Journal of Agricultural and Applied Economics (2023), **55**, 516–535
doi:10.1017/aae.2023.28

CAMBRIDGE
UNIVERSITY PRESS

RESEARCH ARTICLE

How Do Risk Preferences Affect Golf Course Superintendents' Adoption of Precision Irrigation Technologies? Implications from Prospect Theory

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Abstract

Precision irrigation is a potential viable strategy for water use reductions on golf courses by making variable or site-specific irrigation applications. A group of US golf course superintendents were surveyed to examine whether and how superintendents' risk preferences (attitudes) affect the adoption decisions of precision irrigation technologies on their golf courses. Under the prospect theory (PT) framework, a lottery experiment was used to elicit the measures of three risk attitudes, that is, risk curvature, probability distortion, and loss aversion. Using these three measures and other questions in the survey, we found that risk curvature has a significant positive effect on the precision irrigation technologies adoption on golf courses, while probability distortion affects the adoption negatively. Compared to the golf course in low precipitation areas, superintendents' risk attitudes are more likely to affect the precision irrigation technologies adoption in the golf course in high precipitation areas. Additionally, risk curvature dominates the adoption decisions for newer technologies, while probability distortion dominates the older technologies adoption decisions. Our research enriches the literature on the decision-making behaviors of managers by considering how probability distortion, a factor typically ignored by other studies, affects technology adoption decisions and adds to the literature on examining the technology adoption behaviors under PT by focusing on golf course superintendents, a group that has not been studied.

Keywords: Golf course superintendents; precision irrigation technology; prospect theory; water saving

JEL: Q13; Q18

Introduction

Water is essential for life and also plays a significant role in the socioeconomic and environmental development of the world (Food and Agriculture Organization 2007; Zhang et al., 2020). However, due to climate change and population growth (Heidari et al., 2021; Janssen, Radić, and Ameli, 2021), water scarcity in the United States (US) is increasingly serious and has aroused concerns in recent years (Heggie, 2020; Miller, 2022; Wilkerson, 2019). In many cities (e.g., Jackson, Mississippi; Flint, Michigan; and parts of New York City), residents are experiencing poor clean drinking water access (Alfonseca, 2022; Yang and Mufson, 2023). The findings of Meng (2022) imply that such urban water crisis has significantly negative impacts on residents' mental and physical health. Given the increasing water scarcity, the substantial water consumption of the golf industry has drawn much attention because there is an estimated 1.2 million acres of irrigated turfgrass on golf courses in the US (Bauer, 2022; Gammon, 2015; Lyman, 2012). A typical 150-acre golf course uses about 200 million gallons of water every year, which is enough to supply 1800 residences with 300 gallons per day of water (Fluence News Team, 2021). However, limited by the high cost of installing a piping system to recycled water delivery, only about 13% of golf courses in US use recycled water for irrigation (United States Golf Association, 2014). Many golf courses are located in urban areas, and it means that they compete with urban residents for freshwater sources (Carlson, Gaussoin, and Puntel, 2022). With the increasing public concern about drinking water shortages, the golf course industry is under pressure to reduce water use (Straw et al., 2022; Wheeler and Nauright, 2006).

Precision irrigation is a potential viable strategy for water use reductions on golf courses by making variable or site-specific irrigation applications only where, when, and in the amount needed, so it has been regarded as an effective method in other sectors of agriculture (Evans and Sadler, 2008; Kincaid and Buchleiter, 2007; Schoengold and Sunding, 2014). For example, using a simulated analysis of pastures, maize grain, and potatoes planting in New Zealand, Hedley, Yule, and Bradbury (2010) found that variable rate irrigation can reduce water usage by 8%–21% compared to uniform rate irrigation. Similarly, through several case studies, Sadler, Evans, and Camp (2005) concluded that, compared to traditional irrigation, precision irrigation can on average achieve about 8%–20% annual water usage reduction. Precision irrigation can also prevent soil nutrients loss, conserve soil, and decrease input cost in agricultural production (Evans et al., 1996; Sadler, Evans, and Camp, 2005; Smith et al., 2010). Given these advantages, popularizing precision irrigation may be an effective way to accelerate water saving and improve agricultural production efficiency.

Besides, several studies show the spatial variabilities of turfgrass growth conditions (such as soil moisture and turfgrass quality) on golf course and other turfgrass sports fields (e.g., Krum et al., 2011; Straw et al., 2017, 2022). Using data from two large turfgrass sports fields in US, Kerry et al. (2023) found that the spatial soil moisture variability patterns also vary temporally. Scott, Rutty, and Peister (2018) examined the effects of golf course characteristics on water use variability using data from 129 golf courses in Canada and found that a potential 35% water use reduction can be achieved by increasing irrigation efficiency. Due to the spatial and temporal variabilities, applying the same amount of water on the whole golf course would either result in grass death due to overwatering or underwatering and water wasting. This implies that precision irrigation is a suitable method for improving irrigation water use efficiency on golf courses. Furthermore, increasing irrigation efficiency by precision irrigation can help golf courses reduce cost and environmental impact while keeping the function and aesthetics of turfgrass (Carlson, Gaussoin, and Puntel, 2022; Straw et al., 2018). In other words, precision irrigation can reduce operational cost and simultaneously maintain the turfgrass properties that golfers care about, which can result in higher profits for golf courses. At the same time, the reduced environmental impact can bring positive externalities. However, although superintendents have general knowledge of the water need variabilities on their golf courses, the knowledge is not precise enough for precision irrigation practices, so relevant technologies such as mobile and handheld devices with global navigation satellite system (GNSS) are needed (Straw, Wardrop, and Horgan, 2019). Accordingly, precision irrigation can be an attractive water saving method for golf course superintendents, and relevant technologies are necessary for such practices.

Precision irrigation technologies are relatively new,[1] so are not fully known or understood by golf course superintendents before adoption (Carlson, Gaussoin, and Puntel, 2022; Chavas and Nauges, 2020). Such unfamiliarity will bring perceived risks and uncertainties to technology adopters (Chavas and Nauges, 2020). Superintendents are uncertain about the consequences of

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[1] In this paper, the precision irrigation technologies refer to individual head irrigation control systems, handheld soil moisture sensors equipped with global navigation satellite system (GNSS), handheld soil moisture sensors without GNSS, in-ground soil moisture sensors, unmanned aerial vehicles (UAVs) or drones, weather station for evapotranspiration, and other newly applied precision irrigation technologies.

their adoption decisions, thus increasing their perceived risks. For example, they may be attracted by the potential water and cost savings, but simultaneously are concerned with the success rate of the new technology and if the cost saving can be high enough to cover the high initial investment. Besides, the goal of golf course management is not production (i.e., yield), rather it is aesthetic and playability characteristics. These are relatively subjective and may be influenced by some environmental variables, so it can be difficult to clearly quantify benefits of adopting/investing in precision irrigation and technologies for its implementation. This brings further uncertainties to the adoption decisions.

Many studies focus on how key managers' risk preferences affect managerial decisions and operation. These studies applied different kinds of risk preference measures, including management-related measures (e.g., Cen and Doukas, 2017; Niu and Zuo, 2022; Rashad Abdel-Khalik, 2014), personal-life-related measures (e.g., Lin et al., 2022) and general measures (e.g., Caliendo et al., 2022; Kim and Nguyen, 2021), and found that key managers' risk preferences have significant effects on different aspects of operation. Given that superintendent is a multifaceted key manager of golf course (New Jersey Agricultural Experiment Station n.d.), it is reasonable to believe that superintendent's risk attitudes (preferences) will play a significant role in precision irrigation technology adoption decisions under risks and uncertainties. Hence, examining how golf course superintendents' risk attitudes affect their adoption decisions of precision irrigation technologies provides valuable implications about how to accelerate the adoption process.

Exploration of stakeholder decision-making under risk have been widely conducted by economists, many of whom employed prospect theory (PT) introduced by Kahneman and Tversky (1979). Although the expected utility theory (EU) is regarded as the mainstream model for risk preference elicitations (e.g., Dohmen et al., 2010; Holt and Laury, 2002; Katic and Ellis, 2018), many studies find evidence that the EU fails, in many cases, to explain decision-making under risk (e.g., Allais, 1953; Kahneman and Tversky, 1979). As an alternative theory of EU, PT is shown by empirical studies to perform better in explaining risky decision-making behaviors (e.g., Dhami and al-Nowaihi, 2007; Zhao and Yue, 2020a).

In the past decades, researchers have used PT to explore people's behavior that cannot be explained by traditional expected utility theory, some of whom focused using PT to investigate product/technology adoption behavior. For example, Liu (2013) conducted experiments to test how individual-level risk attitudes affect Chinese farmers' adoption decisions of genetically modified Bt cotton and found farmers who are more risk-averse or more loss-averse tend to adopt Bt cotton later, while farmers overweighting small probabilities adopt Bt cotton earlier. Through a series of experiments in rural India, Ward and Singh (2015) demonstrated how risk and ambiguity preferences impact farmers' decisions to adopt new risk-reducing seeds. Different from Liu's findings, they found that both risk aversion and loss aversion can promote the adoption of new seeds. Using similar methods, Hou et al. (2020) examined the effects of risk attitudes on Chinese farmers' pesticide use and found that, compared to risk aversion, loss aversion is more likely to affect pesticide use intensity.

As these examples show, most studies explaining suppliers' technology adoption under the PT framework focused on the adoption decisions of agricultural producers who own the farms. Fewer studies focused on the technology adoption behavior of another group of decision-makers: the executive managers of for-profit organizations.

Although there exist some studies that use the PT frame to explain the decision-making behaviors of managers, most such studies, as pointed out by Holmes et al. (2011), ignored the effect of biased probability (probability distortion) on managers' executive behaviors. For example, without considering probability distortion and using survey and archival data from a sample of IPO firms, Larraza-Kintana et al. (2007) examined how different kinds of compensation risk affect CEOs' executive behaviors. They found that CEOs are loss-averse and tend to take greater risks when facing a loss of personal wealth, which is consistent with the basic assumptions of PT. Lee (2022) combined several datasets to check the effect of a CEO's prior performance on her risk taking in management. The results showed that CEOs tend to choose less risky projects after making gains, supporting the risk-averse gain segment of the PT value function. But they did not include probability distortion in their model.

In this study, PT was employed to study golf course superintendents' adoption behavior of the technologies that can be used for precision irrigation. A survey was conducted with US golf course superintendents that included a lottery experiment to elicit three risk measures in PT: risk curvature, probability distortion, and loss aversion. Using these three measures and other questions in the survey, we found four primary results. First, superintendent's education level has relatively significant effects on risk attitudes. Second, risk curvature has a significant positive effect on golf course precision irrigation technology adoption, while probability distortion affects the adoption negatively. Third, superintendents' risk attitudes are more likely to affect precision irrigation technology adoption in golf courses located in high precipitation areas compared to those in low precipitation areas. Fourth, risk curvature dominates the adoption decisions of new technologies, while probability distortion dominates relatively old technology adoption decisions.

To our knowledge, our research is the first application of PT literature to explain the technology adoption behavior of a unique type of for-profit organization manager, golf course superintendents. They are facing risks similar to agricultural production risks (e.g., climate changes and crop growth condition variability), while their objective is maintaining turfgrasses to attract golfers rather than agricultural production. This may make them think and behave differently from farmers and other kinds of managers when adopting technologies. Besides, our analyses include superintendents' probability perception distortion. Although it is often included in the analyses of farmers' technology adoption, it is rarely considered when the decision-maker is an executive manager.

Theoretical framework

Based on the PT, we measure the superintendents' risk preferences using the lottery experiment. Equations (1)–(3) give the specific form of the PT:

$$v(x) = \begin{cases} x^{\alpha}, & if\ x \geq 0 \\ -\lambda(-x)^{\alpha}, & if\ x < 0 \end{cases} \tag{1}$$

$$w(p) = \frac{1}{\exp[log(1/p)^{\gamma}]} \tag{2}$$

$$U(x_1, p; x_2) = \begin{cases} w(p)v(x_1) + [1 - w(p)]v(x_2), & if\ x_1 \geq x_2 \geq 0\ or \\ & x_1 \leq x_2 \leq 0 \\ w(p)v(x_1) + w(1-p)v(x_2), & if\ x_1 x_2 < 0 \end{cases} \tag{3}$$

Equation (1) is the value function where α represents the curvature of the function, $\lambda(>0)$ measures the extent of loss aversion, and x is the payoff. A positive x represents a gain and a negative one means a loss. A smaller α makes the value function more concave in gains ($x \geq 0$) and more convex in losses ($x < 0$). It means a manager with a smaller α has higher levels of risk aversion for gain and risk-seeking for loss. λ captures the loss aversion level. $\lambda > 1$ implies loss aversion.

Equation (2) is the probability weighting function where $\gamma(>0)$ captures the probability distortion and p is the objective probability. When $\gamma \in (0,1)$, the manager overweights small probabilities and underweights large probabilities; when $\gamma = 1$, the manager weights probabilities objectively; when $\gamma > 1$, the manager overweights large probabilities and underweights small probabilities. Overall, a higher γ indicates a larger weight on large probabilities.

In Equation (3), $(x_1, p; x_2)$ represents the lottery with the payoff x_1 of the probability p and the payoff x_2 of the probability $1 - p$. Given the value function and probability weight function (Equations (1) and (2)), the PT utility $U(x_1, p; x_2)$ of the lottery $(x_1, p; x_2)$ can be defined by Equation (3).

Under the PT framework, a golf course superintendent's risk preference is measured by the three above parameters, α, γ and λ. Following Tanaka, Camerer, and Nguyen (2010), we got the estimates of α, γ, and λ, and Liu (2013) provides an example with the specified values for the specific estimation process.

Data and methods

Experiment design and data

An online survey was designed for golf course superintendents in the US. We obtained Institutional Review Board approval for our survey. We programmed the survey into Qualtrics, and the survey link was posted on the websites of United States Golf Association and state golf course associations. Besides, we publicized the survey at industry conferences. In total, 202 golf course superintendents responded to the survey and 97 superintendents finished all questions. Since our analyses involve information throughout the questionnaire, we only kept the observations with all questions finished. To capture the superintendents' risk preferences, a lottery experiment from Tanaka, Camerer, and Nguyen (2010) was used as the core part of our survey. This lottery experiment is designed based on the PT by Kahneman and Tversky (1979) and is widely used by many recent empirical studies (e.g., Liu, 2013; Magnan et al., 2020; Zhao and Yue, 2020b).

Our experiment included three lottery series, and each lottery series had several rows (see Table 1). There were two alternative binary lotteries in each row, Option A and Option B. Responders had to choose between these two options for every row. The respondent was then asked to report the row in which they would consider switching from Option A to Option B for each series. This procedure guarantees monotonic switching; for example, if a subject prefers Option B to Option A in row X, they cannot prefer Option A to Option B in row Y for any Y > X. We allow subjects to choose "never switch" if they always prefer Option A to Option B.

In lottery series 1 and 2, Option A was a stable (fixed) lottery, while Option B was an incremental binary lottery with one payoff increasing with row number (Table 1). All payoffs were gains (positive). In lottery series 1, the expected payoff of Option A is initially larger than that of Option B. With the increase in row number, the expected payoff of Option B keeps increasing and eventually gets larger than Option A. Similarly, in lottery series 2, the expected payoff of Option B is only slightly larger than that of Option A at first, then gradually goes up, and becomes higher than the expected payoff of Option A. Lottery series 3 consisted of binary lotteries with one gain payoff and one loss payoff. The expected payoffs of Option A and B decrease and increase with row number, respectively. As a result, the expected payoff of Option A is initially larger than that of Option B, but the expected payoff of Option B surpasses Option A starting in row 2 (Table 1). The risk preference parameters under PT can be calculated using the responses to lottery series 1–3 (see Liu, 2013; Tanaka, Camerer, and Nguyen, 2010).

Questions about golf course operation, precision irrigation technology adoption situations, and demographics were also included in the survey. For golf course operation, superintendents were asked to report the zip code, sizes of areas on the golf course managed (e.g., greens, tees, fairways, and roughs), management budget, and type of turfgrasses on their golf course. Additionally, they were also asked how many shares they own in their golf courses and whether they get performance pay (i.e., a salary or wages paid based on how well a superintendent performs). For the irrigation technology adoption situations, they were asked whether specific irrigation technologies were adopted at their golf course. Demographic questions included gender, age, race, education, years of golf course management experience, the membership of a local or national golf course superintendent association, whether they are certified golf course superintendents and their annual income from golf course operation. Table 2 shows the descriptive statistics of the golf course operation and demographics variables included in the study.

Table 1. Lottery experiment used to elicit golf course superintendents' risk preference measures

Lottery series 1 (all value indicating gains)

	Option A		Option B	
Row number	30% probability	70% probability	10% probability	90% probability
1	$400	$100	$680	$50
2	$400	$100	$750	$50
3	$400	$100	$830	$50
4	$400	$100	$930	$50
5	$400	$100	$1,060	$50
6	$400	$100	$1,250	$50
7	$400	$100	$1,500	$50
8	$400	$100	$1,850	$50
9	$400	$100	$2,200	$50
10	$400	$100	$3,000	$50
11	$400	$100	$4,000	$50
12	$400	$100	$6,000	$50

Lottery series 2 (all value indicating gains)

	Option A		Option B	
Row number	90% probability	10% probability	70% probability	30% probability
1	$400	$300	$540	$50
2	$400	$300	$560	$50
3	$400	$300	$580	$50
4	$400	$300	$600	$50
5	$400	$300	$620	$50
6	$400	$300	$650	$50
7	$400	$300	$680	$50
8	$400	$300	$720	$50
9	$400	$300	$770	$50
10	$400	$300	$830	$50
11	$400	$300	$900	$50
12	$400	$300	$1,000	$50
13	$400	$300	$1,100	$50
14	$400	$300	$1,300	$50

Lottery series 3 (note there is probability of losses in this series)

	Option A		Option B	
Row number	50% probability	50% probability	50% probability	50% probability
1	$250	−$40	$300	−$210
2	$40	−$40	$300	−$210
3	$10	−$40	$300	−$210

(*Continued*)

Table 1. (*Continued*)

Lottery series 3 (note there is probability of losses in this series)				
	Option A		Option B	
Row number	50% probability	50% probability	50% probability	50% probability
4	\$10	−\$40	\$300	−\$160
5	\$10	−\$80	\$300	−\$160
6	\$10	−\$80	\$300	−\$140
7	\$10	−\$80	\$300	−\$110

Statistical analyses

Considering many empirical studies have found evidence that demographics can affect risk attitudes (e.g., Tanaka, Camerer, and Nguyen, 2010; Zhao and Yue, 2020b), we investigated how the golf course superintendents' demographics impact their risk attitudes, risk curvature, probability distortion, and loss aversion. Ordinary least squares (OLS) regressions of these three risk attitude parameters were conducted on the superintendent's demographics. Then we examined the effects of risk preferences on the golf course superintendents' adoption decisions of precision irrigation technologies using the Probit Model. The dependent variable of the Probit Model is the dummy variable measuring if a superintendent has adopted a technology, with 1 meaning the technology is adopted and 0 otherwise. For this variable, we considered the adoption of seven kinds of technologies, including individual head irrigation control systems, handheld soil moisture sensors equipped with GNSS, handheld soil moisture sensors without GNSS, in-ground soil moisture sensors, unmanned aerial vehicles (UAVs) or drones, weather station for evapotranspiration (ET), and other technologies. The third column in Table 3 reports the shares of superintendents who have adopted each technology.

The independent variables are the three risk measures, α, γ, and λ, plus three groups of control variables. The first group consists of two variables measuring the kind of superintendent compensation, that is, the indicator of performance pay and the shares in the golf course owned by the superintendent. Many empirical findings showed that a manager's compensation may influence their executive behaviors (e.g., Harris et al., 2014; Larraza-Kintana et al., 2007). The second group captures the characteristics of the golf course operation, including the management budget, the total area of the golf course, the indicator of whether they only use the turfgrasses with low ET rates (the turfgrasses with ET rates smaller than 7 mm d^{-1}, see Huang, 2008), and the estimated average yearly precipitation. The third group includes six indicators of specific precision irrigation technologies (see Table 3; we included the first six indicators but dropped the other indicator and used it as the base for comparison).

The Probit Model was applied to three analyses. First, we applied it to the whole sample. Second, considering that the amount of precipitation received at a particular golf course will affect irrigation practices and thereby influence the way adoption decisions of precision irrigation technologies are made, we divided the samples into two groups: high precipitation (the average yearly precipitation is higher than or equal to the median level, 45.71 inches) and low precipitation (the average yearly precipitation is lower than the median level), and applied the Probit Model to these two groups separately for a comparative analysis. Third, the Probit Model was used to compare the adoptions of newer and older technologies.

As mentioned in the introduction, to some extent, the perceived risk of adopting a technology is partially because the technology is new, and people do not know it well. If so, the adoption decisions of a newer technology and an older technology may be affected by superintendents' risk attitudes in different ways. For example, compared to an older technology, when making an

Table 2. Descriptive statistics of sampled golf course superintendents (sample size $N = 97$)

Variables	Mean (S.D.)	Freq.	Percent (%)
Age (the age of the superintendent)	47.21 (10.89)		
22 = 18 to 25 years old		2	2.06
31 = 26 to 35 years old		13	13.40
41 = 36 to 45 years old		30	30.93
51 = 46 to 55 years old		29	29.90
61 = 56 to 65 years old		21	21.65
71 = Older than 65 years old		2	2.06
Education (the education level of the superintendent)	2.94 (0.54)		
1 = high school diploma or equivalent		3	3.09
2 = some college, but no degree		8	8.25
3 = college degree		78	80.41
4 = graduate degree		8	8.25
Experience (the experience working as a superintendent)	17.08 (10.97)		
2.5 = Less than or equal to 5 years		19	19.59
8 = 6 to 10 years		14	14.43
13 = 11 to 15 years		16	16.49
18 = 16 to 20 years		8	8.25
23 = 21 to 25 years		13	13.40
28 = 26 to 30 years		9	9.28
33 = More than 30 years		18	18.56
Membership	0.93 (0.26)		
1 = the superintendent is a member of a local or national golf course superintendents association		90	92.78
0 = otherwise		7	7.22
Certified	0.21 (0.41)		
1 = the superintendent is a certified golf course superintendent		20	20.62
0 = otherwise		77	79.38
Income (the superintendent's yearly income from golf course operation)	1.67 (2.09)		
0.125 = less than \$25,000		2	2.06
0.375 = \$25,000–\$49,999		8	8.25
0.625 = \$50,000–\$74,999		24	24.74
0.875 = \$75,000–\$99,999		20	20.62
1.75 = \$100,000–\$249,999		32	32.99
3.75 = \$250,000–\$499,999		6	6.19
7.50 = \$500,000–\$999,999		3	3.09
12.50 = more than \$1,000,000		2	2.06

(*Continued*)

Table 2. (*Continued*)

Variables	Mean (S.D.)	Freq.	Percent (%)
Performance pay	0.40 (0.49)		
1 = if the superintendent gets performance pay		39	40.21
0 = otherwise		58	59.79
Share (the shares of golf course owned by the superintendent in %)	0.86 (6.07)		
Management budget (the management budget of the golf course)	15.88 (16.19)		
1.25 = less than \$250,000		11	11.34
3.75 = \$250,000–\$499,999		12	12.37
6.25 = \$500,000–\$749,999		11	11.34
8.75 = \$750,000–\$999,999		16	16.49
17.50 = \$1,000,000–\$2,499,999		32	32.99
37.50 = \$2,500,000–\$4,999,999		11	11.34
75.00 = \$5,000,000–\$9,999,999		4	4.12
125.00 = more than \$10,000,000		0	0.00
Total area (the total acreages of the golf course)	115.59 (109.83)		
OnlylowET	0.30 (0.46)		
1 = if the golf course only uses the turfgrasses with low evapotranspiration (ET) rates		29	29.90
0 = otherwise		68	70.10
Average precipitation (the average yearly precipitation)	42.02 (15.73)		

Note: The average annual precipitation is calculated by the yearly precipitation data from National Centers for Environmental Information. We used the zip codes to map the precipitation data to the golf courses. If the precipitation data of the zip code to which a golf course belongs is not available, the precipitation data of the adjacent zip code are used. The data we used are from 2000 to 2021, but for most zip codes, the precipitation recordings may be missing for several years. We only included the years in which the recordings are available to calculate the average precipitation.

Table 3. Technology indicators and technology adoption shares

The indicator of technology	Definition	Percentage of superintendents who have adopted the technology (in %)
IrriControl	= 1, the technology is individual head irrigation control systems; = 0, otherwise.	68.04
HandheldSensorw/GNSS	= 1, the technology is handheld soil moisture sensors equipped with GNSS; = 0, otherwise.	29.90
HandheldSenserw/oGNSS	= 1, the technology is handheld soil moisture sensors without GNSS; = 0, otherwise.	55.67
IngroundSensor	= 1, the technology is in-ground soil moisture sensors; = 0, otherwise.	20.62
UAV	= 1, the technology is unmanned aerial vehicles (UAVs) or drones; = 0, otherwise.	8.25
WeatherStation	= 1, the technology is weather station for evapotranspiration; = 0, otherwise.	41.24
Others	= 1, the technology is other technology not mentioned above; = 0, otherwise.	4.12

Table 4. Estimation results of the impact of demographic variables on risk preference measures (N = 97)

Variables	(1) α (Risk Curvature)	(2) γ (Probability Distortion)	(3) λ (Loss Aversion)
Age	0.007	−0.005	−0.091*
	(0.007)	(0.005)	(0.055)
Education	0.224**	−0.118*	0.272
	(0.095)	(0.061)	(0.718)
Experience	−0.009	0.008	0.129**
	(0.007)	(0.005)	(0.055)
Membership	−0.047	−0.221*	−1.744
	(0.206)	(0.131)	(1.547)
Certified	0.086	−0.119	−0.271
	(0.135)	(0.087)	(1.018)
Income	0.020	−0.018	−0.077
	(0.024)	(0.016)	(0.183)
Constant	0.007	1.363***	8.451**
	(0.449)	(0.287)	(3.380)

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

adoption decision of a newer technology, a superintendent may perceive it riskier, because the superintendent does not know it very well. Under this situation, the risk curvature may have a more significant impact on the adoption decision. To examine the existence of such differences, according to the inputs of industry experts, we divided our sample into two groups, newer technologies (handheld soil moisture sensors equipped with GNSS, in-ground soil moisture sensors, and UAVs or drones) and older technologies (individual head irrigation control systems, handheld soil moisture sensors without GNSS, weather station for ET, and other technologies), based on the approximate times when these technologies were introduced into the golf course industry, and then used Probit Model to conduct a comparative analysis for these two groups.

Results

Risk curvature, probability distortion, and loss aversion

The means of estimated α, γ, and λ are 0.824, 0.651, and 5.349, respectively, which means that, on average, golf course superintendents are risk-averse, overweight small probabilities, and are loss-averse. Heutel (2019) estimated these three risk attitudes for a representative sample of the adult US population with 2045 individuals and got the mean value of α, γ, and λ equaling 0.809, 0.736, and 3.508, respectively. Our estimates of risk curvature and probability distortion are close to those of the US population, while the estimated loss aversion is larger than that of the US population. In other words, on average, golf course superintendents in our sample are more loss-averse than an average US adult.

Table 4 shows the results of the OLS regressions. Column (1) of Table 4 shows that no demographic variable other than education level had a significant effect on risk curvature at the 10% significant level. The effect of the education level is positive and significant, implying that a superintendent with higher education level is less risk-averse. As Column (2) shows, the coefficient of the education level is significantly negative; this indicates that a higher education level leads superintendents to overweight small probability more, which is somewhat counterintuitive. A potential explanation for this is that superintendents with a higher education level may have more confidence in their judgment, which may exacerbate their existing biases. The results in Column (3) show that the experience level has a positive impact on loss aversion, which means that more experience makes superintendents more loss-averse. Besides, the coefficient of age is negative and significant. That implies older superintendents tend to be less loss-averse.

We also tried to replace the Age variable with three dummies of generations that superintendents belong to, including Millennials, Generation X, and Baby Boomers (i.e., we treated Generation Z as the control group). Appendix 1 shows the results. Our main findings regarding education level and experience as a superintendent are still holding. The only additional finding is that, compared to Generation Z, Baby Boomers are significantly more risk-seeking.

The effect of risk preferences on technology adoption decisions

To check the effects of risk preferences (attitudes) on technology adoption decisions, the Probit Model was applied to the whole sample first (Table 5). Three findings were of interest. First, the estimated coefficient of risk curvature (α) was significantly positive, which means that if golf course superintendents are more risk-seeking (with higher α), they will be more likely to adopt a precision irrigation technology. More risk-seeking means that an individual tends to take risks when making a decision, implying that they will be inclined to adopt a new technology even if there are perceived risks. This finding has some implications for precision irrigation technology adoption promotion. Given the belief that superintendents are overall risk-averse, actions that can help reduce the perceived risks of the technologies (e.g., having educational activities to make superintendents understand the technologies better) will help promote the adoption. Second, the estimated effect of probability distortion (γ) was also significant but negative, implying that a superintendent who overweights small probabilities (with smaller γ) is more likely to adopt a technology. For example, such a superintendent may overweight the small probability that an extreme drought will occur. Under extreme drought, irrigation water usage may sharply increase, which will greatly raise the operational costs of a golf course. In this circumstance, water-saving irrigation technology would be helpful for the superintendent to reduce costs and withstand the impact of drought. As a result, if a superintendent overweights the probability of such drought, he may be more willing to adopt a precision irrigation technology. This result indicates that, in the practical technology adoption promotion, providing superintendents with the information about extreme drought may enhance the adoption by making them unconsciously overweight the probability of drought happening.

As Table 5 shows, the coefficients of the performance pay indicator and the management budget level are positive and significant. Superintendent's performance pay is associated with higher probability of adopting the technology, which may be attributed to a superintendent who is eager to perform better (e.g., saving more water by adopting the technology) under the performance pay. Higher management budget is associated with higher adoption probability, which can be intuitively explained by typically high technology costs. In addition, the coefficients of most technology indicators are significant, implying that the properties of a technology can significantly affect the adoption decision.

Adoption decision by superintendents in high precipitation areas versus low precipitation areas

To figure out the differences between the adoption decisions by superintendents in high precipitation areas and low precipitation areas, we applied the Probit model to these two groups separately for comparative analysis; the results are shown in Table 6. Results for the high

Table 5. The impact of risk preference measures on precision irrigation technology adoption decision

	Estimated coefficients
Variables	
α (Risk Curvature)	0.270**
	(0.120)
γ (Probability Distortion)	−0.551***
	(0.191)
λ (Loss Aversion)	−0.016
	(0.016)
Performance Pay	0.276**
	(0.116)
Share	0.008
	(0.009)
Management Budget	0.017***
	(0.004)
Total Area	−0.000
	(0.001)
OnlylowET	−0.179
	(0.137)
Average Precipitation	−0.002
	(0.004)
IrriControl	2.327***
	(0.272)
HandheldSensorw/GNSS	1.263***
	(0.271)
HandheldSenserw/oGNSS	1.976***
	(0.269)
IngroundSensor	0.932***
	(0.278)
UAV	0.336
	(0.302)
WeatherStation	1.579***
	(0.269)
Constant	−1.776***
	(0.357)

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

Table 6. The impact of risk attitudes on the adoption of technologies by superintendents in high precipitation areas versus low precipitation areas

Variables	(1) High precipitation area (48% of sample)	(2) Low precipitation area (52% of sample)
α (Risk Curvature)	0.043	0.530***
	(0.199)	(0.179)
γ (Probability Distortion)	−0.855***	−0.460
	(0.291)	(0.286)
λ (Loss Aversion)	−0.072***	0.025
	(0.025)	(0.024)
Performance Pay	0.168	0.556***
	(0.171)	(0.192)
Share	0.011	0.009
	(0.011)	(0.019)
Management Budget	0.026***	0.013**
	(0.006)	(0.005)
Total Area	−0.003*	−0.000
	(0.002)	(0.001)
OnlylowET	−0.415**	−0.026
	(0.190)	(0.222)
Average Precipitation	−0.004	0.002
	(0.012)	(0.008)
IrriControl	2.055***	2.895***
	(0.359)	(0.491)
HandheldSensorw/GNSS	1.126***	1.629***
	(0.352)	(0.487)
HandheldSenserw/oGNSS	1.729***	2.484***
	(0.353)	(0.485)
IngroundSensor	0.650*	1.396***
	(0.368)	(0.493)
UAV	0.250	0.552
	(0.392)	(0.538)
WeatherStation	1.223***	2.152***
	(0.355)	(0.484)
Constant	−0.566	−2.872***
	(0.902)	(0.606)

Standard errors are in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

precipitation group are shown in Column (1), and the low precipitation group's results in Column (2). For the high precipitation group, probability distortion and loss aversion were statistically significant, while only risk curvature was significant for the low precipitation group. This difference may imply that, overall, the adoption decisions of superintendents in the high precipitation area are more dependent on the superintendents' risk attitudes. One potential explanation for this is that the demand for the precision irrigation technologies is more elastic for the high precipitation group. Because of the high precipitation level, there is more available water in these areas and these golf courses may not need to irrigate as much, so they do not have a strong motivation to adopt the technologies. As a result, superintendent's risk attitudes drive the adoption decisions in these areas. However, for low precipitation areas, golf courses need a large amount of water for irrigation, so the cost saving from the precision irrigation technologies can be considerable. Hence, no matter what the superintendents' risk attitudes are, these technologies are always attractive. In other words, from the perspective of cost and water saving, the demand for the technologies for superintendents in low precipitation areas is relatively inelastic.[2]

The effects of probability distortion and loss aversion on adoption decisions are significantly negative for the high precipitation group, while the effect of risk curvature is positive and significant for the low precipitation group (Table 6). Given this, policymakers can design different strategies for high and low precipitation areas in the practical technology adoption promotion. For high precipitation areas, information about extreme drought and the serious loss caused by it may promote the adoption, while, for low precipitation areas, the key point of promotion strategy is reducing perceived risks (e.g., spreading relevant knowledge to make superintendents more familiar with the technology).

In addition to the findings regarding risk attitudes, there are other interesting details. First, by comparing these two columns, the coefficient of performance pay is only significant for the low precipitation group. It can be attributed to the above-mentioned considerable saved costs. The precision irrigation technologies can help superintendents in the low precipitation group save a large amount of water cost, so the performance pay may encourage them to adopt the technologies. However, for superintendents in the high precipitation group, the saved water cost may be limited, so they may not be as motivated by the performance pay. Second, the coefficient for the indicator of only using low ET-rate turfgrasses is negative for both groups, but only significant for the high precipitation group. For the high precipitation group, using low ET-rate turfgrasses, which does not need as much water, lowers water consumption, so the superintendents have less incentive to adopt the technology. Hence, the probability that they adopt a precision irrigation technology become significantly smaller. Nevertheless, for the low precipitation group, although the irrigation water consumption can be reduced by the low ET-rate turfgrasses, water usage may still be high because of the low precipitation level. As a result, saving water is still a strong motivation to adopt the technologies, so the negative effect of only using low ET-rate turfgrasses is not significant.

The adoption decision of newer technologies versus older technologies

Table 7 shows the results of the Probit Model to compare adoption decision of new versus older technologies. Column (1) shows results for the newer technologies group, while results for the older technologies group are in Column (2). Although the coefficient of risk curvature is positive for both groups, it is significant only for the newer technologies group. This implies that risk

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[2] We have tried to divide the low precipitation group into two new groups by greater or less than 20 inches of precipitation. However, the superintendents in the group receiving<20 inches of precipitation (arid or semi-arid region) are very homogeneous: 90% of superintendents in this group have adopted some precision irrigation technology. As a result, the regression gives all insignificant results. The homogenous adoption behaviors of these superintendents indicate precipitation as a key driving force for the adoption of irrigation technologies.

Table 7. The impact of risk preference measures on the adoption of newer technologies versus older technologies

Variables	(1) Newer technologies (43% of sample)	(2) Older technologies (57% of sample)
α (Risk Curvature)	0.379**	0.199
	(0.190)	(0.156)
γ (Probability Distortion)	−0.367	−0.722***
	(0.310)	(0.250)
λ (Loss Aversion)	−0.002	−0.027
	(0.025)	(0.021)
Performance Pay	0.574***	0.059
	(0.183)	(0.153)
Share	0.002	0.014
	(0.015)	(0.012)
Management Budget	0.011*	0.024***
	(0.006)	(0.005)
Total Area	0.000	−0.001*
	(0.001)	(0.001)
OnlylowET	−0.089	−0.229
	(0.217)	(0.179)
Average Precipitation	0.000	−0.004
	(0.006)	(0.005)
IrriControl		2.381***
		(0.278)
HandheldSensorw/oGNSS		2.020***
		(0.274)
WeatherStation		1.608***
		(0.273)
HandheldSensorw/GNSS	0.944***	
	(0.239)	
IngroundSensor	0.611**	
	(0.246)	
Constant	−2.008***	−1.394***
	(0.477)	(0.424)

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

curvature only significantly affects the adoption decisions of newer technologies but basically does not affect the older technologies adoption decisions. Another finding is that the negative effect of probability distortion is only significant for the older technologies group. Combining these two findings, the difference between the adoption decisions of newer and older precision irrigation technologies can be well explained. When the technology is newer, due to the unfamiliarity toward the technology, superintendents will have more perceived risks. Hence, superintendents may pay more attention to the perceived risks, their risk curvature (the extent of risk-seeking) will be significant for the adoption decision. However, when the technology becomes older, superintendents will be more familiar with it and the perceived risks will be largely reduced. As a result, the risk curvature may not be that important for the decision. Simultaneously, if superintendents overweight the small probability that extreme drought will occur, they may be willing to adopt the older and familiar technology to withstand the impact of drought, which makes the probability distortion play an important role in the adoption decision. Accordingly, policymakers can make different strategies when promoting newer and older technologies. For newer technologies, the promotion strategy can focus more on reducing perceived risks, while for older technologies, the strategy should emphasize the information about extreme drought.

A potential concern about our results is that, given that golf course superintendents are not the highest administrators of golf courses, they may not be the ones who make the final adoption decision. However, golf course superintendents are multifaceted managers who are responsible for irrigation and other daily maintenance of turfgrass, research, personnel management, budget development, accounting, and a variety of other works (New Jersey Agricultural Experiment Station n.d.), their thoughts about irrigation technology adoption are important references for higher administrators of golf courses and may be able to determine the adoption to a large extent. To verify this, we conducted a robustness check. We added a dummy variable of whether superintendent's adoption decision needs to be approved by higher administrators to our Probit Models. After controlling the dummy, the estimations still give us very similar results. It means that, even if we consider the situation that higher golf course administrators make the final adoption decision, our key findings still hold.

Conclusions

A group of US golf course superintendents were surveyed to examine whether and how superintendents' risk preferences (attitudes) affect the adoption decisions of precision irrigation technologies on their golf courses. Under the PT framework, a lottery experiment was used to elicit the measures of three risk attitudes, that is, risk curvature, probability distortion, and loss aversion. Using these three measures and other questions in the survey, we found several results. First, overall, superintendent's education level has relatively significant effects on risk attitudes. Second, overall, risk curvature has a significant positive effect on the precision irrigation technologies adoption on golf courses, while probability distortion affects the adoption negatively. Third, compared to the golf course in low precipitation areas, superintendents' risk attitudes are more likely to affect the precision irrigation technologies adoption in the golf course in high precipitation areas. Fourth, risk curvature dominates the adoption decisions for newer technologies, while probability distortion dominates the older technologies adoption decisions.

Our study first applies the PT literature to explain golf course superintendents' technology adoption behavior. Given that superintendents are facing risks similar to agriculture production risks but aim to provide services to golfers, their decision-making is different from farmer' and other managers'. Our research provides evidence that, for this unique group of managers, individual risk attitudes can play a significant role in operational decisions, consistent with the findings of other studies about the relationship between manager's risk preferences and business operation (e.g., Caliendo et al., 2022; Cen and Doukas, 2017; Kim and Nguyen, 2021;

Lin et al., 2022; Niu and Zuo, 2022; Rashad Abdel-Khalik, 2014). Due to the uniqueness of golf course superintendents (e.g., more loss aversion than an average adult in US) and the situation they are faced with, our findings may not be generalized to those working in different industries.

Our findings provide relevant stakeholders and policymakers with insights into how to promote the precision irrigation technology adoption on golf courses. First, since the risk curvature has a significant effect on the adoption decision overall, reducing perceived risks may be an effective way to promote the adoption. Learning more about the technologies can reduce superintendents' perceived risks. Specialists or researchers can not only hold educational courses on precision irrigation technologies but also disseminate information about the technologies through various information channels. An example is using social media to precisely push the knowledge of the technologies to superintendents. Providing insurance for the investment in the technologies may also be able to offset risks of adoption. Second, given the overall negative effect of probability distortion on the adoption, manufacturers, industry associations, or governing bodies may promote the adoption by emphasizing the history of extreme drought and its negative impact on golf course operation, because this may make superintendents overweight the small probability that extreme drought will happen. Third, to promote the adoption, researchers, industry stakeholders, related associations, and governing bodies can make different strategies based on the specific technologies and targeted areas. For example, for high precipitation areas, disseminating the information about extreme drought may promote the adoption, because the probability distortion plays a significant role in the adoption decision; for low precipitation areas, since the risk curvature has significant effect on the adoption decision, researchers, industry stakeholders, related associations, and governing bodies can mainly focus on reducing perceived risks. In addition, considering the management budget is positively associated with the adoption decision, they can promote the adoption by subsidizing golf courses adopting new technologies. These results may also be useful when considering the adoption of precision irrigation technologies by other professionals who manage green spaces such as commercial landscape managers, sports field managers, and park managers.

Data availability statement. The data were collected by the authors. The data will be made available upon reader request.

Author contribution. Conceptualization: CY, EW, and CS; Methodology: YW and CY; Formal Analysis: YW and CY; Data Curation: CY, EW, and CS; Writing—Original Draft: YW and CY; Writing—Review and Editing: YW, CY, EW, and CS; Supervision: CY; Funding Acquisition: CY, EW, and CS.

Financial support. This project was funded by Irrigation Innovation Consortium.

Competing interests. None.

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Appendix

Table A1. Estimation results of the impact of demographic variables on risk preference measures (N = 97): age measured by generation dummies

Variables	(1) α (risk curvature)	(2) γ (probability distortion)	(3) λ (loss aversion)
Millennials	0.518	−0.303	−2.066
	(0.354)	(0.229)	(2.680)
GenerationX	0.471	−0.326	−2.192
	(0.374)	(0.242)	(2.829)
BabyBoomers	0.694*	−0.372	−4.555
	(0.402)	(0.260)	(3.043)
Education	0.231**	−0.117*	0.202
	(0.095)	(0.062)	(0.721)
Experience	−0.010	0.006	0.130**
	(0.007)	(0.005)	(0.053)
Membership	−0.050	−0.206	−1.618
	(0.201)	(0.130)	(1.520)
Certified	0.105	−0.122	−0.419
	(0.136)	(0.088)	(1.025)
Income	0.024	−0.020	−0.126
	(0.024)	(0.016)	(0.182)
Constant	−0.234	1.452***	6.990*
	(0.468)	(0.303)	(3.543)

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

Cite this article: Wang, Y., C. Yue, E. Watkins, and C. Straw (2023). "How Do Risk Preferences Affect Golf Course Superintendents' Adoption of Precision Irrigation Technologies? Implications from Prospect Theory." *Journal of Agricultural and Applied Economics* **55**, 516–535. https://doi.org/10.1017/aae.2023.28