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Households' Adoption of Drought Tolerant Plants: An Adaptation to Climate Change?

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Adopting drought tolerant plants (DTPs) to conserve water is a potential adaptation to the predicted effects of climate change in the Midwest. Survey responses from 624 Missouri households were analyzed using a univariate probit model. DTP adoption was positively correlated with both low and high household incomes, living in rural subdivisions, time spent gardening, pro-environment attitudes, and concerns about drought. Policy interventions in newly drought-prone areas might include subsidizing the up-front cost of DTPs, requiring their use in new housing developments so DTPs are the default for buyers, and targeted educational efforts to environmental and gardening groups and rural residents.

Key words: adaptation, adoption, climate change, drought tolerant plants, gardening, residential water conservation

Introduction

In many regions, climate change will not only manifest itself as gradual changes in average conditions but also as increased frequency and intensity of extreme events (Angel and Huff, 1997; Arnell, 1999; Intergovernmental Panel on Climate Change, 2014; Sinha and Cherkauer, 2010). Typically, the Midwest has received sufficient rainfall for both crops and urban landscapes, but it is increasingly threatened by droughts, as are most other regions of the United States. Studies at various scales have reported that hotter summers with longer dry periods as well as milder, wetter winters will become more common in the Midwest (Arnell, 1999; U.S. Environmental Protection Agency, 2014; Murray, Foster, and Prentice, 2012; Sinha and Cherkauer, 2010). For example, the Midwest experienced a severe drought in 2012; Missouri received 31 inches of rainfall compared to its average 43 inches. The potential impacts of these changes on water resources are likely to increase in magnitude, diversity, and severity in future decades (Intergovernmental Panel on Climate Change, 2014).

Household-level adaptation to climatic threats can contribute to increasing the resilience and flexibility of interacting physical and social systems (Qin et al., 2015; Wamsler and Brink, 2014). One strategy that households can adopt to respond to limited or costly water resources is appropriately managing residential landscapes (Martin, Peterson, and Stabler, 2003), which

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account for 50–90% of household water consumption. The majority of this water is used to irrigate lawns (Hurd, Hilaire, and White, 2006; Sovocool, Morgan, and Bennett, 2006).[1] Adopting drought tolerant plants (DTPs) is one way for households to manage residential landscapes to deal with changing water availability induced by climate change. Residential landscapes with more DTPs can reduce the costs of irrigation and maintenance and contribute to sustainable use of water resources. Homeowners are already adopting DTPs to cope with water scarcity, especially in some drought-stricken and urban areas of Florida (Shober, Denny, and Broschat, 2010) as well as New Mexico (Hurd, 2006), Nevada (Curtis and Cowee, 2010) and other Western states.

Landscape choices have been examined in the literature (e.g., Hurd, 2006), but these have focused on the effects of water cost, number of children, education, responsibility for conserving water, and location. To the best of our knowledge, there have been few systematic studies of the determinants of residential DTP adoption or the role of perceptions of climate change in the household decision-making process. These perceptions may be particularly important in areas that have not typically been drought-prone. To help reduce residential water consumption and improve residents' capacity to deal with future climate risks, we studied households' adoption of DTPs in an urbanizing watershed in the Midwest. A deeper understanding of the behavioral factors affecting DTP adoption can provide useful implications for policy development and educational efforts.

Adaptation and Household Water Conservation Practices

As shown in figure 1, a household's decision to adopt DTPs is made in the risk context of climate change. Climate change, specifically more frequent droughts, will increase the costs of irrigating and maintaining residential landscapes (Balling and Gober, 2007; Cook, Hall, and Larson, 2012). Households' responses are influenced by their susceptibility to risks, perceived exposure to risks, and opportunities to make changes (Larson et al., 2013; Qin et al., 2015; Wamsler and Brink, 2014). Households are also affected by the availability of information on adaptation options, undervaluation of potential losses, and individual financial feasibility (Adger, Arnell, and Tompkins, 2005; Adger et al., 2009; Kusangaya et al., 2014; Qin et al., 2015; West et al., 2009). Specific adaptation choices will substantially affect the benefits or costs associated with climate impacts (Larson et al., 2013; Mankad and Tapsuwan, 2011). To examine this issue, we need to better understand residential irrigation and landscape management.

Residential landscapes provide fundamental community amenities and cultural values, such as a sense of place for neighborhood residents (Cook, Hall, and Larson, 2012; Martin, Peterson, and Stabler, 2003). Households also have a preference for green space (Bark et al., 2011). However, irrigating residential landscapes requires substantial amounts of water to maintain various social and cultural values. For instance, in Las Vegas, where residential irrigation accounts for approximately 60% of all water use (e.g., Devitt, Carstensen, and Morris, 2008), increased outdoor water use efficiency has the potential to reduce water consumption (Hurd, 2006; Shober, Denny, and Broschat, 2010).

In the literature, residential water management practices can be divided into irrigation practices and landscape maintenance (Scheiber and Beeson, 2006; Volo, Vivoni, and Ruddell, 2015). Water conservation techniques include "smart irrigation" controllers (McCready and Dukes, 2011; Nautiyal et al., 2015) and residential micro-irrigation systems (e.g., sprinkler, drip systems) (Haley, Dukes, and Miller, 2007; Volo, Vivoni, and Ruddell, 2015). However, installing these automatic residential irrigation systems is costly and can lead to over-irrigation (Haley, Dukes, and Miller, 2007; McCready and Dukes, 2011; Scheiber and Beeson, 2006; Shober, Denny, and Broschat, 2010).

An effective way to conserve water and prepare for uncertain water availability is to develop low-water-consuming landscapes (Sovocool, Morgan, and Bennett, 2006), specifically by planting water-

[1] In this article, "residential landscape" refers to lawn as well as vegetable and flower gardens and is used interchangeably with "yard."

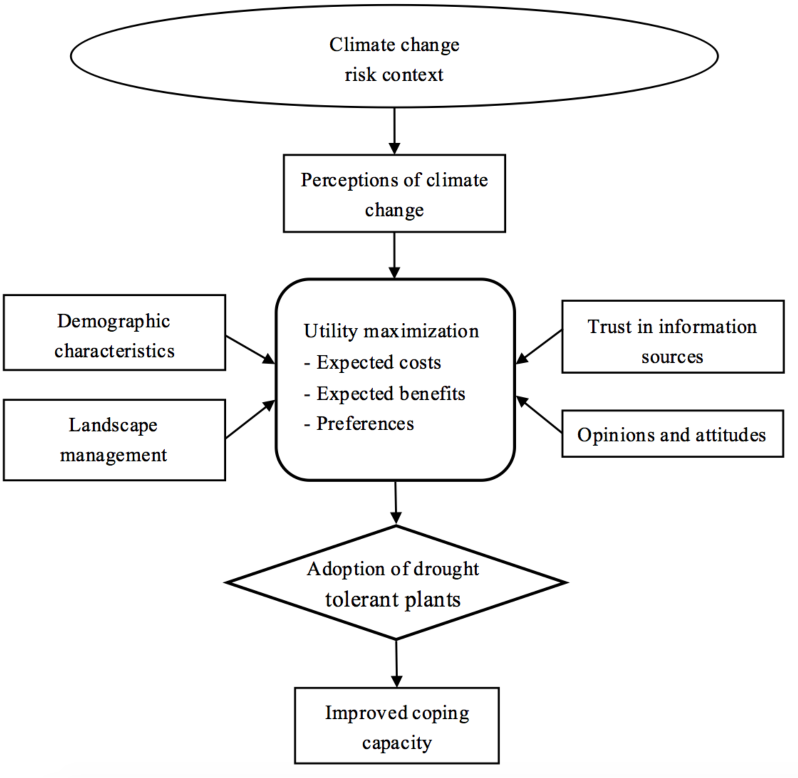

Figure 1. Expected Utility Model and Households' Adoption of Drought Tolerant Plants

efficient species such as native landscape ornamentals (Hurd, Hilaire, and White, 2006; Shober, Denny, and Broschat, 2010), and xeriscape conversion (Chow and Brazel, 2012; Sovocool, 2005; Sovocool, Morgan, and Bennett, 2006). Some fundamental xeriscaping principles include rational planning, low irrigation, and planting low-water-consuming plants (Hurd, Hilaire, and White, 2006). Drought tolerant plant species are an essential component of low-water-consuming residential landscapes (Hurd, 2006; Lockett et al., 2002). In horticulture, these species are also frequently referred to as "drought resistant plants," "desert plants," or "xeriscape plants." Though there is no unified definition for drought tolerant plants, they are generally understood to consume less water once established, tolerate some dry conditions better than other plants, exhibit high water-use efficiency, make landscape maintenance easier in the long term, and present as much comfort and aesthetic value as other plants and lawns (Hilaire, VanLeeuwen, and Torres, 2010; Howley, 2011; Shober, Denny, and Broschat, 2010).

Studies of residential DTP adoption examine i) the adoption of environmental and water-conserving practices, focusing on residential landscape choices and factors influencing those choices including behavioral, demographic, and environmental aspects (e.g., Brehm, Pasko, and Eisenhauer, 2013; Howley, 2011); ii) the effects of respondents' attitudes toward landscapes, perceptions of climate conditions, and landscape water needs (Balling and Gober, 2007; Yabiku, Casagrande, and Farley-Metzger, 2008); and iii) the effects of information providers, educational programs, and income levels on DTP adoption (Helfand et al., 2006; Hilaire, VanLeeuwen, and Torres, 2010; Lockett et al., 2002).

One key limitation of existing analyses of DTP adoption is that most studies have ignored the potential influence of perceptions about climate change, attitudes toward the local environment, and trust in information providers, which may influence landscape management choices and water consumption behaviors. Most studies have focused on residential adoption of water conservation practices in the U.S. South and West; no research has been carried out on DTP adoption as a climate change adaptation strategy in the Midwest. While water resources will probably be sufficient, the volume of water use will increase during droughts and the per unit cost of water may increase due to the need for additional water treatment plants. A review of the literature enables us to put the adoption decision in the broader context of climate adaptation and to identify specific variables for inclusion in our empirical analysis.

Conceptual Framework

Households make adoption decisions to maximize their expected utility. Household utility is a function of expected costs and benefits of adoption as well as their preferences, which are influenced by various factors (figure 1). The explanatory variables in our model fall into five major categories: i) demographic characteristics, ii) landscape management practices, iii) trust in information sources about soil and water, iv) neighbors' opinions and residents' attitudes, and v) perceptions of climate change. These categories follow conventions in adoption studies (e.g., Arbuckle, Morton, and Hobbs, 2015; Mills and Schleich, 2010; Prokopy et al., 2008; Roberts et al., 2004).

Among demographic factors, education and income variables assume a link between knowledge, ability and willingness to adapt to climate change, and the current application of adaptation strategies (Alam, 2015; Alauddin and Sarker, 2014; Arbuckle, Morton, and Hobbs, 2013; Cook, Hall, and Larson, 2012; Hilaire, VanLeeuwen, and Torres, 2010; Lockett et al., 2002; Martini, Nelson, and Dahmus, 2014). Homeowners with higher levels of these attributes are not only exposed to more ideas and have more experience making decisions and effectively using information (Loss, Ruiz, and Brawn, 2009; Prokopy et al., 2008) but are also motivated to learn about consequences of climate risks and more able to take appropriate measures to mitigate negative outcomes (Adger, Arnell, and Tompkins, 2005; Volo, Vivoni, and Ruddell, 2015). Thus, we hypothesize that respondents with either more schooling or higher income are more likely to adopt DTPs. Property ownership determines whether residents can make long-term landscape management plans, as renters may not be allowed to modify the landscape. People who own their homes also receive a stream of future benefits from planting DTPs (des Rosiers et al., 2002), so we hypothesize that residents owning their home are more likely than renters to adopt DTPs.

Gender and the presence of children in the household are also included as control variables in the regression. Residential choices regarding landscape practices may differ due to different behaviors and preferences among men and women and can be affected by different outdoor activities if they have children (Cook, Hall, and Larson, 2012; Martínez-Espiñeira, García-Valiñas, and Nauges, 2014). However, depending on the context, findings differ on whether male- or female-headed households are more likely to adopt DTPs (Bryan et al., 2009). The effect of children is also indeterminate. Households with children may enjoy more time in their yards but want lower maintenance compared to those without children (Dupont and Renzetti, 2013). Lastly, location variables are good predictors of water consumption and area of land (Cook, Hall, and Larson, 2012; Sovocool, 2005). Households located far from urban areas have larger areas to irrigate and, unlike urban homes, may need to install expensive irrigation systems to water plants far from the house. We hypothesize that residents living in rural subdivisions and isolated rural residences are more likely to adopt DTPs to reduce water bills and the likelihood of plants dying.

Landscape management variables include mowing their lawns high, never watering (or watering only during severe droughts), and time spent on yardwork. The practice of mowing lawns high, referring to setting mowers at the highest setting (4 inches), promotes the development of a deeper root system, so households can use less irrigation water and lower their water bills (Smith and Fellowes, 2014). Mowing high may also indicate that residents have a better understanding of responses to drought. Thus, we hypothesize that households are more likely to adopt DTPs if they mow their lawns high. The literature shows that household water conservation practices can also determine landscape plant choices (Martin, Peterson, and Stabler, 2003; Scheiber and Beeson, 2006).

We hypothesize that households are more likely to adopt DTPs if they seldom or never water their lawns since drought tolerant plants may be seen as a substitute for costly irrigation. The amount of time spent taking care of the landscape reflects homeowners' preferences for yardwork and gardening (Lockett et al., 2002; Martin, Peterson, and Stabler, 2003). Therefore, we hypothesize that residents are more likely to adopt DTPs if they spend more time on landscape management activities.

Access to information and trust in information providers can be barriers/stimuli to and limit/promote innovation adoption (Lockett et al., 2002). Homeowners who trust specific information providers would be likely to follow their suggestions regarding water management, lawn maintenance, landscape choices, etc. (Martini, Nelson, and Dahmus, 2014). Different sources spread varying information based on their objectives, and thus their information may have diverse effects. For example, information from local water groups probably encourages less water-intensive and more environmentally friendly landscape management practices. Information from local news media could inform residents about regulations and raise awareness of potential environmental problems. Thus, we hypothesize that households who trust local water groups and local news media are more likely to adopt DTPs. Information from lawn-care companies promotes green, weed-free lawns, and they would not encourage the planting of DTPs. Therefore, we hypothesize that households who trust lawn-care companies are less likely to adopt DTPs.

Valuing neighbors' opinions and residents' environmental knowledge have differing effects on adoption. The effects of neighbors' opinions about lawn-care choices relate to whether households get private satisfaction or gain status if their neighbors appreciate the lawns' appearance (Kiesling and Manning, 2010), which would lead to more frequent irrigation (Larsen and Harlan, 2006). Therefore we hypothesize that those concerned about neighbors' opinions are less likely to adopt DTPs. Homeowners who agree that their landscape management influences local water quality tend to make changes and protect local waterways for the benefit of their community and environment (Clayton, 2007; Kiesling and Manning, 2010), indicating homeowners' attitude toward these impacts can be a proxy for general environmental concerns regarding residential landscapes. Therefore, we hypothesize that knowledgeable residents choose to plant more DTPs.

In addition, landscape choices made by homeowners can be affected by specific climatic conditions (Martin, Peterson, and Stabler, 2003). We hypothesize that households' adoption of DTPs is correlated with their perceptions of phenomena predicted to become more frequent due to climate change. Specifically, if residents are more concerned about longer droughts, we expect them to plant more DTPs. DTP adoption could reduce high water bills resulting from more irrigation during droughts and reduce the likelihood of plant death. However, if they are more concerned about more frequent intense rains, we expect less DTP adoption. Table 1 presents the hypothesized signs of the independent variables (based on the reviewed literature).

Methods and Data

Probit Adoption Model

To analyze the factors influencing DTP adoption, we construct an adoption decision model specifying the explanatory variables. Residents weigh the expected utilities from adoption versus non-adoption. Following Rahm and Huffman (1984), the expected utility can be given by $U(C_{ij}, B_{ij}, P_{ij})$ for household i if it adopts $(j = 1)$ or does not adopt $(j = 2)$ DTPs, where C_{ij} represents the expected costs of planting DTPs, including the price of plants, the time spent planting them, maintenance until they are fully established, etc.; B_{ij} represents the expected benefits from enjoying the beauty of the garden and the ease of future maintenance, including reduced irrigation costs; and P_{ij} represents residents' preferences for gardening, attitudes toward local water quality, etc. The household chooses to adopt if the expected utility of adoption is greater than that of non-adoption (i.e., if $U_{i1} > U_{i2}$). As the parameters of the household's utility function are unobservable,

Table 1. Independent Variables and Definitions

Independent Variables	Expected Sign	Definition
Demographic characteristics		
Education		Highest grade completed by respondents
≤ High school	–	
Two-year college	Base	
≥ Four-year college	+	
Household income		Household income in 2013
< $25,000	–	
$25,000–$49,999	Base	
$50,000–$74,999	+	
$75,000–$99,999	+	
≥ $100,000	+	
Own home	+	Own the home or have mortgage (yes=1; otherwise=0)
Male	+/–	Family head is male (yes=1; female=0)
Children	+/–	Have children under the age of 12 (yes=1; no=0)
Location		Where the respondent's home is located
City	–	City of Columbia, Missouri (yes=1; no=0)
Suburban	–	Suburban area in or near the city (yes=1; no=0)
Rural subdivision	Base	Rural subdivision (yes=1; no=0)
Isolated rural area	+	Isolated, non-farm or farm area (yes=1; no=0)
Landscape management		
Mowing high	+	Set mower at highest setting (i.e., 4 inches) (use=1; otherwise=0)
Watering in drought	+	Never water or only water lawn when in severe drought (yes=1; otherwise =0)
Time		Hours per month spent on yardwork during the growing season
0–5 hours	–	
6–15 hours	Base	
> 15 hours	+	
Trust in information sources about soil and water		
Water group	+	Local watershed group/project (moderately or very much=1; otherwise=0)
Media	+	Local news media (moderately or very much=1; otherwise=0)
Lawn-care company	–	Lawn-care company (moderately or very much=1; otherwise=0)
Neighbors' opinions and residents' attitudes		
Nice lawn	–	It is important to me that my neighbors think I have a nice lawn (agree or strongly agree=1; otherwise=0)
Water quality	+	The way I care for my yard can influence water quality in local streams and lakes (agree or strongly agree=1; otherwise=0)
Perceptions of climate change		
Drought	+	I am concerned about longer dry periods or drought (agree or strongly agree=1; otherwise=0)
Rain	–	I am concerned about more frequent intense rain (agree or strongly agree=1; otherwise=0)

the function is usually defined by a latent variable, U^*_{ij}, which is associated with a set of explanatory variables (X_i):

$$(1) \qquad U^*_{ij} = X_i \boldsymbol{\alpha}_j + e_{ij} \quad i = 1,2,\ldots,N;\; j = 1,2,$$

where $\boldsymbol{\alpha}_j$ is a vector of adoption parameters and e_{ij} is a random error term. After knowing the household's decision, the observed pattern of DTP adoption can be represented by the binary variable (y_i), and these observed values of y_i are related to U^*_{ij}:

$$(2) \qquad y_i = \begin{cases} 1 \text{ if } U^*_{i1} > U^*_{i2} \\ 0 \text{ otherwise} \end{cases}$$

Accordingly, the probability of adoption can be denoted as (Rahm and Huffman, 1984)

$$(3) \qquad P_r[y_i = 1] = F(\boldsymbol{X}_i \beta),$$

where F is the cumulative distribution function and $\beta = \alpha_1 - \alpha_2$. The parameters β can be estimated using maximum likelihood estimation. Binary choice models differ only in the assumption about the functional form of F.

A probit or logit model is commonly used in studies of the factors influencing adoption likelihood (Hahn and Soyer, 2005). All of the variables in our adoption model are binary, where 1 represents agree or yes, and 0 represents no or otherwise. Probit models have been preferred primarily due to the relative ease of computation. For probit models, we assume p_i is given by the standard normal distribution function $\Phi(x'\beta)$ (Greene, 2008). Thus given the dichotomous nature of the dependent variable, we use the following univariate probit model:

$$(4) \qquad P_r(y = 1|x_1, x_2, \ldots, x_k) = \Phi(\boldsymbol{x}'\boldsymbol{\beta}),$$

where $\boldsymbol{x} = (x_1, x_2, \ldots, x_k)$ are independent variables and $\boldsymbol{\beta} = (\beta_1, \beta_2, \ldots, \beta_k)$ are parameters, which can be estimated for each corresponding x variable.

All analyses are conducted using the data analysis package STATA version 13.1. Coefficients in probit models cannot be directly interpreted as marginal effects, and marginal effects for discrete (i.e., binary or dummy) variables used in our model must be computed separately.[2]

Data

We use data from a mail survey of randomly selected Columbia, Missouri, households in single-family homes conducted between February and May 2014.[3] The survey covered specific water-management and nutrient-use practices adopted by residents related to their lawns and gardens as well as their attitudes toward these issues. Some of the questions were designed to learn whether households had adopted DTPs as a residential water conservation practice and how the household's and residential landscape characteristics had affected the adoption decision.

The questionnaire was designed using the Dillman survey method (Dillman, 2000). A focus group pretesting method was used and minor modifications were made based on participant comments. In the spring of 2014, 2,000 questionnaires were initially mailed out to a random sample of households, followed by a reminder postcard two weeks later. A second questionnaire was sent out two weeks after that to those who had not responded to the first. The person most responsible for landscape management in each household was asked to fill out the survey. The effective response rate (adjusted for those who had moved or died) was 44%, which is higher than some other studies (Brehm, Pasko, and Eisenhauer, 2013).

[2] For a categorical variable, x_k, the marginal effect of $x_k = Pr(y = 1|x, x_k = 1) - Pr(y = 1|x, x_k = 0)$.

[3] The source of our sample was Survey Sampling Incorporated. The survey covers three ZIP codes (65201, 65202, and 65023), roughly the Columbia Metropolitan Area.

Table 2. Comparison of Sample to Census Data

	Survey Respondents (2014)	**City of Columbia (2010–2014)**	**Metropolitan Area (2005–2007)**
Education			
Less than bachelor's degree	29%	44%	55%
Bachelor's degree or higher	71%	56%	45%
Household income			
< $25,000	7%	55%	30%
$25,000–$49,999	19%		27%
$50,000–$74,999	27%	15%	18%
$75,000–$99,999	18%	10%	11%
≥ $100,000	29%	20%	15%

Notes: Data included individuals living in both apartments and detached homes (U.S. Census Bureau, 2010, 2015).

There were 751 households providing responses on the DTP adoption question.[4] Among these respondents, the DTP adoption rate was 32.89%. A total of 127 observations were excluded due to one or more missing values (e.g., on income, education, and information sources). Of the remaining 624 observations, 200 households had adopted DTPs, so the adoption rate was 32.05%.

The variables shown in table 1 reflect the combining of some response categories in the original survey. These transformations were made primarily for Likert-scale variables to preserve degrees of freedom and to develop a more parsimonious model. Likert-scale variables cannot be treated as continuous variables, because the intervals are not equal. The dependent variable was DTP adoption (1="currently use it" and 0=otherwise, including responses of "know how to use it, but not using it," "somewhat familiar with it, but not using it," "never heard of it," and "not applicable").

The education variable included three subcategories: some schooling or high school diploma, some college or two-year college degree (base category), and four-year college or post-graduate degree. Annual household income was divided into five subcategories in the survey: ≤$25,000, $25,000–$49,999 (base category), $50,000–$74,999, $75,000–$99,999 and ≥$100,000. Dummy variables were also used for variables of male (versus female), owning home (versus renting), and the presence of children under the age of twelve (versus none). Location variables included living in the City of Columbia, its suburbs, a rural subdivision (base category), and isolated rural residence.[5]

The adoption of mowing high was treated the same way as DTP adoption. Four categories of lawn-watering frequency were provided to respondents: watering on an as-needed basis to keep it green, only in summer, only in severe droughts, and never watering. We combined the last two as a low-watering variable and the rest as the base in the regression. Variables for time spent on yardwork were recoded to reflect three subcategories (i.e., 0–5 hours, 6–15 hours [base category], and >15 hours). Response options for the degree of trust in various information providers included not at all, slightly, moderately, very much, and not familiar. For each information provider, the moderate and very much categories were combined to a dummy variable and the others were combined into a base category. Variables for neighbors' opinions about their lawn, the effects of landscape management on local water quality, and perceptions of climate change were obtained by asking respondents to rate their views on these statements using a Likert scale (1=strongly disagree, 2=disagree, 3=neither

[4] The survey examined other practices in addition to DTPs. The specific question and responses were:

> Please indicate which statement most accurately describes your level of experience with each practice listed below.
> e. Plant drought tolerant plants in my garden.

Response options: Not applicable; never heard of it; somewhat familiar with it, but not using it; know how to use it, but not using it; currently use it.

[5] In the Columbia area, one does not find a continuum from small urban/city yards to larger suburban yards, followed by even larger yards at the rural/urban interface (or the peri-urban region). Some rural subdivisions may have yards similar in size to suburban ones, but they are separated from the suburban areas by several miles, with an area of farms in between.

agree nor disagree, 4=agree, and 5=strongly agree). Responses of 4 and 5 were combined into an "agree" category and responses of 1, 2, and 3 were combined into the base category in the regression.

Results and Discussion

Descriptive Statistics

Table 2 compares survey respondents to the populations of both the City of Columbia and the Columbia Metropolitan Area (CMA). While our survey covered an area similar to that of the CMA, the survey timing was closer to the latest city Census data. The Census data are for all residents, while the surveyed population was only those living in single-family homes. Compared to the U.S. Census data for both the City of Columbia and the CMA, the sample had a higher proportion of respondent households with a bachelor's degree or higher. Survey respondents also had higher household income levels than the populations in both the city and CMA (i.e., for categories \$50,000–\$74,999, \$75,000–\$99,999, and $\geq$\$100,000). More than half of the population of both the city and CMA had incomes less than \$50,000. The education and income levels of respondents may be fairly representative of the surveyed population living in single-family homes because those living in houses versus apartments tend to be more educated and have higher incomes (Bourassa, Cantoni, and Hoesli, 2007, Mary Ann Groves, personal communication).[6]

Summary statistics for the survey data used in the regression are presented in table 3. Approximately 32% of respondents reported adopting DTPs. The most common educational category according to the survey was completion of four-year college or post-graduate degree (71%). The percentages of residents with some formal schooling, high school diploma, GED, and some college or a two-year college degree were 10% and 20%, respectively. A majority of respondents were male (62%), and almost all respondents owned their home or had a mortgage (91%) rather than renting. Around 13% of the surveyed households had one or more children under the age of twelve. Most respondents were living in the City of Columbia (61%), with fewer living in suburbs (25%), rural subdivisions (8%), and isolated rural areas (6%).

Regarding residential landscape management practices, 66% of people set their mowers at the highest level. About 62% of respondents never watered or only watered their lawns during severe droughts. More than half of households (56%) spent 6–15 hours per month on landscape maintenance and 20% spent 0–5 hours, while 23% spent more than 15 hours. Generally, more than half of residents trusted information from local watershed groups and projects (61%) about soil and water. Fewer people trusted local news media and lawn-care companies (35% and 37%, respectively).

About 37% of households valued their neighbors' attitudes about the appearance of their lawns. Most people (87%) agreed that the way they cared for their yards could influence water quality in local streams and rivers. More people were concerned with long dry periods or droughts (77%) than frequent intense rains (36%), which may relate to the drought in 2012.

Comparison of Adopters and Non-adopters

Table 3 compares characteristics of adopters versus non-adopters. The mean for homeownership was higher for adopters than for non-adopters, while a significantly lower proportion of male respondents were adopters. More adopters than non-adopters lived in rural subdivisions, but there were no significant differences for other types of locations. More adopters than non-adopters mowed lawns high, implying a correlation between DTP adoption and mowing high. Fewer adopters than non-adopters spent less than 5 hours per month on yardwork, but the reverse was true among those

[6] Groves pointed out that Columbia, Missouri, is a college town with two universities and three colleges as well as a medical town with five medical centers. Both facts would increase the education level of local residents compared to similar-sized cities elsewhere.

Table 3. Summary Statistics and Characteristics of Adopters and Non-adopters of DTPs (n = 624)

Variables	Mean	Standard Deviation	Adopters (%)	Non-adopters (%)	% Difference
Dependent variable					
DTP adoption	0.32	0.47			
Independent variables					
Demographic characteristics					
Education					
≤ High school	0.10	0.30	8.00	10.38	−2.38
Two-year college	0.20	0.40	23.00	18.40	4.60
≥ Four-year college	0.71	0.46	69.00	71.23	−2.22
Household income					
< $25,000	0.07	0.26	8.00	6.60	1.40
$25,000–$49,999	0.19	0.39	16.50	20.52	−4.02
$50,000–$74,999	0.27	0.44	25.50	27.12	−1.62
$75,000–$99,999	0.18	0.38	18.00	17.93	0.08
≥ $100,000	0.29	0.45	32.00	27.83	4.17
Own home	0.91	0.29	94.00	89.62	4.38*
Male	0.62	0.48	55.00	65.80	−10.80***
Children	0.13	0.33	10.00	13.92	−3.92
Location					
City	0.62	0.49	59.50	62.50	−3.00
Suburban	0.25	0.43	21.50	26.65	−5.15
Rural subdivision	0.08	0.26	12.00	5.43	6.58***
Isolated rural area	0.06	0.24	7.00	5.43	1.58
Landscape management					
Mowing high	0.66	0.47	80.50	59.67	20.83***
Watering in drought	0.62	0.49	65.00	60.14	4.86
Time					
0–5 hours	0.20	0.40	10.00	25.00	−15.00***
6–15 hours	0.56	0.50	53.50	57.78	−4.28
> 15 hours	0.23	0.42	36.50	17.22	19.28***
Trust in information sources about soil and water					
Water group	0.61	0.49	70.50	55.80	14.60***
Media	0.35	0.48	34.50	34.90	−0.41
Lawn-care company	0.37	0.48	31.50	39.62	−8.12**
Neighbors' opinions and residents' attitudes					
Nice lawn	0.37	0.48	39.50	35.38	4.12
Water quality	0.87	0.34	93.00	83.73	9.27***
Perceptions of climate change					
Drought	0.77	0.42	77.83	76.00	1.83
Rain	0.36	0.48	33.26	43.00	−9.75**

Notes: Sums of means may not equal 1 due to rounding. % Difference = mean of Adopters – mean of Non-adopters. A positive value means the first group ("1 = adopting DTPs") has a higher mean than the second group ("0 = otherwise"). χ^2 test was conducted to analyze the difference with H_0: difference = 0; Ha: difference $\neq$ 0. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Range for all independent variables is (0,1) and is used to calculate the mean and standard deviation.

spending more than 15 hours, indicating that adopters spent more time gardening. More adopters trusted information from local water groups/projects, and fewer adopters trusted information from lawn-care companies. More adopters agreed that the way they cared for the yard could influence local water quality. Over 75% of both adopters and non-adopters were concerned about future droughts. Fewer adopters were concerned with intense rainfall. While these comparisons are useful, regression allows us to examine the combined effects of these factors in determining DTP adoption and the magnitudes of those effects.

Regression Results and Discussion

Because the five variable categories included a wide variety of independent variables, we examined correlation coefficients for each pair of variables and tested for multicollinearity in the regression as a whole. The correlation coefficients had absolute values smaller than 0.40 for all variable pairs. We found no evidence of multicollinearity, as indicated by the variance inflation factor (VIF) values.[7] The pseudo-R^2 value for the probit regression was 0.15 (table 4).[8] The likelihood ratio (LR) Chi-square indicated that the model as a whole was significant ($p < 0.001$).

Probit regression results for our preferred specification are shown in table 4. For this model, the values for marginal effects measure the conditional probability changes in adoption, given the level of the other independent variables. For the variables for demographic characteristics, diverse effects were found in the model. Unexpectedly, education levels were nonsignificant. Very high annual household income (≥$100,000) had a positive effect on adoption ($p < 0.10$), consistent with the research by Brehm, Pasko, and Eisenhauer (2013), Helfand et al. (2006), and Loss, Ruiz, and Brawn (2009) that wealthier people were more willing to pay for residential plant species. Meanwhile, respondents with very low incomes (<$25,000) were also significantly more likely to adopt ($p < 0.01$), contrary to our expectation. However, this finding could be due to low income limiting household expenditure on residential landscapes (Balling and Gober, 2007; Cook, Hall, and Larson, 2012), including irrigation. Contrary to western states where residents replaced lawns with DTPs, in the Midwest DTP adoption typically means choosing to plant drought tolerant species of trees and bushes rather than water-consuming species, which reduces costs relative to lawn replacement. DTPs generally cost less over time compared to planting water-consuming plants and lawns,[9] in terms of expenditure on irrigation water, irrigation systems, fertilizer, maintenance equipment and professional services (Martin, Peterson, and Stabler, 2003; Shober, Denny, and Broschat, 2010).

Being male was negatively correlated with DTP adoption ($p < 0.01$). A male-headed household was 11.5% less likely to use DTPs. The literature has shown that gender may have mixed effects depending on context (Bryan et al., 2009; Cook, Hall, and Larson, 2012). Some research suggests that men may express lower environmental concerns than women (Hunter, Hatch, and Johnson, 2004; Martínez-Espiñeira, García-Valiñas, and Nauges, 2014). Our result was in line with Larson et al. (2009); Martin, Peterson, and Stabler (2003); and Yabiku, Casagrande, and Farley-Metzger (2008). Consistent with our prediction, residents owning their homes were significantly more likely

[7] The VIF values for all variables were less than 2.40, with an average of 1.40, where a VIF of greater than 8 indicates that a variable may be deemed a linear combination of other independent variables in the model. For the original model, we also included dummy variables for respondents' age, age of house, and money spent on the lawn. However, there was a strong correlation between age and income as well as age of house and homeownership. One third of observations had missing values for money spent. Excluding these variables improved the model's overall goodness of fit.

[8] For models with binary dependent variables, the traditional ordinary least squares measure of fit, R^2, cannot be applied. Moreover, the regression had binary independent variables, so the appropriate measure reported in the probit regression results was a pseudo-R^2 value, a likelihood-based measure. It ranges from 0 to 1, with higher values indicating better fit of the model. The pseudo-R^2 value was low but acceptable for adoption studies (Alcon et al., 2014; Sharp, Daley, and Lynch, 2011), indicating that other variables not included in this regression probably affected the adoption of DTPs.

[9] For many technologies, a higher up-front cost can be dwarfed by the benefit of reduced future expenditures (Mills and Schleich, 2010).

Table 4. Results of Probit Regression for the Adoption of Drought Tolerant Plants

	Parameter Estimate		Marginal Effect	
Independent Variables	**Coefficient**	**Robust Std. Err.**	**dy/dx**	**Delta-method Std. Err.**
Intercept	−1.145***	0.410		
Demographic characteristics				
Education (base = two-year college)				
≤ high school	−0.302	0.224	−0.091	0.067
≥ four-year college	−0.122	0.142	−0.037	0.043
Household income (base = $25,000–$49,999)				
< $25,000	0.590**	0.261	0.178**	0.077
$50,000–$74,999	0.088	0.177	0.027	0.053
$75,000–$99,999	0.240	0.197	0.072	0.059
≥ $100,000	0.309*	0.186	0.093*	0.056
Own home	0.384*	0.225	0.116*	0.067
Male	−0.381***	0.119	−0.115***	0.035
Children	−0.175	0.178	−0.053	0.054
Location (base = rural subdivision)				
City	−0.591***	0.214	−0.178***	0.064
Suburban	−0.637***	0.234	−0.192***	0.069
Isolated rural area	−0.654**	0.293	−0.197**	0.087
Landscape management				
Mowing high	0.626***	0.130	0.189***	0.037
Watering in drought	0.114	0.131	0.034	0.039
Time (base = 6–15 hours)				
0-5 hours	−0.406**	0.168	−0.122**	0.050
> 15 hours	0.429***	0.135	0.129***	0.040
Trust in information sources about soil and water				
Water group	0.409***	0.125	0.123***	0.037
Media	−0.067	0.121	−0.020	0.036
Lawn-care company	−0.279**	0.122	−0.084**	0.036
Neighbors' opinions and residents' attitudes				
Nice lawn	0.140	0.125	0.042	0.038
Water quality	0.475**	0.187	0.143**	0.056
Perceptions of climate change				
Drought	0.253*	0.148	0.076*	0.044
Rain	−0.230*	0.127	−0.069*	0.038
Goodness of fit				
Observations	624			
Wald Chi-square	101.08			
Prob > Chi-square	< 0.001			
Log likelihood	–332.09			
Pseudo R^2	0.15			
Variance inflation factor (VIF)	Mean: 1.40 (min-max: 1.04–2.40)			

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

to adopt DTPs compared to those who rented. People who own their property may obtain benefits over time from the lower costs associated with DTPs and from any improvements at the time of sale.

Residents living in city, suburban, or isolated rural residences (versus those living in rural subdivisions) were significantly less likely to adopt DTPs. Rural residential lots are usually somewhat larger and households might choose to plant DTPs due to the difficulty of watering large areas and to save time and money on yard care and maintenance. Isolated rural residences or farms also have much larger areas to irrigate, so these respondents may think that preventing the consequences of droughts is infeasible, even with DTPs.

The practice of mowing lawns high showed a positive effect on adoption ($p < 0.01$),[10] as expected, since both are adaptive responses to drought. Additionally, using the time category of 6–15 hours of yardwork as the base in the regression, spending 0–5 hours was negatively correlated with adoption ($p < 0.05$) and spending more than 15 hours was positively correlated with adoption ($p < 0.01$). These results were consistent with our hypothesis. Respondents who spent more than 15 hours probably like to garden and are curious about plants. The lowest time category corresponds to the time required just to mow the lawn. Interestingly, the low watering variable reflecting never watering or only watering lawns in severe droughts was not significant, *ceteris paribus*.

The trust in various information sources had mixed effects on adoption. Trust in information from local watershed groups/projects had a positive effect on adoption ($p < 0.01$) and could lead to a household being 12.3% more likely to adopt compared to the base case. On the other hand, trust in information from lawn-care companies had a negative effect on adoption ($p < 0.05$). These findings were in line with our expectations based on the literature (Martini, Nelson, and Dahmus, 2014).

The effect of valuing neighbors' opinions on lawn-care choices was not significant, which indicates that social norms are probably not a barrier to DTP adoption in this area. On the other hand, our regression results indicated that households who agreed that the way they cared for yards could influence local water quality were more likely to adopt DTPs ($p < 0.05$), which was consistent with the literature. To be environmentally friendly and benefit their community, residents are more willing to use plant species and reduce water pollution induced by fertilization and irrigation (Kiesling and Manning, 2010).

According to our results, concern about droughts was positively associated with adoption ($p < 0.10$), while concern about intense rains was negatively associated with adoption ($p < 0.10$). These results were in line with our hypotheses that respondents who were concerned about longer droughts were more likely to adopt DTPs, while those concerned with more frequent intense rains were less likely to adopt (Hilaire, VanLeeuwen, and Torres, 2010; Martin, Peterson, and Stabler, 2003). While there was no significant difference between adopters and non-adopters in the level of concern about droughts when comparing means,[11] this variable was significant in the regression, which shows the importance of statistically controlling for other factors.

Robustness checks were conducted in multiple ways. We estimated two models with additional variables: i) using four dummies for the original five-point Likert-scale variables and ii) using dummies combining some minor scales.[12] To test for endogeneity between DTP adoption and mowing high, other models were tested, including bivariate probit regression, seemingly unrelated bivariate probit, two-stage bivariate probit, and the Heckman selection model.[13] Comparisons across

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[10] For a discussion of how we tested for potential endogeneity, see the end of this section and footnote 13.

[11] The nonsignificant difference may be a result of combining response categories "agree" with "strongly agree" since more adopters strongly agreed with the drought concern.

[12] Specifically, we tried combining "strongly disagree" and "disagree" as well as "strongly agree" and "agree" (with "neither" as the base).

[13] The ρ in the bivariate probit regression with DTP adoption and mowing high was not significant ($p > 0.10$), indicating no evidence of endogeneity (Knapp and Seaks, 1998), which was confirmed by the nonsignificant ρ in seemingly unrelated biprobit models (Cameron and Trivedi, 2009) and nonsignificant inverse Mills ratio in the two-stage models (Wooldridge, 2015).

the results from these models showed that the signs and significance levels of most variables were robust (Knapp and Seaks, 1998)[14] and that the current model does not exhibit endogeneity.

Conclusions and Implications

One dimension of climate change is that rainfall will become more unevenly distributed in time, which could affect the availability and use of local water resources (Wanders and Wada, 2015). Because Midwestern states are not typically drought-stricken, local infrastructure and landscape design give little consideration to possible climate risks, which is one reason why the 2012 Midwest drought not only devastated agricultural production but also damaged residential properties (U.S. Department of Agriculture, Economic Research Service, 2012). Households can adapt to future climate risks by adopting various practices to conserve water use, including adopting DTPs for the landscape (e.g., Bryan et al., 2009). By analyzing survey data from an urbanizing watershed in the Midwest, we obtained unique findings that could contribute to the literature and to future policy design on adaptation to climate change and water shortages.

Household income and location were found to be fundamental factors impacting adoption decisions. High income facilitates higher adoption due to the ability to purchase new plants, while low income may motivate households to limit irrigation costs. At the same time, households in rural subdivisions have larger areas to irrigate and DTP adoption could potentially save costs on irrigation water and equipment. An interest in gardening (with time spent as a proxy) and understanding of responses to drought (e.g., mowing lawns high) enable higher resilience and lower vulnerability to droughts. Environmental attitudes, as revealed by trust in local water groups and awareness of the effect of their landscape management on local water quality, are associated with more environmentally friendly practices.

Our findings suggest that educational programs can be designed to address the concerns of different types of residents. Presentations to gardening clubs would reach serious gardeners who may be concerned with water use but also want attractive plants. For lower income people, the benefit of reduced irrigation costs should be highlighted in educational materials, and economic incentives such as subsidies could reduce the up-front costs. The City of Columbia is also considering subsidizing moisture sensors for people installing automatic irrigation systems (Connie Kacprowicz, personal communication). Columbia already has an increasing block-rate structure, but households with higher than average water use could be sent fliers on water conservation strategies along with their utility bills.

In addition, residential water-use efficiency evaluations—which increase households' awareness of their water use and the potential for conservation—could motivate the adoption of low-water-consuming plants. For new housing developments, incentives or regulations could promote installation of more drought-tolerant landscaping as the default for new homes. For isolated rural residences and farms, local farm and home stores might collaborate with Extension specialists on point-of-purchase information on DTPs and their long-term private benefits. Extension specialists and local government personnel should have programs on water conservation strategies that can be quickly mobilized when droughts do occur in order to take advantage of a teachable moment. Environmental groups and programs associated with water quality and water resources can explain the broader environmental benefits of DTPs.

Our findings also suggest some interesting areas for future research. Contrary to expectations, both income and property size seem to have non-linear impacts on DTP adoption; these phenomena need to be examined more carefully. The impact of climate change perceptions on adaptation is

[14] For the climate change concern variables, nonsignificant results were obtained when using two or four dummy variables, but the p values were 0.12–0.18. We found that both the combined category "strongly disagree & disagree" and "neither" have the same effect on DTP adoption, and the effect was opposite to that of "strongly agree & agree." Thus combining "strongly disagree," "disagree," and "neither" as a base used in the regression yielded a significant effect of "strongly agree & agree" for both drought and rain variables.

another area that merits further research. For example, as memories of the 2012 drought recede, will perceptions and behaviors change? Comparative research on regions that are and are not prone to droughts and water shortages would be another interesting extension of this research. Future research could also more directly test effects of climate change perceptions, rather than focusing on specific impacts. More generally, improved understanding of factors affecting households' adaptation to increased rainfall variability can reduce the negative consequences of climate change and allow effective policies and educational programs to be developed.

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