Decreases Yield Risk		Practice Does Not Decrease Yield Risk	
Practice	**Adopted**	**Not Adopted**	**Adopted**	**Not Adopted**
Continuous no-till	115	26	35	66
Conservation crop rotations	106	50	43	43
Cover crops	35	32	45	130
Variable-rate applications	40	59	24	117

Approximately 76% of these farms are primarily crop producers and 16% identified as crop/livestock producers. Working with members of KFMA allowed survey data to be matched with KFMA financial data. A total of 1,513 farmers were mailed letters inviting them to attend one of the workshops. Of those, 40 were no longer farming, were deceased, or could not be located; and 432 responded to the letter. In total, 250 of the 432 farmers who responded attended the workshops. The remaining farmers who responded were interested but could not attend the workshops on the dates held. This resulted in an adjusted response rate of approximately 30% and an attendance rate of 17%. Workshop attendees were compensated for their time and travel expenses with a stipend of $125.

The workshops consisted of an introductory presentation covering the basic aspects of conservation practices, a time for farmers to answer a survey questionnaire, a set of stated-choice and behavioral experiments, and a focus group to discuss farmers' views on conservation. At the workshop, farmers were asked to complete a survey with questions to elicit their farming history, farm operation, and the conservation practices used on their farms.

Data from farmers with incomplete responses were not considered, leaving a different number of farmers for analyses across conservation practices. The number of complete observations was 177, 155, 136, and 125 for continuous no-till, conservation crop rotations, cover crops, and variable-rate application of inputs, respectively.

Summary data for the dependent and independent variables are presented in Tables 1–3. The dependent variables concerning perceived yield risk were obtained by asking whether the respondent believed that a practice reduces yield risk on a Likert scale. Given limited variation across responses, each question was recoded as a binary variable, with 1 representing "Agree" and "Strongly Agree" and 0 representing "Neutral," "Disagree," and "Strongly Disagree." Current-use variables are also binary, where 1 indicates the farmer is currently using the practice, and 0 otherwise. Cross-tabulated

Table 3. Summary Data for Explanatory Variables

Variable	Description	*N*	Average
Farmer characteristics			
COLLEGE	= 1 if farmer is a college graduate, and 0 otherwise	248	0.50
AGE	Age of farmer in years	248	57.10
Farm characteristics			
HUNDAC	Total acres in crops, hay, pasture, or CRP (hundreds of acres)	245	24.53
NFISCALE	Net farm income ($thousands)	238	104.04
PER_CORN	Share of acres devoted to corn	202	0.15
PER_SORG	Share of acres devoted to sorghum	208	0.07
PER_SOY	Share of acres devoted to soybeans	208	0.17
PER_W	Share of acres devoted to wheat	208	0.23
Environment variables			
NEIGHBOR	= 1 if farmer's neighbor uses soil conservation practices, and 0 otherwise	247	0.90
EAST	= 1 if farmer's operation is in "East" region of Kansas, and 0 otherwise	248	0.38
WEST	= 1 if farmer's operation is in "West" region of Kansas, and 0 otherwise	248	0.21
Attitudes and beliefs			
RISK2	= 1 if farmer is "cautious" or relatively risk averse, and 0 otherwise	241	0.16
RISK3	= 1 if farmer is "willing to take risks after adequate research," and 0 otherwise	241	0.60
ENVIMP	= 1 if farmer "agrees" or "strongly agrees" that he can improve or harm local environment through cropping choices, and 0 otherwise	247	0.90
CCCOSTS	= 1 if farmer believes cover crops reduce production costs, and 0 otherwise	207	0.24
CCFERT	= 1 if farmer believes cover crops improve soil fertility, and 0 otherwise	206	0.51
CCWEEDS	= 1 if farmer believes cover crops will reduce weed pressure, and 0 otherwise	182	0.68
CCRCOSTS	= 1 if farmer believes conservation crop rotations reduce production costs, and 0 otherwise	207	0.24
CCREROS	= 1 if farmer believes conservation crop rotations reduce erosion, and 0 otherwise	208	0.75
CCRFERT	= 1 if farmer believes conservation crop rotations improve soil fertility, and 0 otherwise	206	0.51
CCRINSCT	= 1 if farmer believes conservation crop rotations reduce insect pressure, and 0 otherwise	205	0.52
NTFERT	= 1 if farmer believes continuous no-till improves soil fertility, and 0 otherwise	227	0.50
VRAFERT	= 1 if farmer believes variable-rate applications improve soil fertility, and 0 otherwise	169	0.67
Conservation variables			
ENV_ORG	= 1 if farmer is a member of an environmental organization, and 0 otherwise	248	0.10
PROGRAM	= 1 if farmer has participated in CRP, CSP, EQIP or Kansas conservation programs, and 0 otherwise.	248	0.77

Notes: Own survey, 2013–2014. Number of observations changes across variables due to incomplete survey responses. The values in parentheses in the "Mean" column are standard deviations. The risk variable was measured using a 6-point scale, with 1 being an extreme risk avoider and levels 4–6 being risk neutral or risk seeking behavior. There were no observations for level 1 in the sample. The base group is 4–6, or being risk neutral or risk seeking.

Table 4. Average Farmer Characteristics

Variable	Survey Data[a] N	Mean	Std. Dev.	Min.	Max.	Mean 2012 Census of Agriculture[b]	Mean 2013 KFMA
Age (years)	248	57	13.20	20	90	58	—
Acres	245	2,453	1,994	40	14,875	747	2,196
Sales	242	$400,000–$599,000		< $25,000	> $1 million	$298,845	$618,416

Notes: [a] Own survey, 2013–2014;
[b] (U.S. Department of Agriculture, 2013a).

statistics for the two binary variables are found in Table 2, which indicates a strong positive relationship between adoption and a belief that the practice reduces yield risk for continuous no-till and conservation crop rotations. For those who believe that cover crops reduce yield risk, there is less of a relationship, with similar numbers in both the adopter and nonadopter groups. The VRA statistics are notable, where a majority of farmers who believe VRA reduces yield risk have not adopted. This likely results from financial barriers to VRA adoption. For those farmers who do not believe a practice reduces yield risk, the table shows they largely have not adopted the practice. An exception is conservation crop rotations, where the numbers of adopting and nonadopting farmers are equal. Explanatory variables include a range of binary and continuous variables, defined and summarized in Table 3. The inclusion of these variables is supported by the literature on perceived risk and conservation adoption discussed in the previous section (e.g., Koundouri, Nauges, and Tzouvelekas, 2006; Pannell et al., 2006; Greiner, Patterson, and Miller, 2009).

Table 4 presents sample farmer demographics and compares them to the 2012 U.S. Census of Agriculture (U.S. Department of Agriculture, 2013a) and 2013 KFMA (2014) demographics. Surveyed farmers were 20–90 years old, with a sample average of 57 that can be considered representative of the average Kansas farmer (58 years, 2012 U.S. Census of Agriculture). The average size (including CRP land) of farms in the sample (2,453 acres and sales of $400,000 to $599,999) is larger than the average Kansas farm size reported in the 2012 Census of Agriculture (747 acres and sales of $298,845). Farm size is important for conservation practice adoption, particularly for management intensive practices, as operators must be devoted to farming due to additional learning, time, and financial investment requirements (Lambert et al., 2007). Comparing sample demographics to those of all KFMA members, the sample is representative of the KFMA group. Thus, results in this study should be interpreted as representing conservation practice adoption decisions on Kansas farms that are, on average, larger than the typical Kansas farm.

Empirical Model

Given the conceptual framework and that the objectives are to assess both farmers' yield-risk perceptions and how these perceptions influence adoption, we adopt a reduced-form system of equations for the empirical model. This model captures the joint determination between farmers' risk perceptions about and use of a conservation practice. That is, farmer i's yield-risk perceptions for conservation practice j (R_{ij}) and the decision to adopt practice j (E_{ij}) are modeled as a joint-decision process that is dependent on a number of key dimensions.

Assume that R^*_{ij} is a latent-continuous variable described by

$$(1) \qquad R^*_{ij} = \beta_{j,0} + \boldsymbol{\beta}'_{j,1}\boldsymbol{x}_{i,1} + \boldsymbol{\beta}'_{j,2}\boldsymbol{x}_{i,2} + \boldsymbol{\beta}'_{j,3}\boldsymbol{x}_{i,3} + \boldsymbol{\beta}'_{j,4}\boldsymbol{x}_{j,i,4} + \boldsymbol{\beta}'_{j,5}\boldsymbol{x}_{i,5} + u_{ij},$$

where $\left[\boldsymbol{\beta}'_{j,1}\ \boldsymbol{\beta}'_{j,2}\ \boldsymbol{\beta}'_{j,3}\ \boldsymbol{\beta}'_{j,4}\ \boldsymbol{\beta}'_{j,5}\right]'$ is a vector of parameters to be estimated; $\boldsymbol{x}_{i,1}$, $\boldsymbol{x}_{i,2}$, $\boldsymbol{x}_{i,3}$, $\boldsymbol{x}_{j,i,4}$, and $\boldsymbol{x}_{i,5}$ are sets of explanatory variables related to each of the key dimensions in the conceptual framework; $\beta_{j,0}$ is an intercept term; and u_{ij} is a mean 0 *i.i.d.* error term.

As indicated in Figure 1, we assume the variables that influence yield-risk perception will also impact adoption (Pannell et al., 2006; Bergtold et al., 2012). Thus, we model the change in expected utility, ΔV_{ij}, as

$$\Delta V_{ij} = \delta_{j,0} + \boldsymbol{\delta}'_{j,1}\boldsymbol{x}_{i,1} + \boldsymbol{\delta}'_{j,2}\boldsymbol{x}_{i,2} + \boldsymbol{\delta}'_{j,3}\boldsymbol{x}_{i,3} + \boldsymbol{\delta}'_{j,4}\boldsymbol{x}_{j,i,4} + \boldsymbol{\delta}'_{j,5}\boldsymbol{x}_{i,5} + \varepsilon_{ij}, \tag{2}$$

where $\left[\boldsymbol{\delta}'_{j,1}\ \boldsymbol{\delta}'_{j,2}\ \boldsymbol{\delta}'_{j,3}\ \boldsymbol{\delta}'_{j,4}\ \boldsymbol{\delta}'_{j,5}\right]'$ is a vector of parameters to be estimated, $\delta_{j,0}$ is an intercept term, ε_{ij} is a mean 0 *i.i.d.* error term, and the $\boldsymbol{x}$ vectors are as described previously. To capture the joint determination of R^*_{ij} and ΔV_{ij}, both reduced-form equations (1) and (2) must be estimated simultaneously, taking into account that the errors u_{ij} and ε_{ij} are correlated.

Given that R^*_{ij} and ΔV_{ij} are latent, what is observed by the researcher is the choice of adoption and an indication of yield risk. As indicated in the previous section, the observed dependent variables will be indicator or binary variables, defined as

$$\begin{aligned} R_{ij} &= 1 \ \text{ if } \ R^*_{ij} > 0 \ \text{ and } \ 0 \ \text{ otherwise,} \\ E_{ij} &= 1 \ \text{ if } \ \Delta V_{ij} > 0 \ \text{ and } \ 0 \ \text{ otherwise.} \end{aligned} \tag{3}$$

A value of $R_{ij} = 1$ indicates that a farmer perceives practice j as reducing yield risk and a value of $E_{ij} = 1$ indicates that a farmer uses practice j on their farm. Assuming that

$$\begin{pmatrix} u_{ij} \\ \varepsilon_{ij} \end{pmatrix} | \boldsymbol{X}_{ij} \sim NIID\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}\right]$$

and taking into account that the observed dependent variables are correlated binary random variables, equations (1) and (2) can be simultaneously estimated as a bivariate probit model (BPM). Under this specification,

$$P(R_{ij} = h, E_{ij} = \ell \mid \boldsymbol{X}_{ij} = \boldsymbol{x}_{ij}) = \int_{-\infty}^{(2R_{ij}-1)\boldsymbol{x}'_{ij}\boldsymbol{\beta}_j} \int_{-\infty}^{(2E_{ij}-1)\boldsymbol{x}'_{ij}\boldsymbol{\delta}_j} \frac{\exp\left(-\frac{\boldsymbol{x}'_{ij}\boldsymbol{\beta}_j + \boldsymbol{x}'_{ij}\boldsymbol{\delta}_j - 2\left(\boldsymbol{x}'_{ij}\boldsymbol{\beta}_j\right)\left(\boldsymbol{x}'_{ij}\boldsymbol{\delta}_j\right)}{2(1-\rho^2)}\right)}{2\pi\sqrt{1-\rho^2}} \tag{4}$$

for $h, \ell = 0, 1$ (Greene, 2012). The BPM is a nonlinear model that is estimated using full information maximum likelihood. The joint process between R_{ij} and E_{ij} is explicitly captured during estimation and no additional model modifications are needed to account for the underlying joint process. The parameter ρ measures the tetrachoric correlation, or the association between R_{ij} and E_{ij}. This discrete-based correlation measure captures the theoretical correlation between the latent dependent variables R^*_{ij} and ΔV_{ij}. As such, larger, positive values for $\hat{\rho}$ would suggest that lower levels of perceived yield risk ($R_{ij} = 1$) are associated with practice adoption ($E_{ij} = 1$), which is the expectation. Estimation of the BPM is performed using LIMDEP 10 and is thoroughly outlined in Greene (2012).

Using the BPM, a modeler can explore the relationship between the two dependent variables as the explanatory variables change. A particular statistic of interest is the marginal effect of an explanatory factor on the probability of adopting a practice. However, the marginal effect of an explanatory factor on adoption may be different for farmers who do not believe a practice reduces yield risk ($R_{ij} = 0$) compared to those who believe it does ($R_{ij} = 1$). For example, soil-fertility improvements from continuous no-tillage may be more important for farmers who do not believe the practice reduces yield risk. In this example, the impact of perceived soil-fertility benefits may be augmented by the fact that adoption is not encouraged through a belief in yield-risk reductions. Thus, of interest in this study are the marginal effects on adoption given a farmer's yield-risk perception about that conservation practice (i.e., $\frac{\partial P(E_{ij}=1|R_{ij}=m,\boldsymbol{x}_i)}{\partial x_k}$ for $m = 0,1\}$ and a particular explanatory factor x_k (Greene, 2012). Estimating these conditional marginal effects can help identify factors that may enhance adoption of conservation on-farm, allowing policy makers and specialists to shape policy and outreach to their particular audience. Asymptotic standard errors are obtained via the delta method and used to conduct significance tests (Greene, 2012).

Results

Estimated coefficients for each model can be found in Table 5. Goodness of fit, measured by pseudo-R^2, was lowest in the continuous no-till model and highest in the VRA model. The tetrachoric-correlation coefficient was positive and statistically significant across all models except VRA, lending support to the assumption of the joint determination of perceived yield risk and use of a practice. As expected, this suggests farmers who view a practice as yield-risk reducing are more likely to be using it. Perhaps more interestingly, it may also indicate that farmers who adopt a practice see changes in their perceptions. That is, their experience has been one of (perceived) positive yield impacts that in turn has influenced their perceptions. Thus, promoting on-farm trials of practices—over a sufficiently long time period—may lead to more widespread adoption. Within the conservation-adoption literature, small-scale trials are often viewed as an important phase or step that precedes and can lead to large-scale adoption (e.g., Rogers and Shoemaker, 1971; Pannell et al., 2006; de Graaff et al., 2008). Certainly, this is due in part to increasing familiarity and comfort with a practice, but, as suggested here, trialing may also expose practice benefits that had not been known prior to adoption.

It should be noted that positive yield-outcomes—and thus an adjustment of perceptions to those of less risk—is not the only possible outcome. Almost surely, some farmers' experiences with the practices were ones of negative yield impacts or no yield impacts, leading to different (or no) changes in yield-risk perceptions. It is likely that at least some of these farmers would have discontinued use of the practice. Conditional on all other factors, there may be some maximum level of perceived yield risk below which a farmer will adopt and above which the farmer will not adopt. As with perceived yield risk itself, this maximum-tolerable level is likely unique to each farmer. To say something more definitive about this is beyond the scope and feasibility of this study. However, if there is truth to the maximum-tolerable level scenario, then if there are factors that increase or decrease perceived yield risks across a group of farmers, these could be exploited via educational or policy mechanisms in an effort to increase trialing.

Table 6 presents conditional probabilities, and Table 7 reports model results and conditional marginal effects (CMEs) for each practice, discussed below. For each practice, CMEs on adoption given yield-risk beliefs are discussed for farmers who do and do not believe the practice reduces yield risk.

Continuous No-Till

Estimated conditional probabilities suggest the probability of continuous no-till (CNT) adoption, given a farmer believes it reduces yield risk, is 0.835. If a farmer does not believe CNT reduces yield risk, the estimated probability of adoption is 0.425. The tetrachoric correlation for this model was 0.63 (i.e., $\hat{\rho} = 0.63$), significant at the 1% level.

A number of factors impact the perceived yield-risk impacts from adopting CNT (*CNTR*). Statistically significant explanatory factors included: membership in an environmental organization (*ENV_ORG*), share of acres devoted to wheat (*PER_W*) and soybeans (*PER_SOY*), net farm income (*NFISCALE*), operating in eastern Kansas (*EAST*), and a belief that CNT improves soil fertility (*FERTILITY*). The coefficient on *ENV_ORG* was negative, indicating that membership in an environmental organization decreases the probability of viewing CNT as yield-risk reducing. It

Table 5. Estimated Bivariate Probit Model Coefficients

	Dependent Variables							
Variable	*CNTR*	*CNTCURR*	*CCRR*	*CCRCURR*	*CCR*	*CCCURR*	*VRAR*	*VRACURR*
CONST	−0.95	−0.82	0.57	−0.62	−1.24	−2.11	1.36	0.70
	(1.30)	(1.09)	(1.36)	(1.48)	(1.53)	(1.35)	(1.67)	(1.98)
AGE	0.01	0.01	−0.01	0.01	0.01	0.01	−0.03	−0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
COLLEGE	0.31	0.12	0.62*	−0.32	0.37	0.29	−0.46	−0.12
	(0.29)	(0.27)	(0.32)	(0.32)	(0.43)	(0.35)	(0.40)	(0.61)
ENV_ORG	−1.07**	0.37	−0.12	0.26	−0.07	−0.10	0.43	0.49
	(0.53)	(0.57)	(0.50)	(0.50)	(0.61)	(0.59)	(0.45)	(0.71)
PER_CORN	−0.97	−0.46	−0.93	0.93	−1.23	1.34	3.18*	6.47**
	(1.43)	(1.38)	(1.46)	(1.52)	(1.85)	(1.52)	(1.79)	(3.00)
PER_SORG	−0.81	2.48	0.01	1.39	1.86	1.65	1.89	−0.85
	(2.14)	(2.10)	(2.06)	(2.32)	(2.57)	(2.19)	(2.62)	(3.55)
PER_SOY	3.23**	0.71	3.10	−0.66	0.27	0.71	0.89	1.24
	(1.51)	(1.13)	(2.04)	(1.50)	(1.47)	(1.28)	(1.43)	(1.94)
PER_W	−1.86*	−1.07	−0.40	−0.82	−2.81*	−2.87**	−0.47	−1.30
	(1.00)	(0.91)	(1.08)	(1.01)	(1.51)	(1.28)	(1.19)	(2.06)
NFISCALE	0.01**	4.41E-3*	0.00	0.00	0.00	0.00	0.00	0.00
	(0.00)	(2.43E-03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
HUNDAC	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02*
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
RISK2	−0.58	−0.73	0.72	0.01	−0.59	−0.71	−0.64	−1.40
	(0.50)	(0.47)	(0.60)	(0.47)	(0.66)	(0.55)	(0.77)	(1.16)
RISK3	−0.28	−0.71**	0.45	−0.15	−0.77**	−0.80**	−0.10	−0.99**
	(0.38)	(0.35)	(0.35)	(0.34)	(0.35)	(0.32)	(0.35)	(0.47)
ENVIMP	0.49	0.62	−0.97	0.90	0.38	0.45	−0.54	−0.65
	(0.52)	(0.45)	(0.73)	(0.59)	(0.84)	(0.73)	(0.97)	(0.78)
PROGRAM	0.42	0.05	−0.09	−0.03	0.92	0.32	0.20	0.26
	(0.40)	(0.34)	(0.33)	(0.39)	(0.59)	(0.40)	(0.54)	(0.72)
EAST	−1.49***	−0.24	−0.73	−0.77	−0.51	−0.73*	−0.88	−1.49
	(0.50)	(0.42)	(0.61)	(0.62)	(0.61)	(0.44)	(0.60)	(0.94)
WEST	−0.19	0.17	−0.30	−0.77	−0.90	−1.03*	−0.33	−0.82
	(0.39)	(0.46)	(0.43)	(0.49)	(0.66)	(0.60)	(0.57)	(0.89)
NEIGHBOR	0.38	−0.28	0.66	0.06	−0.87	0.24	−0.72	−0.24
	(0.52)	(0.69)	(0.76)	(0.86)	(1.01)	(0.30)	(0.74)	(0.80)
COSTS	—	—	−0.22	−0.41	−1.76	1.54*	—	—
			(0.43)	(0.40)	(1.11)	(0.95)		
EROSION	—	—	(0.15)	(−0.20)	—	—	—	—
			(0.36)	(0.32)				
FERTILITY	0.48*	0.76***	0.39	(0.64**)	−0.20	−0.34	(0.74*)	0.36
	(0.27)	(0.27)	(0.33)	(0.28)	(0.40)	(0.34)	(0.38)	(0.51)
INSECTS	—	—	−0.37	−0.17	—	—	—	—
			(0.32)	(0.29)				
WEEDS	—	—	—	—	0.30	0.31	—	—
					(0.35)	(0.30)		
RHO	0.63***		0.35**		0.73***		0.40	
	(0.15)		(0.15)		(0.22)		(0.27)	
Fit statistics								
Log likelihood	−165.70		−157.59		−119.07		−110.12	
Pseudo-R^2	0.44		0.50		0.59		0.63	
AIC/N	2.29		2.59		2.35		2.35	
No. of obs.	177		155		136		125	

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Standard errors are in parentheses.

Table 6. Estimated Conditional Probabilities

Practice	$\mathbf{P}(E_{ij}=1\|R_{ij}=1,\bar{X})$	$\mathbf{P}(E_{ij}=0\|R_{ij}=1,\bar{X})$	$\mathbf{P}(E_{ij}=1\|R_{ij}=0,\bar{X})$	$\mathbf{P}(E_{ij}=0\|R_{ij}=0,\bar{X})$
Continuous no-till	0.835	0.165	0.425	0.575
Conservation crop rotation	0.785	0.215	0.492	0.508
Cover crops	0.774	0.226	0.217	0.783
Variable-rate applications	0.386	0.614	0.169	0.831

could be that environmental organizations that disseminate CNT information have included more evidence on negative rather than positive yield outcomes. Results for *PER_W* and *PER_SOY* imply that farmers with a lower share of wheat and/or a higher share of soybeans are more likely to believe CNT reduces yield risk. As suggested by Canales (2016), the low adoption of no-till and CNT by farmers producing wheat may imply that they, on average, perceive the use of no-till practices to increase wheat-yield risk. Conversely, farmers have adopted no-till in soybeans at relatively higher rates than in other major crops (e.g., corn, wheat, and sorghum) (Horowitz, Ebel, and Ueda, 2010). The coefficient on *NFISCALE* was positive, suggesting that farmers with higher NFI are more likely to believe CNT reduces yield risk. The coefficient on *FERTILITY* was also positive. This could have important implications for farmer education, particularly if associating CNT with soil-fertility benefits proves easier than associating it directly with reduced yield risk. *EAST* was found to have a negative impact, indicating that farmers in eastern Kansas are less likely to believe CNT reduces yield risk compared to those in central Kansas (the omitted group). Geographic climate variability may be driving this result. A primary consequence of CNT is additional crop residue left on the field, which can lead to wetter and cooler conditions that may increase pest and/or disease pressures (Reicosky, 2008). Eastern Kansas typically receives more rainfall than central or western Kansas, thus making pest or disease risks even more severe under CNT.

For the CNT current-use model (*CNTCURR*), a positive and statistically significant CME was estimated for *FERTILITY* regardless of whether the marginal effect was conditional on a belief or nonbelief in yield-risk reductions. The estimated impact, however, was approximately 47% larger if the farmer believed that CNT does not reduce yield risk. Potentially, one benefit of improved soil fertility is a reduction in yield risk. Thus, if a farmer already believes CNT reduces yield risk for other reasons, then a change in soil-fertility perceptions will have a smaller impact on adoption than had he not believed the practice reduces yield risk. Because a belief that CNT improves soil fertility increases the probability a farmer also believes it reduces yield risk, providing information on positive soil-fertility impacts could have an additional, indirect adoption impact through changes in yield-risk perceptions.

A statistically significant and negative CME was estimated for *RISK3*, where a value of 1 indicates a farmer is willing to take risks after adequate research, given a farmer believes CNT reduces yield risk, and 0 otherwise. In other words, a (moderately) risk-averse farmer is less likely to adopt CNT even if he believes it reduces yield risk. This result again stresses the need to emphasize trialing of conservation practices on farm, which may be enhanced through existing federal and state conservation programmatic efforts. For this group of farmers, a positive and significant CME was also estimated for *ENV_ORG*, where a value of 1 indicates membership in an environmental organization, and 0 otherwise.

Conservation Crop Rotations

In the conservation crop rotation (CCR) model, the tetrachoric correlation was 0.35, significant at the 5% level. Estimated conditional probabilities indicate the probability of adoption, given a farmer believes CCR reduces yield risk, was 0.785. If a farmer does not believe CCR reduces yield risk,

Table 7. Conditional Total Marginal Effects of Explanatory Factors on Practice Adoption Given Conservation Practice Risk Perceptions

	$\frac{\partial P(E_{ij}=1\|R_{ij}=1,\bar{X})}{\partial x_k}$				$\frac{\partial P(E_{ij}=1\|R_{ij}=0,\bar{X})}{\partial x_k}$			
Variable	**CNT**	**CCR**	**CC**	**VRA**	**CNT**	**CCR**	**CC**	**VRA**
AGE	0.00	0.00	0.00	−0.01	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
COLLEGE	0.00	0.14	0.18	0.00	−0.01	−0.23	0.15	0.00
	(0.08)	(0.10)	(0.22)	(0.24)	(0.14)	(0.15)	(0.16)	(0.16)
ENV_ORG	0.16***	0.08	0.10	0.16	0.35	0.13	0.04	0.12
	(0.06)	(0.12)	(0.25)	(0.29)	(0.22)	(0.20)	(0.23)	(0.25)
PER_CORN	−0.02	0.36	1.23	2.27**	0.00	0.55	0.85	1.51
	(0.43)	(0.46)	(0.82)	(1.15)	(0.71)	(0.66)	(0.58)	(1.06)
PER_SORG	0.62	0.43	1.95	−0.55	0.98	0.60	1.34	−0.35
	(0.66)	(0.71)	(1.42)	(1.47)	(1.04)	(1.02)	(1.01)	(0.92)
PER_SOY	−0.16	−0.43	−0.03	0.40	−0.38	−0.76	0.02	0.27
	(0.31)	(0.46)	(0.44)	(0.69)	(0.53)	(0.70)	(0.40)	(0.48)
PER_W	−0.10	−0.23	−1.14	−0.47	−0.09	−0.30	−0.99*	−0.31
	(0.30)	(0.31)	(0.74)	(0.84)	(0.49)	(0.47)	(0.51)	(0.57)
NFISCALE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
HUNDAC	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
RISK2	−0.17	−0.04	−0.16	−0.37*	−0.20	−0.11	−0.13	−0.20*
	(0.17)	(0.14)	(0.31)	(0.23)	(0.19)	(0.18)	(0.16)	(0.11)
RISK3	−0.17*	−0.08	−0.25	−0.38**	−0.27	−0.13	−0.25*	−0.28**
	(0.09)	(0.09)	(0.17)	(0.19)	(0.16)	(0.14)	(0.13)	(0.16)
ENVIMP	0.14	0.40*	0.09	−0.21	0.17	0.44***	0.08	−0.16
	(0.17)	(0.22)	(0.35)	(0.32)	(0.17)	(0.12)	(0.20)	(0.30)
PROGRAM	−0.03	0.00	0.48*	0.08	−0.06	0.00	0.26**	0.05
	(0.09)	(0.12)	(0.28)	(0.29)	(0.16)	(0.18)	(0.10)	(0.17)
EAST	0.10	−0.19	−0.18	−0.46	0.19	−0.22	−0.15	−0.30
	(0.11)	(0.20)	(0.26)	(0.29)	(0.21)	(0.25)	(0.17)	(0.23)
WEST	0.07	−0.24	−0.40	−0.26	0.12	−0.28	−0.23**	−0.15
	(0.11)	(0.18)	(0.38)	(0.27)	(0.21)	(0.20)	(0.12)	(0.14)
NEIGHBOR	−0.10	−0.04	−0.17	−0.02	−0.21	−0.07	−0.27	−0.01
	(0.13)	(0.28)	(0.26)	(0.34)	(0.32)	(0.42)	(0.45)	(0.24)
FERTILITY	0.17*	0.17*	−0.01	0.06	0.25**	0.22*	0.02	0.05
	(0.08)	(0.09)	(0.17)	(0.21)	(0.12)	(0.12)	(0.14)	(0.13)
COSTS	—	0.10	0.21	—	—	0.15	0.45	—
		(0.10)	(0.26)			(0.15)	(0.44)	
WEEDS	—	—	0.03	—	—	—	0.06	—
			(0.14)				(0.10)	
EROSION	—	−0.07	—	—	—	−0.11	—	—
		(0.09)				(0.13)		
INSECTS	—	0.02	—	—	—	0.02	—	—
		(0.09)				(0.13)		

the estimated probability of adoption was 0.492, the highest across the four practices. These results suggest that while perceived-yield-risk benefits increase the probability of adoption, other CCR benefits also encourage adoption.

The only statistically significant coefficient in the yield-risk model (*CCRR*) was that on *COLLEGE*, which was positive, suggesting that college graduates are more likely to believe CCR reduces yield risk. It is possible that farmers with a college education are better equipped to incorporate CCR, or at least perceive themselves to be well equipped. Rahm and Huffman (1984) posit that the allocative skills necessary to assess and implement a conservation practice efficiently are learned rather than innate, and that farmers with higher levels of formal education will therefore be better equipped to face conservation-adoption decisions.

A belief that CCR improves soil fertility had a statistically significant and positive CME, regardless of yield-risk beliefs. Given a belief that CCR reduces yield risk, the marginal effect was again larger, by approximately 29% in this case. CMEs associated with *ENVIMP* (whether farmers believe their actions impact the local environment) were also positive and statistically significant for both groups. Again, the impact is larger when a farmer does not believe CCR reduces yield risk: 0.44 compared to 0.40. As with CNT, these results suggest that increasing awareness of soil benefits from CCR may have a positive adoption impact.

Cover Crops

Tetrachoric correlation in the cover crop (CC) model was estimated at 0.73, significant at the 1% level. The estimated probability of adoption was 0.774 for farmers who believe CC reduces yield risk and 0.217 for those who do not believe CC reduced yield risk. The gap between these conditional probabilities suggests that evidence of yield-risk reductions from CC may do more to promote adoption compared with the other practices.

In the CC risk-perception equation (*CCR*), we estimated a statistically significant and negative coefficient for *RISK3*, indicating that farmers who need adequate research before adoption are less likely to believe CC reduces yield risk. CC may place a larger management burden on farmers compared to the other practices due to the need for correct timing, CC variety decisions, etc. (Bergtold et al., 2019). A statistically significant negative coefficient was estimated for *PER_W*, indicating that farmers with a larger share of acres in wheat are less likely to view CC as yield-risk reducing. This may be caused by additional burdens placed on producers to conduct a timely and efficient termination of the CC prior to winter wheat planting. For spring-planted crops, this burden may be reduced by a CC choice that allows for a winter kill (Bergtold et al., 2019).

Statistically significant and positive CMEs were found for *PROGRAM* in both groups, suggesting that farmers who have experience with federal or state conservation programs are more likely to adopt CC. In this case, the impact was larger conditional on believing CC reduces yield risk: 0.48 compared to 0.26. If the majority of first CC experiences come through conservation practices, previous experience with the agency or agencies involved may lessen hesitations felt by others who have not worked with these programs.

For those who do not believe CC reduces yield risk, three additional CMEs were negative and statistically significant. The first was associated with *PER_W*, suggesting that farmers who devote a greater share of acres to wheat are less likely to incorporate CC into their cropping systems. Potentially, this arises from the fact that many farmers will use reduced tillage when switching to wheat, whereas cover crops are generally used in conjunction with no-till. If a farmer does not believe he will see yield risk benefits from CC, he may be less likely to make these management changes. The second significant factor was associated with *RISK3*. This indicates that moderately risk-averse farmers—who do not believe CC reduce yield risks—are less likely to adopt. Again, this suggests trialing as a good first step to show potential CC benefits and how they may work in different cropping systems. Last was the CME associated with *WEST*. This result is not surprising, given that western Kansas typically sees less rainfall and CC may reduce water availability for cash crops (Bergtold et al., 2019).

Variable-Rate Application

The tetrachoric-correlation coefficient for this model was not statistically significant, which is not altogether surprising. Many of the environmental and financial benefits of this practice come from avoiding over-application of inputs. As a result, it may have little impact on the perceived reductions yield risks. This is suggested in Table 2: Only 27% of all farmers believed VRA reduces yield-risks, but this does not suggest that the remaining 73% believe VRA increases yield risks. Rather, the predominant belief may be that there is no impact, good or bad, on yield risks. The probability of adoption when it is believed that VRA reduces yield risk was estimated at 0.386, the lowest across all four practices, which may be due to some of the barriers mentioned previously, such as large investment costs or the need for additional precision agriculture technologies. If it was not believed that VRA reduces yield risk, the estimated probability of adoption was 0.169, which was again the lowest across the four practices.

Another potential difficulty in linking yield-risk perceptions and adoption for VRA is that farmers may have differing views on what would constitute adoption. For example, it has been suggested that some farmers may use custom operations for the application of some nutrients but apply nitrogen themselves.[1] If custom applications of select nutrients are done using VRA technology, a farmer may or may not view this as adoption of the technology. The survey used in this study did not capture the level of detail needed to parse out different implementations of VRA, and this should be kept in mind when interpreting the results for this practice. VRA adoption and implementation could be more nuanced and complex than presented here. This issue may be exacerbated by the fact that the practice is relatively new; the (relative) lack of availability and consensus of research on its impacts likely influences yield-risk perceptions and adoption.

In the VRA risk-perception equation (*VRAR*), only two statistically significant factors were found: the share of acres planted to corn (*PER_CORN*) and *FERTILITY*. The coefficient on *PER_CORN* was positive, suggesting that a higher share of land under corn production increased the likelihood of a farmer perceiving VRA to be yield risk reducing. *FERTILITY* again had a positive impact on yield-risk perceptions: If a farmer believes that VRA improves soil fertility, he is more likely to believe VRA reduces yield risk.

Two CMEs were negative and significant across both groups—*RISK2* and *RISK3*—suggestsing that, regardless of yield-risk beliefs, farmers who only take risks after adequate research (*RISK3*) or describe themselves as "cautious" or relatively risk averse (*RISK2*) are less likely to adopt VRA. These results underscore the importance of the financial burden this practice may impose, which may exacerbate the perceived riskiness of VRA. Surprisingly, the magnitude of the impacts was larger for both *RISK2* and *RISK3* when it is believed VRA reduces yield risk. However, it may be that when this belief is not held, the probability of adoption is in a nonresponsive part of the distribution (i.e., in the tail). The results in Table 6 suggest this may be true. The CME of *PER_CORN* was positive and statistically significant given that a farmer believes VRA reduces yield risk.

Conclusions

This study examined farmers' adoption of four in-field conservation practices—continuous no-till, conservation crop rotations, cover crops, and variable-rate application of inputs (VRA)—with special attention given to each practice's perceived impact on yield risks. Using survey data from Kansas farmers, we estimated separate bivariate probit models for each practice to examine the factors impacting farmer adoption decisions. Variables included in the empirical models were

[1] Thank you and credit to a reviewer for the suggestions and insights on this.

selected to capture five key dimensions: farmer characteristics, farm characteristics, environment, attitudes and beliefs, and experience with conservation efforts. Estimated tetrachoric correlations were positive and statistically significant for the continuous no-till, conservation crop rotation, and cover-crop models, suggesting that farmers are more likely to be using a practice if they believe it will reduce yield risk. Estimated conditional probabilities provided similar conclusions: The probability of adoption, given a farmer believes a practice reduces yield risk, was 0.75 or higher for all but VRA. Conversely, estimated adoption probabilities given a farmer does not believe yield risk will be reduced were less than 0.50 for all practices. As farmers' yield-risk perceptions will likely change given experience with a practice, fostering and promoting trialing may be an effective policy approach, even if not every farmer experiences positive yield outcomes.

Conditional marginal effects (CMEs) associated with age, education, farm size, and net farm income had no statistically significant impact on practice adoption. Additionally, no evidence was found to indicate that neighboring conservation management decisions influence, or are at least associated with, adoption decisions. However, physical proximity—captured in this study—does not necessarily capture social network proximity, so social networks or peer effects may still be an important factor.

Statistically significant and negative CMEs were found for risk-aversion variables for continuous no-till (when believed to reduce yield risks), cover crops (when not believed to reduce yield risks), and VRA (regardless of yield-risk beliefs). Use of cover crops, regardless of yield-risk beliefs, was also positively impacted by previous conservation program experience. Membership in an environmental organization increased the likelihood of current use of continuous no-till for farmers who believe this practice reduces yield risk. Thus, increased knowledge about continuous no-till may increase the likelihood of adoption. However, as membership in specific organizations was not identified, it is unclear to what types of information farmers had access, and so this result may simply indicate that increased environmental concern is associated with continuous no-till use.

The situation/context of the farm operation was found to be important in some instances. The share of acres devoted to corn increased the likelihood of VRA adoption for farmers who believe VRA reduces yield risk, and the share devoted to wheat decreased the likelihood of cover-crop adoption for farmers who do not believe cover crops reduce yield risk. These results suggest that the same practice may not be viewed consistently across different contexts (e.g., different cropping decisions). Geographic location, meanwhile, had just one statistically significant CME: Farmers in western Kansas were less likely to be using cover crops if they did not believe it would reduce yield risks. Providing information—when available—on positive yield impacts from cover crops in more arid environments may help increase adoption in this region.

Other practice perceptions were seen to impact the decision to adopt certain practices. A perception of beneficial soil-fertility impacts increased the likelihood that a farmer is using continuous no-till or conservation crop rotations. Both impacts were found to be larger if a farmer does not believe that the practice reduces yield risks. The likelihood a farmer is using conservation crop rotations was also positively impacted by a belief that cropping decisions can improve/harm the local environment. Thus, disseminating information on soil or environmental benefits may promote adoption, even in the absence of a belief that a practice reduces yield risk.

In half the cases when a CME was statistically significant for the same practice regardless of yield-risk beliefs, the magnitude was larger given that a farmer does not believe the practice will reduce yield risk. When a practice is believed to reduce yield risks, the probability of adoption moves into the less-responsive tail of the probability function, as seen in the estimated conditional probabilities. Thus, if a practice can reduce yield risks (at least in some situations), providing evidence of this to increase awareness may be effective. Two of the cases where the magnitude was larger given a belief in yield-risk reductions were seen for VRA, which had a low probability of adoption, regardless of yield-risk beliefs. Thus, this may also be explainable by being in the tail of the distribution, though at the opposite end. The other instance was the impact of conservation program experience on cover-crop adoption. This may suggest that farmers feel technical guidance is needed to realize yield-risk benefits due to management burdens.

Ultimately, how an individual farmer forms and later changes his risk perceptions and how these risk perceptions subsequently effect conservation adoption is a complex question. However, this study shows that advancing the knowledge of this process can have important consequences for conservation-oriented outreach and extension efforts. With the help of richer datasets, future research should seek to expand upon this study to further the understanding of farmer risk perceptions.

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