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Investigating Homeowners' Preferences for Smart Irrigation Technology Features

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Abstract: Smart irrigation systems are relatively new technologies that optimize irrigation schedules in residential landscapes, thus leading to reduced irrigation water use and potential contamination. To promote the use of such technologies, the landscape services industry has introduced innovative features such as the integration of local weather data into irrigation controller systems or mobile phone control and alert notifications that help to facilitate usability and prevent over-irrigation. Very few studies have addressed homeowners' preferences for outdoor irrigation technologies. This study investigates homeowners' preferences for smart irrigation systems for residential landscapes. We utilized online survey data to examine how homeowners' knowledge and perceptions influence their preferences for specific features such as automatic failure alert and notifications, mobile control, integration with weather-based and soil-moisture sensor-based irrigation, home automation, and touchscreen displays. Results estimated by the rank-ordered logit model revealed that knowledge and perceptions of smart irrigation controllers are significantly correlated with homeowners' preferences for water efficiency features. The results offer practical implications for policymakers and the residential irrigation industry as they develop and promote smart irrigation technologies to conserve water resources.

Keywords: water conservation; smart irrigation systems; landscape irrigation; online survey; rank-ordered logit model

1. Introduction

Water scarcity is becoming a global environmental issue. Although industry and agriculture utilize the majority of water resources, the percentage of residential use in overall water consumption ranges from 10% to 30% in developed countries [1]. Previous studies have shown that the majority of residential water is being used for outdoor purposes, including landscape irrigation [2,3]. Although irrigation is necessary for plant health, excessive irrigation can have negative environmental and economic consequences, such as decreased water availability, increased water resource pollution and/or contamination due to chemical fertilizer runoff, and increased households' utility expenses [4].

Residential irrigation efficiency becomes imperative when considering sustainable water management practices in urban areas. Smart irrigation systems are relatively new technologies that have the potential to optimize irrigation schedules in residential landscapes and reduce irrigation water use and potential contamination. In the past decade, smart irrigation controllers have been developed and promoted in an attempt to reduce excessive irrigation as part of the broader residential water conservation programs [5]. For example, initiatives such as the Florida WaterStar^{SM} Program provide water conservation certifications for indoor fixtures and appliances, landscape designs, and irrigation systems. User incentives from such conservation programs include environmental (i.e., reduced water waste) and financial (i.e., reduced water bill) benefits from installing water-efficient appliances [1,6,7].

Smart irrigation controllers are more efficient than traditional time-based irrigation controllers [5]. Previous studies have shown that evapotranspiration (ET)-based and soil moisture sensor (SMS)-based controllers have the potential to save irrigation water by up to 40 percent and improve water quality [5,8,9]. The ET-based controllers utilize meteorological information from on-site weather stations or local/regional weather networks to determine landscape irrigation needs [5,10]. The SMS-based controllers use real-time soil moisture information to bypass irrigation events based on plant needs, i.e., when the soil moisture exceeds the preset thresholds. In summary, the automation of landscape irrigation scheduling by smart controllers is promising to improve usability and minimize irrigation application while maintaining landscape and plant quality.

In addition to the integration of local weather data and soil moisture information into irrigation controllers, the residential landscape services industry has also introduced innovative technologies such as mobile phone control and failure alert notifications to facilitate usability and prevent over-irrigation. The irrigation technology features include operation types (i.e., wired vs. wireless sensors), remote access to irrigation control and adjustment (i.e., using smartphones), and automatic failure alert and notification. These features can reduce the controller setup complexity and provide effortless management. In addition, smart irrigation systems can be controlled and adjusted using a wall-mounted unit with the option of a touchscreen display or using any internet-connected computer, as well as smartphone, from any location. The smart irrigation systems have the option to install a notification function with a system failure alert. This function provides a smart irrigation system that detects irregularities (e.g., unscheduled irrigation due to faulty sprinkler heads) and notifies the users via their smartphone. More advanced controller features include integration with other home automation technologies, i.e., lighting or home climate control systems.

Existing research efforts have focused on households' indoor water use and consumers' preferences for water-saving home appliances [11], but very few studies have addressed outdoor water use [1]. Thus far, homeowners' preferences for specific smart controller features of outdoor/landscape irrigation systems are not yet well understood. It is important to understand which functional features homeowners prefer and how they rank those features in a most to least important hierarchy. The findings can provide insights for researchers interested in smart irrigation technology adoption and practical implications for the landscape services industry and relevant regulatory agencies (e.g., water management districts). To address the research gap, this study investigates homeowners' preferences for functional features of smart irrigation systems through a feature-ranking based experiment.

The functional features embedded in controllers can influence homeowners' preferences and subsequent decisions on the adoption of smart irrigation controllers. Among specific technology features, such as automatic failure alert and notification, mobile control, integration with local weather data or soil moisture information, home automation, and touchscreen displays, we focused on finding out which features homeowners will prefer more. Next, we examined the underlying mechanisms—how homeowners' knowledge and perceptions regarding smart irrigation and environmental concerns, as well as individual characteristics, affect their preferences for specific smart irrigation technology features. We hypothesized that knowledge and perceptions of smart irrigation controllers were significantly correlated with homeowners' preferences for those features. For example, a high level of water conservation concerns will be positively correlated with preferences for water efficiency features.

The remainder of this paper is organized as follows. The next section describes the survey method and econometric model used. A rank-ordered logit (ROL) model, used for empirical analysis, is described in this section. The third section presents the effects of participants' knowledge and perceptions on water efficiency features. The final section provides implications for policy makers and the residential landscape services industry as they develop and promote smart irrigation technologies.

2. Methods and Econometric Models

2.1. Survey and Sample Summary

As a part of a broader research study, the sample data were collected in May 2014 to assess the adoption of smart irrigation systems by homeowners in three states (Florida, California, and Texas). The survey was based on an online questionnaire administered by Qualtrics, Inc., a professional survey company. In the survey, we prescreened the homeowners to include those who had automated irrigation systems in their yards. Specifically, we selected homeowners based on the following criteria: Whether they have a lawn; whether they live in a single-family house with a lawn; and whether they have an automated irrigation system installed. Responses from homeowners living in homes without a lawn (and potential need for outdoor irrigation) would not be useful for the specific purposes in this study.

The survey consisted of four sections. The first section started with questions regarding respondents' landscape and irrigation practices and their knowledge about irrigation systems. In the second section, respondents were asked to rank the smart irrigation technology features they perceived as most to least important (rank order from one to six). The third section represented respondents' perceptions related to the smart irrigation systems and water conservation. Finally, the survey included questions about respondents' socioeconomic and demographic characteristics.

A total of 3000 homeowners completed the questionnaire. Among them, 2241 answered the ranking question regarding the technology features. There were 735 respondents from Florida, 758 from California, and 748 from Texas. These three states were chosen because they are leaders in developing water conservation regulations and water-saving programs due to population growth. and all publicly face issues with fresh water quantity and quality. (At the time of the survey, the combined population in Florida, California and Texas was 84.3 million or 25.8% of the total U.S. population.) Approximately, 63% of respondents were female, less than 3% of respondents were less than 20 years old, about 29% were in the 20–34 age range, about 37% were in the 35–54 age range, and about 32% were over 55-years-old (Table 1). In addition, about 87% of respondents completed college or university, and around 59% were employed (full employment and part-time employment). Annual income levels ranged from below $19,999 to above $300,000, but most responders (80%) were in the $20,000–$119,999 income range (Table 1).

Table 1. Statistical summary of sociodemographic variables.

Demographic Characteristics	Sample
Gender	
Female	63.68%
Male	36.32%
Age	
Less than 20	2.86%
20–34	28.83%
35–54	36.64%
More than 55	31.68%
Income	
Less than $19,999	4.86%
$20,000–$59,999	33.83%
$60,000–$99,999	30.97%
$100,000–$139,999	15.97%
$140,000–$179,999	6.60%
$180,000–$299,999	5.80%
More than $300,000	1.96%
Employment	
Some employment	58.99%
Not employed	41.01%

The survey asked a ranking question regarding what technology features are more important for landscape irrigation systems. By dragging the items up or down, respondents ranked the six technology features from one, as most preferred, to six, as least preferred. The six proposed technology features were: 1) Automatic failure detection, alert, and shut-off; 2) Mobile app control; 3) Weather-based automatic irrigation; 4) Wireless soil-moisture sensor based irrigation; 5) Integration with other home automation technologies (e.g., lighting or climate control); and 6) Touchscreen displays for wall-mounted units. Those technology alternatives were selected because they are important innovative functional features and can influence homeowners' decisions on the adoption of smart irrigation controllers. To enhance respondents' understanding of smart irrigation technologies and technology alternatives, those technology features were explained at the beginning of the questionnaire.

Table 2 shows the summarized proportion of respondents for the ranking of each feature, with the ranking mean and standard deviation. On average, respondents' mean ranking order of the six features from the most preferred to the least preferred was automatic failure detection, alert and shutoff, wireless SMS, weather based automatic irrigation, mobile app control, integration with home automation, and touchscreen displays.

Table 2. Proportion of respondents for each technology feature ranking.

Technology Features	Rank Frequency Rank = 1 (%)	Rank = 2 (%)	Rank = 3 (%)	Rank = 4 (%)	Rank = 5 (%)	Rank = 6 (%)	Ranking Mean	Ranking Std. Dev.
Automatic failure alert	33.9	28.3	22.6	8.6	4.4	2.2	2.28	0.03
Mobile app control	7.5	12.4	15.0	25.0	19.4	20.7	3.98	0.03
Weather-based automatic irrigation	18.2	27.1	25.4	13.8	9.2	6.4	2.88	0.03
Wireless SMS based irrigation	34.7	23.3	19.7	12.9	6.4	2.9	2.42	0.03
Integration with home automation	3.7	5.0	9.3	23.3	33.1	25.6	4.54	0.03
Touchscreen displays	1.9	4.0	7.9	16.3	27.5	42.3	4.90	0.03

Table 3 provides a summary for the explanatory variables used for empirical analysis. The survey incorporated variables into four clusters, which included: (1) Knowledge about irrigation systems, (2) perceptions of the smart irrigation systems, (3) perceptions on water conservation, and (4) socioeconomic and demographic characteristics.

Regarding knowledge about landscape irrigation systems, the questions focused on the understanding of the characteristics of the irrigation controllers. Homeowners were quite knowledgeable about their own lawn/landscape and related regulations, with a mean score of 4.94 on a seven-point Likert scale for the question regarding their knowledge about outdoor irrigation and relevant local ordinances. The mean values for the answers regarding knowledge about irrigation zones, SMS, and ET sensors, were 4.57, 2.18, and 1.91, respectively.

The questions regarding homeowners' perceptions of smart irrigation systems compared with conventional irrigation systems included advantages and disadvantages in terms of its cost and reliability. Specifically, the survey gauged respondents' perceptions regarding the cost of smart irrigation systems with a seven-point scale (1 = conventional controller is much better; 7 = smart controller is much better). The survey results showed that 51% of the respondents believed smart controller costs were higher than those of conventional controllers. About 25% of respondents believed the costs of smart controllers were lower than the costs of conventional controllers, implying a quarter of respondents recognized that smart controllers were worth the cost. The mean values of these perception questions were 3.37 and 4.54, for price and reliability, respectively (Table 3).

The questions regarding homeowners' perceptions of water conservation assessed respondents' agreement with water conservation related statements. We asked the respondents whether they agree that their individual water conservation practices affect the overall supply. Answers consisted of a five-point Likert scale (1 = strongly disagree; 5 = strongly agree). Sixty-eight percent of the respondents agreed or strongly agreed with the statement, while only 16% disagreed or strongly disagreed. The mean value for this question was 3.72. In addition, we asked the respondents whether their state has insufficient water resources and if they need to conserve water. With the mean value of 4.35, many respondents (84%) tended to agree with the water scarcity statement and about 12% were not sure (Table 3).

Table 3. Explanatory variables used in estimation with sample means.

Name	Description	Full Sample (N = 2241)	
		Mean	**Std. Dev.**
	Knowledge Related Variables		
Knowledge about Irrigation system and lawn/landscape	**"How knowledgeable are you about each of the following characteristics of your irrigation system and lawn/landscape?" (1 = Not at all knowledgeable to 7 = Strongly knowledgeable)**		
Irrigation Zone Knowledge	- Irrigation zone location	4.571	0.018
Permitting Knowledge	- Locally permitted irrigation days/hours	4.937	0.018
Knowledge about smart irrigation controllers	**"How knowledgeable are you about each of the following irrigation controllers?" (1 = Not at all knowledgeable to 7 = Strongly knowledgeable)**		
SMS Knowledge	- Soil moisture sensor (SMS)-based controllers	2.183	0.013
ET Knowledge	- Evapotranspiration (ET)-based controllers	1.908	0.012
	Perception Related Variables		
Perception on smart irrigation controllers	**"What is your perception of the advantages and disadvantages of conventional vs. smart irrigation controllers?" (1 = Conventional controller is better to 7 = Smart irrigation controller is better)**		
Price	- Price	3.370	0.015
Reliability	- Reliability	4.541	0.014
Perception on water conservation	**"Please indicate your agreement with the following statements." (1 = strongly disagree to 5 = strongly agree)**		
Water Conservation	- My conservation of water affects the overall supply	3.721	0.009
Insufficient Water Resource	- My state has insufficient water resources and I need to conserve water	4.350	0.008

2.2. Rank-Ordered Logit Models

Technology features were rank-ordered by respondents in the experiment. Correspondingly, a rank-ordered logit (ROL) model was chosen for the estimation. Compared to a choice experiment, which requires respondents to choose only the most preferred alternative amongst the choice set of multiple alternatives, a rank-ordered experiment obtains a complete ranking of the alternatives [12]. Researchers obtain more specific insights from the ranking experiments compared to the commonly used choice experiments. In addition, the ROL model can estimate the parameters of the choice model and the preferences more efficiently [13]. The ROL model allows estimating the probability of any ranking of the alternatives from the most preferred to the least preferred as the product of a standard logit formula [14]. The model initially introduced by Beggs et al. [15] was used to analyze the preferences for electric cars using rank data. Allison and Christakis [16] introduced a generalized rank-ordered model to allow for ties in the ranking. Fok et al. [13] introduced a latent-class ROL model to identify the individual's ranking. Also known as the exploded logit model, the ROL model was applied to identify the consumers' preferences in marketing field [14,17].

In this study, the ROL model estimates the probability of how the homeowners will rank the different technology features of the smart irrigation system. We present this model, following Beggs et al. [15], and assume that respondent i has a certain utility U_{ij} for each alternative, and s/he will give alternative j

a better rank than any other alternative k whenever $U_{ij} > U_{ik}$. The random utilities for individual i are U_{i1}, ... , U_{iJ}, as:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

where i = 1, ... , N represents individuals and j = 1, ... ,J represents the alternatives. V_{ij} is the deterministic component of the utility and ε_{ij} is the random component of the utility function. In turn, the deterministic component can be presented as follows:

$$V_{ij} = x_i{}'\beta_j \tag{2}$$

where x_i is a vector of variables that describes the characteristics of the respondent i and β_j is a vector of parameters to alternative j.

A respondent provides a complete ranking from most preferred to the least preferred according to the underlying utilities (prefer an alternative with a higher utility over another with lower utility). For an observed full ranking R_i, the order of the utility for features is:

$$U_{iri1} > U_{iri2} > U_{iri3} > \ldots > U_{irij} \tag{3}$$

Since the observed response is the rank order of the alternatives, the independence of irrelevant alternatives assumption (IIA) still applies. Allison and Christakis [16] indicated that the IIA applies to both ranked data and data respondents choose the most preferred alternative. In ranked data, the respondent first chooses the most preferred alternative from the entire set and ranks it in the first place. After the first choice is made, the respondent can choose the second most preferred alternative among the remaining items, and so on [14].

In this study, the rank-ordered response was constructed to represent the homeowners' preferences for technology features. The ranking response of respondent i is denoted by $y_i = (y_{i1}, \ldots\ y_{iJ})'$ where y_{ij} denotes the rank that individual i gives to jth alternative. We follow Fok et al. [13] to use the equivalent notation $R_i = (r_{i1}, \ldots , r_{ij})'$, where r_{ij} denotes the alternative number that received rank j by respondent i. For $r_{ij} = k$, k = 1, ... ,J. For example, if we summarize the mean ranks from the sample data, we obtain the result as (1, 4, 3, 2, 5, 6), where automatic failure alert and notification > wireless SMS-based > weather-based automatic irrigation > mobile app control > integration with home automation > touchscreen displays.

Under the utility assumption and extreme value distribution assumption of ε_{ij}, the rank-ordered logit model is shown below. See Beggs et al. [15] and Fok et al. [13] for more details. The probability of a particular ranking R_i by ith individual is:

$$\pi[R_i;\beta] = \Pr[U_{iri1} > U_{iri2} > U_{iri3} > \ldots > U_{iriJ}\ for\, H \leq J] = \prod_{j=1}^{J-1} \frac{\exp(V_{irij})}{\sum_{l=j}^{J} \exp(V_{iril})} \tag{4}$$

By specifying a linear form for V_{ij} in Equation (2) as $V_{ij} = x_i{}'\beta_j$, the log likelihood function becomes:

$$LL(\beta) = \sum_{i=1}^{N} \log \pi(R_i;\beta) = \sum_{i=1}^{N}\sum_{j=1}^{J-1} x_{irij}\beta - \sum_{i=1}^{N}\sum_{j=1}^{J-1} [\log \sum_{l=j}^{J} \exp(x_{iril}\beta)] \tag{5}$$

We used the maximum likelihood method to estimate the model parameters for Equation (5).

In this section, we showed the rank-ordered logit model specification. The parameters specified in this model are relevant to the probability of the observed ranking. Positive parameters represent that the explanatory value is likely to increase the probability of the ranking of the related technology feature. On the other hand, negative parameters indicate that the explanatory variable tends to decrease the probability of the ranking.

3. Empirical Results and Discussion

3.1. Model Specification

We estimated the survey data in two different models: Model 1 estimates features-only effects, and Model 2 estimates features and individual characteristic effects. The second model includes the explanatory variables measuring homeowners' knowledge levels related to landscape management and smart irrigation systems. It also incorporates their perceptions of smart irrigation systems and of water conservation. Sociodemographic variables were also incorporated to control for individual heterogeneity and examine the effects on preferences for each feature. Those characteristic (i.e., demographics, knowledge, and perceptions) variables entered the model as interactions with the feature variables. The touchscreen display feature was chosen as the base feature because it ranked, on average, the least preferred feature. The estimated ranking parameter results for the rest of the features were then interpreted as homeowners' preference in relation to the least preferred feature.

In Model 1, the estimated parameters represent the log odds ratio of the corresponding feature against the base feature. The odds ratios are the exponential results of the corresponding parameters. In Model 2, which includes the individual characteristic effects, we also report the odds ratio as an exponential value of the estimated parameters for the categorical characteristic variables and the percent change in odds ratio for quantitative variables. The percent change in the odds ratio over the base feature of one unit increase in the quantity variable was calculated by $[\exp(\beta) - 1] \times 100\%$ [14].

We observed identical rankings for the mean ranking and the ranking from Models 1 and 2 (Table 4). The mean ranking, taken from the survey results, are (1, 4, 3, 2, 5, 6), where automatic failure alert and notification > wireless SMS > weather-based automatic irrigation > mobile app control > integration with home automation > touchscreen displays for wall-mount units. The ranking reflects homeowners' preferences for the irrigation controller functional features.

We also conducted a Hausman test between a conditional logit and rank-ordered logit model [18]. The Hausman test rejected the null hypothesis that both model specifications are consistent and the estimated parameters are equal, with the test statistic as 3489, which is significant at the 1% level. Therefore, we conclude that the rank-ordered logit model is more appropriate for estimation.

Table 4. Ranking of technology features in different model specifications.

Technology Features	Sample Mean	ROL (Model 1) (Features Only)	ROL (Model 2) (Features and Characteristics)
1. Automatic Failure Alert (*Detection*)	1	1	1
4. Wireless SMS-based irrigation (*SMS*)	2	2	2
3. Weather-based automatic irrigation (*ET*)	3	3	3
2. Mobile app control (*Mobile*)	4	4	4
5. Integration with home automation (*Home*)	5	5	5
6. Touchscreen displays (*Screen*)	6	6	6

3.2. Preference Estimates

For Model 1, the estimated coefficient and odds ratio for each feature are presented in Table 5. The odds ratios indicate how many times other features were preferred over the base feature (i.e., touchscreen displays). In other words, the estimated odds ratios for the automatic failure alert and notifications (7.64) and mobile app control (1.89) indicate that automatic failure alert/notifications feature and mobile app control are 7.64 and 1.89 times more preferred over the touchscreen displays (base) feature (Table 5). Participants' preference for this feature can be related to not only cost-saving and water conservation, but also to a peace of mind about being notified and in control of outdoor irrigation equipment conditions. Considering situations when the homeowner is away from home, the automatic failure alert and shut-off function can be important compared to the system without this feature. Despite their importance, the two other water efficiency features are ranked the second (SMS) and third (ET).

As mentioned above, the integration with home automation and the touchscreen display were reported as the two least important features. One plausible explanation is that touchscreen display technologies have become common in recent years (e.g., smartphone devices), and homeowners may have treated it as a basic feature and not a particularly preferred or important feature to have on the controller itself. According to the estimated coefficient, the integration with home automation feature is not that important for participants, but one can argue that with the current rapid developments in consumer technologies, smart irrigation systems may become an integral part of home automation in the near future.

Table 5. Estimated parameters and odds ratios for Rank-Ordered Logit (ROL) Model 1 with only feature effects.

Variable[a]	Detection	Mobile	ET	SMS	Home
	Rank-Ordered Logit Model 1				
Features	2.033*** [b]	0.638***	1.542***	1.894***	0.340***
(Touchscreen Display	(0.042) [c]	(0.039)	(0.041)	(0.041)	(0.038)
as the base)	[7.64] [d]	[1.89]	[4.67]	[6.65]	[1.40]
Log likelihood = −12,546.12					
p-value = 0.0000					

[a] See Table 4 for variable definitions; base alternative is touchscreen displays (*Screen*). [b] ***, **, * indicate 1%, 5%, and 10% significant level, respectively. [c] Standard errors are provided in parentheses. [d] Odds ratios calculated as exponential value are provided in brackets.

Table 6 displays the estimated parameters for the ROL Model 2 with both the effects of features and individual characteristics. We conduct a log-likelihood ratio test to check the statistical significance of all individual characteristics. The log-likelihood ratio test (log-likelihood ratio, 328.54, and significant at 1% confidence level) rejects the null hypothesis that all parameters of individual characteristics are zero. As a result, we conclude that the estimates of Model 2 are significant, and these estimates are reported.

After controlling for individual characteristics, the odd ratios for automatic failure detection, mobile app control, weather-based automatic irrigation, wireless sensor-based irrigation, and home automation integration are 14.64, 3.71, 5.64, 7.20, and 3.33, respectively, demonstrating the extent to which these alternative features are more likely to be preferred than the base (touchscreen) feature (Table 6). The effects of technology features of Model 2 then yield a similar ranking to Model 1, where homeowners prefer the automatic failure alert and notification the most, followed by the two water efficiency features (ET and SMS). Hence, we confirm that the ranking of the technology features of smart irrigation systems and the two water efficiency features rank at the second and third places, after the feature of automatic failure detection and notification.

3.3. *Effects of Homeowners' Characteristics*

To assess how individual characteristics affect the preference and ranking of technology features, selected explanatory variables were incorporated. The estimated coefficients reveal the effects of homeowners' knowledge level about landscape irrigation systems on their preferences for functional features. Additionally, the effects of homeowners' perceptions of smart irrigation and water conservation were investigated. Homeowners' sociodemographic information was also included to control for individual heterogeneity, since the sociodemographic aspects may influence homeowners' preferences for smart irrigation systems or specific functional features. Table 6 displays the estimated parameters for the individual characteristic effects.

Table 6. ROL Model 2 estimated parameters and odds ratios.

Variable	Detection	Mobile	ET	SMS	Home
Effects of Technology Features					
Features	2.684*** [a]	1.310***	1.729***	1.974***	1.204***
(Touchscreen Display as the base)	(0.312) [b]	(0.291)	(0.304)	(0.306)	(0.284)
	[14.64][c]	[3.71]	[5.64]	[7.20]	[3.33]
Effects of knowledge about landscapes/controllers					
Irrigation Zone Knowledge	−0.006	−0.002	−0.011	0.0595**	−0.002
	(0.024)	(0.023)	(0.024)	(0.024)	(0.022)
Permitting Knowledge	[0.994]	[0.998]	[0.990]	[1.06]	[0.998]
	0.001	−0.022	−0.042*	−0.014	−0.053**
	(0.025)	(0.023)	(0.024)	(0.024)	(0.022)
SMS Knowledge	[1.001]	[0.98]	[0.96]	[0.99]	[0.95]
	−0.018	−0.077*	−0.018	−0.004	−0.061
	(0.048)	(0.045)	(0.047)	(0.048)	(0.044)
ET Knowledge	[0.98]	[0.93]	[0.98]	[0.996]	[0.94]
	−0.004	0.001	0.006	−0.120**	0.092*
	(0.054)	(0.050)	(0.053)	(0.054)	(0.049)
	[0.996]	[1.00]	[1.00]	[0.87]	[1.10]
Effects of perceptions about smart controllers/water conservation					
Reliability	0.068**	0.090***	0.159***	0.060**	0.053**
	(0.027)	(0.026)	(0.026)	(0.027)	(0.025)
	[1.070]	[1.094]	[1.172]	[1.062]	[1.054]
Price	−0.073***	−0.034	−0.049*	−0.080***	0.004
	(0.026)	(0.024)	(0.026)	(0.026)	(0.024)
	[0.930]	[0.967]	[0.952]	[0.923]	[1.004]
Water Conservation	0.066	0.062	0.118***	0.099**	0.052
	(0.043)	(0.041)	(0.042)	(0.042)	(0.039)
	[1.068]	[1.064]	[1.125]	[1.104]	[1.053]
Insufficient Water Resource	−0.030	−0.076	0.048	0.042	−0.086*
	(0.052)	(0.049)	(0.050)	(0.051)	(0.048)
	[0.970]	[0.927]	[1.049]	[1.043]	[0.918]
Effects of sociodemographics					
Age	−0.148***	−0.303***	−0.305***	−0.192***	−0.194***
	(0.055)	(0.051)	(0.053)	(0.054)	(0.050)
	[0.862]	[0.739]	[0.737]	[0.825]	[0.824]
Income	−0.056**	0.047**	−0.030	−0.004	−0.037*
	(0.024)	(0.023)	(0.024)	(0.023)	(0.022)
	[0.946]	[1.048]	[0.970]	[0.996]	[0.964]
Employed	−0.150*	0.154*	−0.150*	−0.158*	−0.013
	(0.089)	(0.082)	(0.086)	(0.088)	(0.081)
	[0.861]	[1.166]	[0.861]	[0.854]	[0.987]
Education	0.126	0.076	0.117	0.279*	0.089
	(0.090)	(0.084)	(0.088)	(0.090)	(0.082)
	[1.134]	[1.079]	[1.124]	[1.32]	[1.093]
Log likelihood = −12,381.8					
p-value = 0.0000					

[a] ***, **, * indicate 1%, 5%, and 10% significant level, respectively. [b] Standard errors are provided in parentheses. [c] Odds ratios calculated as exponential value are provided in brackets.

3.3.1. Effects of Knowledge Level

Table 6 shows the effects of homeowners' knowledge level regarding landscapes and irrigation systems on functional feature ranking. Knowledge related to irrigation zone location (*Irrigation Zone Knowledge*) showed positive effects only on the probability that the wireless SMS-based irrigation feature would be preferred over the base (touchscreen) feature. The odds ratio shows that a one-unit increase in knowledge level regarding the irrigation zone locations increases preferences for the wireless SMS-based irrigation feature over touchscreen displays by 6% (Table 6). Further, the estimated coefficients show that more knowledge about local irrigation related ordinances (*Permitting Knowledge*) decreases the likelihood that ET-based and home automation integration features would be ranked above the base feature. Specifically, a one-unit increase in the homeowners' understanding of the local irrigation ordinances makes it less likely that the ET-based and home automation integration features would be ranked over the base feature by 4% and 5%, respectively. Similarly, a higher level of knowledge about SMS controllers (*SMS Knowledge*) is associated with a reduced probability that mobile app feature would be ranked higher than the touchscreen feature. A one-unit increase in the homeowners' knowledge about the SMS systems makes it 7% less likely that the mobile app feature would be ranked higher than the base feature. Finally, with a one-unit increase in homeowners' knowledge about the ET-based system (*ET Knowledge*), homeowners would be 13% less likely to prefer wireless SMS and 10% more likely to prefer home automation integration features over the base feature.

The positive correlations between irrigation zones related knowledge levels and preference for SMS-based features is expected, as the SMS sensors are installed directly in the ground. Hence, irrigation zone-related knowledge may have contributed to this result. Similarly, the positive effects of the ET feature knowledge on preference for the home automation integration could be due to the common connection between ET-based controllers and home automation, meaning both systems are linked with and exchange information with local IT networks. However, the negative relationship between local ordinances related knowledge and ET/home automation integration features could be due to homeowners' concerns about local restrictions, which may have decreased the probability that these features be ranked higher than the touchscreen feature. Finally, the negative relationship between higher levels of knowledge of the ET feature and the probability to rank SMS-based feature higher than the base feature could be due to operational difference between the ET and SMS-based sensors.

3.3.2. Effects of Perceptions on Smart Controllers and Water Conservation

Homeowners' perception about smart irrigation controllers may also affect their preferences for technology features. Smart irrigation technology incorporates not only hardware components (e.g., innovative sensors), but also local networks and access to reliable internet connection. Therefore, the perceived reliability of smart irrigation systems includes a component of uncertainty in the consumers' mind when they evaluate different features. The perception of equipment reliability can be a significant predictor for overall preferences and feature ranking, and it confirms the reason why higher knowledge levels (for some of the relevant factors discussed above) are associated with lower ranking probabilities.

The results reveal that as the perception of reliability of smart irrigation controllers (*Reliability*) improves, homeowners are more likely to rank the technology features higher. Specifically, if the homeowners' perceptions of reliability increased by one unit, they would be 1.07, 1.09, 1.17, 1.06, and 1.05 times more likely to prefer automatic failure alert and notification, mobile app control, weather-based automatic irrigation, wireless sensor-based system, and integration with home automation over the base feature, respectively. Perception of reliability reduces concerns about sophisticated technology features, allowing homeowners to feel more comfortable in making decisions. Thus, improved perceptions of smart controllers' reliability could help to overcome relevant concerns and increase preferences for water efficiency features and likelihood to adopt smart irrigation systems.

Regarding perceptions about the advantages of smart irrigation systems in terms of price (*Price*) compared with that of the conventional irrigation controllers, homeowners rank the water efficiency features lower than the technology-oriented touchscreen display feature. Specifically, if homeowners believe that the price of a smart controller is worth the money (compared with that of a traditional irrigation controller), they are 4.8% and 7.7% less likely to rank weather-based automatic irrigation and wireless SMS features higher compared to the base (touchscreen display) feature.

Similarly, the automatic failure alert and notification feature is also 7% less likely to be ranked higher than the base feature. Conversely, the respondents with positive perceptions about smart irrigation system prices slightly prefer the integration with home automation feature (by 0.4%) over the touchscreen displays. However, this coefficient is not statistically significant. These results point to a conclusion that homeowners who accept the price premium of smart controllers assign a higher weight to the convenience features (e.g., integration with home automation) in the decision-making process, as opposed to water efficiency-oriented features (e.g., ET or SMS sensors). Correspondingly, homeowners in the former group can be characterized as convenience-oriented users, and those in the latter group can be characterized as water efficiency-oriented users.

The effects of homeowners' perception of water conservation (*Water Conservation*) on the technology feature ranking are also summarized in Table 6. Water efficiency features are much preferred if respondents bear water conservation concerns in mind. Perception about water conservation is positively correlated with the probability to rank water efficiency-related (ET and SMS) features. This finding is in line with our hypothesis, showing a high level of water conservation concern is positively correlated with the preferences for water efficiency features. A one-unit increase in the conservation related statement scale (i.e., that water conservation efforts impact the overall water supply) causes the water efficiency features to be ranked 1.13 and 1.10 times higher than the base feature. As expected, the higher the concern for water conservation, the more attention the homeowners would pay for water-saving features of irrigation systems. Besides, the effects of homeowners' perception of insufficient water resources in the state (*Insufficient Water Resource*) are only significant for the home automation integration feature, suggesting that this feature is ranked lower than the touchscreen display feature.

3.3.3. Effects of Sociodemographic Characteristics

Sociodemographic characteristics were also included in the model as relevant explanatory variables that correlate with the rankings of technology features. Gender effects are not significant; hence, we removed them from the estimation. Older homeowners are not only less likely to purchase smart irrigation systems (given all negative coefficients), but also less likely to rank all the technology features higher than the touchscreen feature. Compared with the base feature of the touchscreen displays, the negative odds ratios range from 18% to 26% for the rest of the technology features in the model. Older homeowners are likely to be more experienced in landscaping practices and more knowledgeable about irrigation systems. Sophisticated technology features, like mobile app control, home automation integration, and water efficiency features, such as wireless sensors and weather based automatic irrigation, may not be as attractive or important for them. Current touchscreen-based technologies are widespread and user-friendly. Although the touchscreen feature is ranked the least important in the survey overall, it is the most preferred feature for older people specifically. One plausible explanation could be that older homeowners may find user-friendly touchscreen controller displays easy to use, as opposed to integrating smart controllers with home automation or controlling the irrigation systems via a mobile application.

The above findings can also be related to the effects of income and employment status. Our results show income levels and employment status significantly impact feature rankings. Those who have higher incomes and are employed are more likely to prefer the convenience features such as the mobile app control, but less likely to prefer water-saving features such as the ET or SMS sensors. For example, higher income and employed homeowners rank mobile app control by 4.8% and 16.7% more than the base feature. Although the automatic failure alert and notification feature ranks the first on average, homeowners with higher income levels or those employed are 5.4% and 13.9% less likely to rank these features high. This group of homeowners may care less about the economic benefits gained from water efficiency features compared to lower income or unemployed participants. Further, homeowners with higher income or employed status rank the home automation integration feature lower than the base feature, though the coefficient for the employment status variable is not significant. A potential reason for a higher ranking for the mobile app feature (i.e., convenience attribute) and a lower ranking for home automation integration or failure alert and notification feature (i.e., water-saving attribute) by higher income households could be that higher income households generally assign comparatively lower weights to monthly water utility bills compared to lower income households. Emphasizing both the convenience benefits and water-saving effects of the advanced technology could improve the adoption of smart irrigation systems for this particular sociodemographic group.

4. Conclusions

Smart irrigation controllers are more efficient than traditional time-based irrigation systems and have the potential to save irrigation water and improve water quality. Technology features focusing on the ease of use, reliability, and notifications of system failure on smart irrigation systems play important roles and could encourage homeowners to adopt such technologies. Adoption of such innovative controllers depends on homeowners' preferences for these features. This study contributes to the literature that investigates mechanisms for increased adoption of smart irrigation by providing a better understanding about 1) homeowners' preferences for smart irrigation technology features; 2) the effects of homeowners' knowledge levels of smart controllers on preferences for the technology features; 3) the effects of homeowners' perceptions of smart controllers on preferences; and 4) the effects of homeowners' perceptions of water conservation on preferences.

Our findings reveal homeowners' preferences for the technology features and provide empirical insights for promotions of smart irrigation controllers for the residential landscape services industry. Homeowners prefer the feature of automatic failure alert and notification the most. The two water efficient smart controller features, ET and SMS features, are also ranked high. The two convenience functional features, mobile app control and integration with home automation, are slightly preferred than the touchscreen displays, as a base feature. Besides, older homeowners prefer the touchscreen display feature over all other features. Higher income and employed homeowners rank water efficiency features lower than touchscreen display and the convenience related features.

In terms of the effects of homeowners' knowledge levels and perceptions regarding smart irrigation systems, homeowners with higher knowledge of landscape maintenance and smart irrigation controllers are less likely to prefer the water efficiency features, suggesting that homeowners might have concerns regarding the reliability of the innovative smart irrigation technology. In addition, homeowners with greater water conservation concerns are more likely to prefer water efficiency features. These findings reveal insights for the landscape services professionals and demonstrate that educating homeowners may help to overcome the potential barriers for adoption of smart irrigation technologies. First, to encourage the adoption of smart irrigation technologies, relevant stakeholders could promote easy-to-understand materials through educational campaigns or advertisements to improve homeowners' knowledge and perceptions about smart irrigation technologies and outdoor water conservation practices in general. If homeowners' perceptions of smart controllers' reliability are improved, concerns about such innovative technology may be alleviated. Because perceptions of reliability influence homeowners' preferences significantly, industry stakeholders must improve smart irrigation systems' actual (not perceived) reliability before marketing those advanced technologies to the public. Second, to encourage the adoption of smart irrigation systems, the industry should highlight the water efficiency and water-saving features. Rather than emphasizing sophisticated features such as the integration with overall home automation and mobile app control, it might be more useful to highlight water efficiency features (e.g., automatic failure alert and notification, weather-based automatic irrigation, and wireless SMS-based systems) and keep the touchscreen display as a default function.

In summary, stakeholders such as landscape services industry professionals, local governments, or state water management districts could use these findings to improve the technology features of smart irrigation systems and to promote appropriate features to different groups of users. These findings also have practical applications for policymakers when establishing water policies that affect homeowners' behavior at state and local levels.

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