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Upper Midwestern U.S. consumers and ethanol: Knowledge, beliefs and consumption

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ABSTRACT

This study uses multivariate statistical methods to explore the beliefs of upper Midwestern U.S. residents about global climate change, and possible consumer responses to determine their willingness to pay more for cellulosic ethanol from multiple feedstocks. A mail survey was sent to residents of Michigan, Minnesota, and Wisconsin to determine baseline knowledge, attitudes and beliefs on several aspects of these issues, with a focus on the emerging market for cellulosic ethanol. First, survey responses were compiled and principal components analysis was used to reduce the dimensionality of the data. This resulted in seven factors and a theoretical framework to help understand consumers' beliefs about climate change and possible energy policy responses. Second, these results were combined with insights from previous studies that were used as input for further research hypotheses and multivariate analyses. The factor scores from principal components analysis along with the some of the key control variables (i.e., gender, income, and rural/urban) served as independent variables in three revised multiple regression models of consumer's willingness to pay (WTP) their fair share of any additional cost of cellulosic ethanol, as reported in an earlier study. Four explanatory variables were found to be significant determinants of WTP in every model: environment, energy consumption, and climate change; concerns about climate change impacts; inability to stop climate change; and gasoline prices and consumption. These results suggest strong public support and consumer WTP for cellulosic ethanol production in the region.

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1. Introduction

Without a doubt, global climate change is one of the most important and vexing problems facing humanity. A major part of any successful mitigation strategy will include energy and environmental policies to reduce greenhouse gas emissions from fossil fuel combustion, especially the development of renewable sources of energy that enjoy substantial public support [1]. In the United States, recent renewable energy policies have focused on electric power production tax credits at the federal level and state Renewable Portfolio Standards that have helped to stimulate the rapid development of wind power in particular. However, wind power can only offset greenhouse gas emissions in the electric power sector which, while important, does not cut emissions in the industrial, buildings, and transportation sectors. Many other sources of renewable energy are available in the US and could be used more widely, but have been hampered by higher costs in most regions (solar energy), limited regional availability (geothermal and water power), environmental challenges (biomass energy), or are similarly

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limited to the electricity sector (hydroelectricity, ocean thermal energy conversion, tides, waves).

As Amory Lovins argued in a seminal paper, renewable sources of energy are best analyzed on a regional basis [2]. In this manner, policy-makers can determine which energy resources have the greatest potential, are most practical, and best matched to the end use needs of a particular state or region. For example, in the U.S. context wind power may be best used in the Great Plains, especially Texas and the Dakotas, Pacific states, and perhaps offshore the Eastern Seaboard [3,4], while geothermal energy has the most potential in California and Nevada. Hydroelectricity has been most heavily developed in the Western states, especially California and the Pacific Northwest. Agricultural biomass energy, in turn, naturally has the most potential in the farm states, while forest biomass resources are more widespread [5].

The upper Midwestern states of Minnesota, Wisconsin, and Michigan have substantial biomass energy potential. For instance, research has found that this region has large potential for biomass (cellulosic) ethanol production, especially based on agricultural and forestry residues (e.g., corn and wheat stover, logging residues normally left on the forest floor) and waste paper [6]. The fuel could displace up to one-third of gasoline use in the three-state region and significantly reduce greenhouse gas emissions [6]. However, traditionally biomass energy production and usage has been dominated by corn ethanol in Iowa, Illinois, Nebraska, South Dakota, and Minnesota [7]. This traditional use of biomass energy has been a boon for the farm areas in this region, but the cost and environmental performance has been controversial [8]. As a consequence, a significant research and development focus of the last 5–10 years has been the transition to "second-generation" biofuels that use the non-food parts of crops as well as new feedstocks, and which are thereby more sustainable, requiring the separation, pretreatment and conversion of cellulose and hemicellulose contained in residues and grasses [9]. While cellulosic ethanol is not yet commercial, several refineries are being built in the next few years and the market will be catalyzed by the ambitious Renewable Fuel Standard (mandate) approved by the U.S. Congress under the Energy Independence and Security Act of 2007 [6].

The objectives of this study were to use multivariate statistical methods to learn more about U.S. Midwestern consumers' beliefs regarding global climate change and possible responses, and determine if their beliefs influence willingness to pay (WTP) and, therefore, support for cellulosic ethanol from different feedstocks. This work expands upon previous analysis of a survey that was part of a larger study completed by a team of multidisciplinary researchers at Michigan Technological University [6,10]. The purpose of the earlier study was to determine the baseline knowledge, attitudes, and beliefs of the public in the Upper Midwestern states of Michigan, Minnesota and Wisconsin regarding global climate change and potential energy policy solutions. While the problem was framed in terms of climate change, the potential public response focused on biofuels in the transportation sector.

The next section provides a brief literature review of public perceptions on global climate change, and possible energy policy solutions. We also review the pertinent literature on consumer WTP for green energy and greenhouse gas reduction. Section 3 describes the study methodology, which included a survey of Michigan, Minnesota, and Wisconsin residents and principal components analysis (PCA) as an intermediate step to reduce the dimensionality of the survey data. The PCA results are presented in Section 4. This led to a series of hypotheses and bid curve analyses (by use of regression models), discussed in Section 5. Our major results are then summarized and conclusions close the paper in Section 6.

2. Literature review

Climate change is a complex, politically charged problem. This can make it more difficult for citizens/consumers in a democracy to support effective solutions to this global problem. Numerous studies have found that Americans are concerned about climate change, but mixed in their support for the most effective measures to prevent it from happening, such as energy conservation or renewable energy policies [1,11–13]. This is likely tied at least partially to their misunderstandings of climate change causes and associated solutions. Kempton and colleagues [12] performed research with U.S. residents in the early 1990s to assess what they termed their "cultural models" of climate change causes, impacts, and solutions. The authors found that individuals used the cultural models they already had for understanding seemingly similar problems, like the hole in the stratospheric ozone layer and classic air pollution issues, to understanding climate change. Thus people conflated climate change with ozone depletion and believed that it was being caused by industries emitting dirty pollution that could be solved with filtering technologies. They posited, but did not test, the notion that these misunderstandings would reduce support for effective policy and market solutions to climate change. We set out to determine: (a) whether these early 1990s findings still held true in the U.S. in 2007, and (b) if they were indeed linked to lower support for effective solutions to climate change, including the development of cellulosic ethanol. However, it should be noted that our methodological approaches were distinctly different. Kempton et al.'s work was more qualitatively oriented, focusing on describing the models and their values and beliefs subcomponents, rather than constructing indices and quantitative models that can be evaluated with statistical analysis. They did not attempt to assess the general distribution of these beliefs within a larger population. We replicated some of their questions and integrated them into a closed-ended survey that was designed to assess the distribution of some of the key beliefs and values identified by Kempton et al. and incorporated them into indices and quantitative models designed to explain differences in attitudes toward cellulosic ethanol.

The cultural model of climate change resulted in the preliminary theoretical framework for the beliefs variables based on the initial dimensions and related constructs (each question) as defined in the survey. Each of the questions was coded based on its inclusion in six categorical grouping. Coding for these questions is as follows: Self-Perceived Familiarity with Global Climate Change (SFCC), Concerns about Climate Change (CACC), Causes of Climate Change (COCC), Climate Change Solutions (CCS), Energy and America's Future (EAAF), and Views on Environmental Issues (VOEI). The coding of the primary dimensions is important as constructs (each survey question) were loaded on factors (or principal components) through principal components analysis.

Another literature stream was reviewed to understand the potential consumer WTP for cellulosic ethanol. Several contingent valuation method (CVM) surveys and choice modeling experiments have been applied to questions of climate change mitigation, renewable energy, and biofuels. For example, Berrens et al. used a split-sample treatment referendum design to determine WTP for greenhouse gas reduction [14]. While several recent prominent studies have cast doubt on the potential for biofuels to reduce greenhouse gas emissions, this is generally only the case for first-generation ethanol and biodiesel, not cellulosic ethanol [9]. In this research, three national internet-based samples and a national telephone sample baseline were compared. The authors found a conservative mean estimator of $191.70 for household annual WTP, which rose to $816 when only households with a positive WTP were considered. The major explanatory variables included political ideology, education, age, gender, respondent assessments of the fairness and effectiveness of the Kyoto Protocol, and belief in the greenhouse effect. A follow-up study explored WTP to support energy research and development to reduce U.S. reliance on fossil fuels [15]. This second study found that WTP was significantly related to gender, political ideology, income, perceived importance of crop-based energy, and the stated importance of lowering reliance on foreign sources of energy.

Several additional CVM, WTP, conjoint analysis, and choice modeling studies have examined consumer support for "green" energy, including biomass sources, with mixed findings. For example, a typical study has considered consumer willingness to make a voluntary premium payment on electric bills for renewable energy. One study based on telephone interviews in Wisconsin and Colorado found that the mean WTP varied greatly across respondents between the CVM and market simulations employed [16]. It was concluded that the CVM was capable of reliably estimating WTP of customers who would make payments, though not of predicting who would actually pay the electric rate premiums. Another study found contrary findings through conjoint analysis, which were approximately twice as large as the actual price premiums paid by consumers for green electricity [17].

A recent national dichotomous choice, split-sample CVM mail survey was conducted that crossed payment method (voluntary vs. collective) and provision arrangement (private vs. government) for renewable electricity purchases [18]. The responses indicated generally higher WTP values under the collective payment and private provision options. Logit analyses of the bid curves found that significant explanatory variables included bid offer amount, income, political liberalism, gender, and a few attitudinal variables. Two parallel studies in Delaware and Bath (UK) used choice modeling and found that solar energy was the most popular renewable electricity option, with biomass energy and farm methane the least preferred [19,20]. These studies found conflicting results on WTP for green energy in voluntary vs. mandatory programs.

To extend prior analysis by the authors of this paper [21], several research questions were formulated. This study thus expands upon previous research and models to frame the research problem in a slightly different fashion. Based on the theoretical framework from prior research [10,21], the primary research questions are:

1 Do consumers' beliefs about global climate change have an impact on their WTP a fair share extra cost per gallon for cellulosic ethanol?
2 What are the major factors (attitudinal variables) that predict consumers' WTP a fair share of the extra cost of renewable fuel?

3. Methodology

3.1. Survey design and sampling

During 2007–2008 we conducted a randomized mail survey of 1500 residents of the U.S. upper Midwestern states of Minnesota, Wisconsin and Michigan (see Fig. 1 for a map of the study region). These states contain significant forest and agricultural industries, providing ready access to extensive feedstock for cellulosic ethanol [6]. Each state has at least one cellulosic ethanol plant planned for construction in the next few years and each already has extensive biomass and corn ethanol facilities [22]. This made it an appropriate region to assess linkages between beliefs about climate change and support for cellulosic ethanol.

Survey questions covered beliefs about climate change causes, solutions, concerns, and impacts; demographic questions; environmental values; US energy security; ethanol usage; and beliefs about paying more for cellulosic ethanol. Questions regarding beliefs about paying more for cellulosic ethanol were asked as part of a contingent valuation method (CVM) survey scenario in two ways: as questions about self-perceived "fair share" charges and as WTP extra. Two variations on a willingness to pay (WTP) question were administered to half the survey respondents each. In one case, respondents were asked how much they were WTP extra per gallon to purchase cellulosic ethanol. In the other case, respondents were alerted to the possibility of a food shortage in the next decade along with adverse climate change and the need to greatly lower CO_2 emissions, and asked under those circumstances what was the most that they thought their household should be charged per gallon extras as its "fair share" to purchase cellulosic ethanol instead of gasoline. This was designed to test hypotheses about the effects of the different wordings as described in a previous publication by one of the authors of this paper [10]. Because the previous analysis found no significant differences in how the two wordings operated [10], for simplicity's sake in this manuscript we refer to these questions as "fair share" questions. Table 1 provides a sample of one of the "fair share" questions used in the survey.

The sample was chosen from telephone records and was proportional to the population of each state. In order to collect

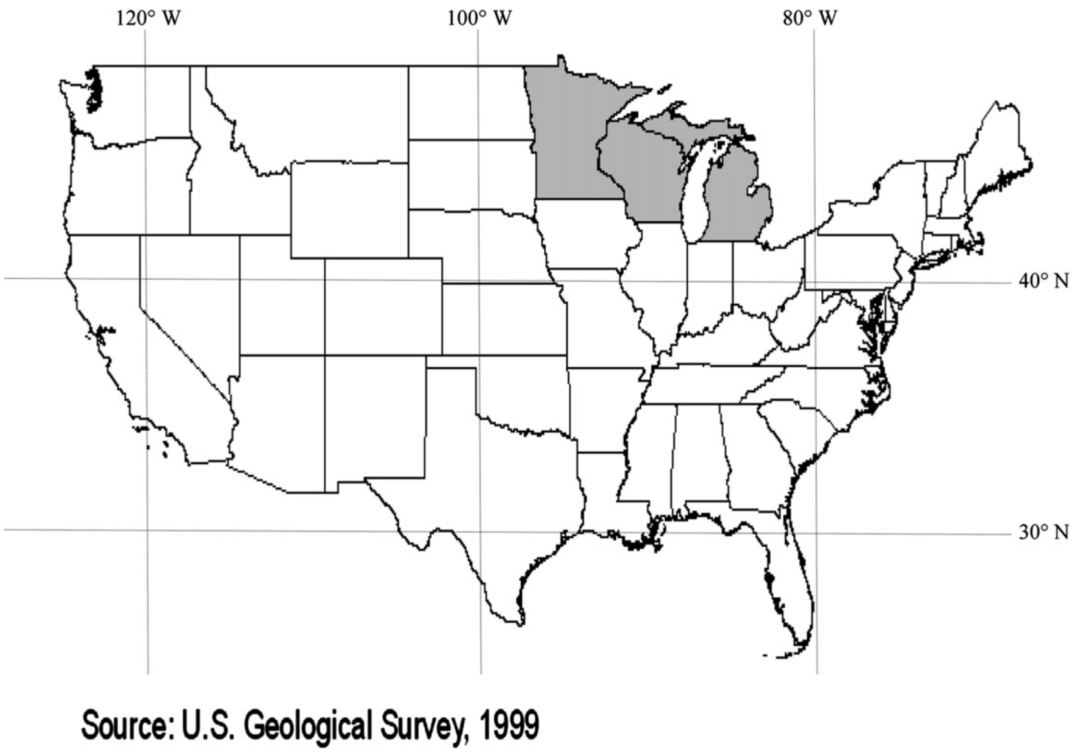

Fig. 1 – Study area Sates of Minnesota, Wiscosin, and Michigan.

enough responses from forest and farm landowners for a related study [6], rural areas were oversampled. However, when conducting the analysis presented in this paper, sampling weights were used to correct for this oversampling and adjust the rural vs. urban resident responses back to those of the three states for the six sub-populations, based on Census Bureau data.

Survey Sampling International (SSI) provided recipient names and addresses, including whether they were urban or rural. After accounting for bad addresses, the final survey pool was reduced to 1432. We followed an expanded version of Dillman's tailored design method of survey administration, which used several steps to increase the response rate in an eight-wave mailing [23]. We personalized the pre-survey notification letters, survey cover letters, and envelopes. Each survey included a small incentive in the form of a $2 bill. We used professional color photographs of fall woods scenes on the survey covers. These covers were visible through a large window in the mailing envelope. We also used these photographs on reminder postcards.

We assessed and reduced non-respondent bias in several ways: by following the expanded version of Dillman's "tailored design method" in administering the survey [23]; conducting telephone interviews using several key survey questions with non-respondents; comparing early and late respondents; and comparing the demographic characteristics

Table 1 – Willingness to pay extra introductory information and sample question.

Willingness to pay introductory information:
In order to lower pressure on food prices and cut your state's carbon dioxide (CO_2) emissions, the establishment of a cellulosic ethanol industry is under consideration. Even if this does not happen, the state will probably continue to build corn ethanol plants, only fewer if cellulosic ethanol becomes established. Cellulosic ethanol initially may cost more than corn ethanol, which needs to be traded off with the benefits of lowering carbon dioxide (CO_2) emissions and using farm, forestry, or urban wastes. If municipal solid wastes are used to make ethanol, for example, less landfills will be needed.
Assume that corn prices continue to rise and a food shortage occurs within the next decade. Because of the seriousness of this problem and the need to lower CO_2 emissions, the state and federal governments are considering requiring that all gasoline stations must sell a high percentage of cellulosic ethanol (e.g., half of the pumps), once the fuel becomes commercially available.
Sample question
Under these conditions and keeping in mind your family income and other expenses, what is the most that you think your household should be charged extra per gallon as its "fair share" to purchase cellulosic ethanol from *farming residues* if the fuel becomes available in your area? Circle the maximum amount.

$0.00	$0.01	$0.02	$0.03	$0.04	$0.05
$0.10	$0.25	$0.40	$0.65	$1.00	$1.00+

of respondents compared to state populations. Our respondents were older, more educated, with higher incomes, and more likely to be male than the general populations of the states. Respondents were also more concerned about climate change than non-respondents. Consequently, we need to be cautious in the generalization of our results.

A total of 745 households responded to the multiple mailings of the survey for an overall response rate of 52%. A more detailed description of our methods is available [10].

3.2. *Principal components analysis*

Because of the large number of attitudinal variables (44) employed in this study, Principal Components Analysis (PCA) was used to reduce the dimensionality (number of variables) of a large number of interrelated variables down to a small number of independent linear combinations, or principal components (pc's), while retaining as much of the information (variation) as possible [24]. These principal components or factors are ordered so that the first few retain most of the variation present in all of the original variables [25,26]. It is necessary to have uncorrelated factors to serve as independent variables for predictive modeling techniques, specifically multiple regression analysis.

3.2.1. *Model specifications*

There were several technical specifications used to develop a refined set of factor scores. Each of these specifications is briefly discussed.

3.2.1.1. *Missing values*. There are several ways to address missing values. One of the approaches is to ignore the entire observation. Because of the large sample size in this study, the missing values were ignored. There were 362 observations remaining after accounting for missing values.

3.2.1.2. *Varimax rotation*. This technique simplifies the interpretation of the factors or pc's to a consideration of two or three variables. Another way of stating the goal of varimax rotation is that it clusters variables into groups, so that each "group" is a new factor. Varimax rotation was used in arriving at the factors from PCA.

3.2.1.3. *Selection of factors*. The eigenvalues of the *R–U (correlation)* matrix are used to determine how many factors to retain. One rule-of-thumb is to retain those factors whose eigenvalues are greater than 1.0. Kaiser [27] proposed dropping factors whose eigenvalues are less than 1.0, since these provide less information than is provided by a single variable. In this research, we retained factors with an eigenvalue greater than 1.0, which resulted in seven factors included in the analysis.

3.2.1.4. *Robust covariance matrix estimation*. In the initial data screening, it was noted that many of the consumers' beliefs variables had standard deviations greater than 1.0, indicating a large amount of variation. To include as many data points as possible in the model, robust covariance matrix estimation was used. This weighting approach allows for more data to be included in the model development by weighting all observations. This parameter controls the weighting function in robust estimation of the covariance matrix.

3.2.1.5. *Minimum loading*. The minimum loading factor includes the absolute loading greater than a set amount. In this study, to explain the greatest amount of variation, the minimum absolute value for loading was set at 0.60. This allowed for more refined analysis than in an earlier study by the authors that used 0.50 for the minimum absolute value, as well as increased explanation of model variation [21]. The purpose of using a higher minimum value for loading is to avoid correlation between factors. This is critical, since uncorrelated factor scores will serve as independent variables for the robust regression models.

4. Principal components analysis results

In this study, eigenvalues were used to determine the number of factors to retain in the model. The model retained seven factors with the cumulative variation of 64.97% explained by the model. This finding was surprising, and somewhat contrary to our initial conceptual framework, since the initial set of questions was grouped in six different categories. The cumulative variation is higher than our initial PCA results found in the authors' earlier work [21]. Table 2 shows the eigenvalues greater than or equal to 1.0, along with the individual and cumulative percent of explained variation.

4.1. *Factor loadings*

As a result of the PCA, seven factors loaded with 28 variables out of an original 44 variables subdivided into six categories (Table 3). The factor loadings represent the correlations between the variables and factors. These groupings have been named to reflect the majority variables that loaded on each factor. The original constructs were identified by coding in the earlier section. Letters a–h denote the construct within the former dimensions.

Table 4 shows the factors, the variables (constructs) loaded on each factor, and the operational definitions based on the majority of questions for a given factor. "R" denotes a reversed question. Only those loadings that exceeded the threshold of 0.60 are included in Table 4. The rotated factor solution was used to compute the factor scores used in further analysis.

Table 2 – Eigenvalues after varimax rotation.

No.	Eigenvalue	Individual Percent	Cumulative Percent
1	8.86	20.14	20.14
2	8.11	18.42	38.56
3	3.26	7.42	45.98
4	2.56	5.81	51.79
5	2.40	5.46	57.25
6	1.88	4.27	61.52
7	1.52	3.45	64.97

Table 3 – Question groupings before and after principal components analysis.

Survey question dimension	Principal components analysis – factor descriptions
Self-Perceived Familiarity with Climate Change (SFCC) Concerns and Climate Change (CACC) Causes of Climate Change (COCC) Climate Change Solutions (CCS)	Factor 4: Self-Perceived Familiarity with Climate Change Factor 2: Concerns about Climate Change Impacts
Energy and America's Future (EAAF)	Factor 5: Gasoline Prices and Consumption Factor 7: Energy Security
Views of Environmental Issues (VOEI)	Factor 1: Environment, Energy Consumption, and Climate Change Factor 3: Inability to Stop Climate Change Factor 6: Self-Perceived Lack of Knowledge About Climate Change

The complete matrix that contains the factor loadings for all scale questions on all seven factors is available from the authors upon request.

Based on the factor loadings, two similar groupings emerged. The first factor that was similar is Factor 2: Concerns about Climate Change, which is similar to the original dimension Concerns about Climate Change (CACC). Factor 4: Self-Perceived Familiarity with Climate Change is similar to the original dimension of Self-Perceived Familiarity with Climate Change (SFCC). Factor 5: Gasoline Prices and Consumption and Factor 7: Energy Security splits the variables from the original Energy and America's Future (EAAF). Three new groupings emerged based on the factor loadings: Environment, Energy Consumption, and Climate Change (Factor 1), Inability to Stop Climate Change (Factor 3), and Self-Perceived Lack of Knowledge about Climate Change (Factor 6). The last three factors represent factor loadings from multiple original categories (Table 4). The theoretical framework (Fig. 2) reflects the PCA results.

4.2. Factor scores

The individual factor scores were scaled to be standardized with a mean of 0 and a standard deviation of 1.0. The factor scores are independent variables based on the constructs loaded on each factor. Fig. 2 shows just those factors that had values greater than 0.60. These represent the independent variables in the predictive model.

When the results from PCA serve as input for further multivariate analysis, several approaches can be used. If there is one variable that has a higher absolute factor loading, the raw data from this variable should be used as input for further analysis. However, it is better to use either factor scores or raw data (i.e., Likert-scaled data) to avoid complexity [28] in model development. Since no single variable "represents" each factor or component, then factor scores were more appropriate and were included for further analysis using regression [28]. The dimensionality of each scale is generally supported by the "clean" interpretation of each factor, with high factor loadings of each variable on only one factor [28, p. 129]. A "clean" interpretation means that the variables loaded onto each factor can be described as a group. In a couple of the factors, there are questions that do not necessarily fit the description of the majority of the variables. These factors must continue to be included as they are statistically loaded on the factor and cannot be removed because they do not exactly fit with the other variables. An important consideration when constructing summated scales is the positive and negative loadings [29]. The variables with negative loadings are reverse scored so that the correlations and the loadings are all positive with the factor [28, p. 130]. Reverse scoring is the process by which the data values for a variable are reversed so that its correlations with other variables are reversed [28, p. 130].

5. Hypotheses and bid curve analyses

Based on the results of the PCA, hypotheses were formulated.

5.1. Hypotheses

The hypotheses for the theoretical framework in Fig. 2, which parallel the factors, are as follows:

H1. : Understanding the environmental impact of climate change caused by energy consumption of fossil fuels will not impact consumers' willingness to pay more for cellulosic ethanol. (Factor 1).

H2. Consumers concerned with the impacts of climate change are not willing to pay more for cellulosic ethanol. (Factor 2).

H3. Consumers with stronger environmental values are not willing to pay more for cellulosic ethanol. (Factor 3).

H4. Self-perceived familiarity with global climate change will not impact consumers' willingness to pay more for cellulosic ethanol. (Factor 4).

H5. Higher gasoline prices and consumption will not impact consumers' willingness to pay more for cellulosic ethanol. (Factor 5).

H6. Self-perceived lack of knowledge about climate change will not impact consumers' willingness to pay more for cellulosic ethanol. (Factor 6).

Table 4 – Factor loadings and factor descriptions.

Question abbreviation	Underlying variable description	Factor loadings	Cronbach's alpha
Factor 1: Environment, Energy Consumption, and Climate Change			0.76
COCCh-R	Increased industry is one of the biggest causes of climate change. (Question stated as shown on survey but reverse scored)	0.741	
COOCe-R	Climate change is caused by burning "dirty" fuels. (Question stated as shown on survey but reverse scored).	0.714	
COCCf	Burning fossil fuels is one of the primary causes of climate change.	−0.710	
COCCg	Carbon dioxide emissions are one of the major causes of climate change.	−0.703	
EAAFd	Using too much energy is causing climate change.	−0.681	
CCSe	Saving energy is a way to stop climate change.	−0.672	
COCCd	Rapid increases in greenhouse gases are causing climate change.	−0.659	
VOEIc	Humans are severely abusing the environment.	−0.642	
VOEIa	The balance of nature is delicate and easily upset.	−0.630	
Factor 2: Concerns about Climate Change Impacts			0.79
CACCa	Climate change will cause problems for people.	−0.818	
CACCc	Climate change will cause severe weather.	−0.802	
CACCb	Climate change will cause human health problems.	−0.791	
CACCg	Climate change will cause economic problems.	−0.786	
CACCf	Climate change will cause weather pattern changes, such as droughts.	−0.770	
CACCe	Climate change will cause the loss of wildlife species.	−0.735	
CACCd	Climate change will cause coastline losses as sea levels rise.	−0.717	
SFCCg-R	Climate change is not likely to be a serious problem. (Question stated as shown on survey but reverse scored)	−0.608	
Factor 3: Inability to Stop Climate Change			
CCSc	We can't stop climate change because we can't control human activities.	−0.692	
Factor 4: Self-Perceived Lack of Familiarity with Climate Change			0.78
SFCCa	I have heard the term "climate change".	0.885	
SFCCb	I have heard the term "global warming".	0.880	
SFCCc	I hear a lot about climate change in many places, such as on TV.	0.806	
Factor 5: Gasoline Prices and Consumption			0.77
EAAFg-R	I don't support increasing gasoline prices in order to stop climate change because many people can afford these increases. (Question stated as shown on survey but reverse scored)	0.790	
EAAFf-R	It is unreasonable to expect people to use less energy than they do now. (Question stated as shown on survey but reverse scored)	−0.702	
EAAFb-R	Recent gasoline prices are a not big problem for me and my family. (Question stated as shown on survey but reverse scored)	0.626	
Factor 6: Self-Perceived Lack of Knowledge About Climate Change			0.65
SFCCd	I don't know a lot about global warming or climate change	0.840	
COCCa	I don't know what causes climate change.	0.675	
Factor 7: Energy Security			0.75
EAAFa	I am concerned about America's energy security	−0.682	
EAAFc	America should produce all of its own energy.	−0.659	

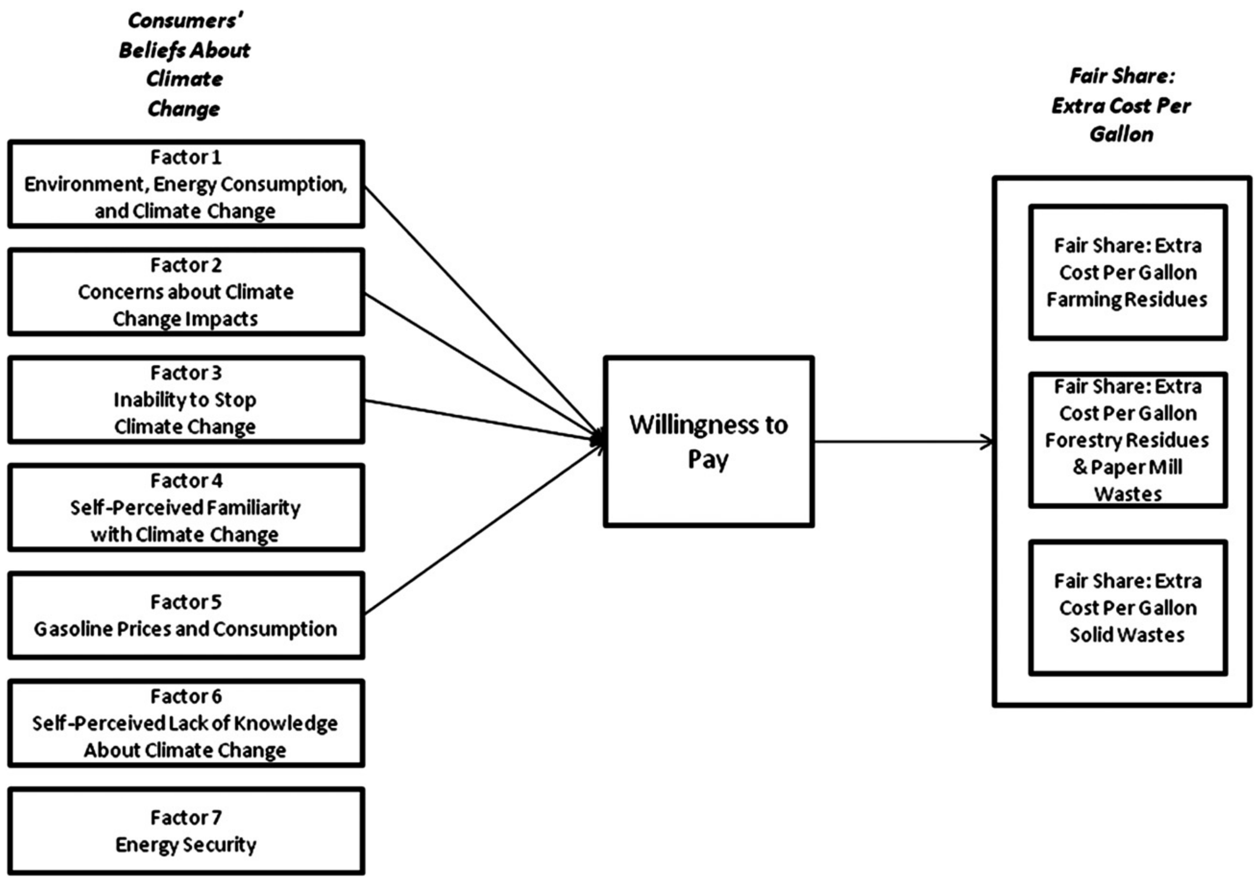

Fig. 2 – Theoretical framework based on principal components analysis.

H7. Consumers who value America's energy security are not willing to pay more for cellulosic ethanol. (Factor 7).

To test the hypotheses, factor scores representing the dimensionality of the underlying variables were used to identify statistically significant regression models. The results are presented here.

5.2. *Bid curve analysis*

To further test our seven hypotheses, multiple regression analysis was applied using the factor scores and demographic variables (i.e., gender, income, and rural vs. urban) as independent variables and the fair share bid values in dollars for the dependent variables. There were 12 different price increments above the price of retail gasoline shown to respondents on a payment card, ranging from $0.00 to $1.00+ for each of three alternative feedstocks (Table 1). This price range reflects the likelihood that consumers will not buy ethanol if its price is significantly above that of gasoline. Previous analysis found a mean total fair share value of $472 per capita per year, or $192 when assuming that all non-respondents were WTP zero extra for cellulosic ethanol [10].

Because of the variation present in the initial data as well as the factor scores, it was more appropriate to use robust regression. After data reduction through data screening and PCA, 362 observations remained to develop the following predictive models of consumers' WTP more for cellulosic ethanol from the three different feedstocks. Alternative feedstocks were considered to examine whether they influenced WTP for cellulosic ethanol, given the negative publicity received by food-based biofuels [8,9].

5.2.1. *Fair share – cellulosic ethanol from farm residues*

The question posed was, "what is the most that you think your household should be charged extra per gallon as its "fair share" to purchase cellulosic ethanol from *farming residues* if the fuel becomes available in your area?" The resulting model for cellulosic ethanol from farming residues resulted in an adjusted R^2 of 0.31 (Table 5).

Based on these result, we fail to reject the null hypothesis for factors 4, 6, 7, and rural/urban, meaning that Self-Perceived Familiarity with Climate Change (Factor 4) or Self-Perceived Lack of Knowledge about Climate Change (Factor 6) or Energy Security (Factor 7) were not statistically significant at the 5% level and they have no impact on WTP for cellulosic ethanol from farm residues. Additionally, it should be noted that Factor 1: Environment, Energy Consumption, and Climate Change, and Factor 2: Concerns about Climate Change, have negative coefficients. This can be interpreted as those

Table 5 – Regression equation section – Fair share: cellulosic ethanol from farm residues.

Independent variable	Estimated coefficient	t-Statistic
Intercept	0.240	2.881**
Environment, Energy Consumption and Climate Change (Factor 1)	−0.031	−4.778**
Concerns about Climate Change Impacts (Factor 2)	−0.0283	−4.192**
Inability to Stop Climate Change (Factor 3)	0.020	2.873**
Self-Perceived Lack of Familiarity with Climate Change (Factor 4)	0.002	0.331
Gasoline Prices and Consumption (Factor 5)	0.062	8.421**
Self-Perceived Lack of Knowledge About Climate Change (Factor 6)	−0.0075	−1.104
Energy Security (Factor 7)	−0.0023	−0.344
Gender	0.044	2.296*
Income	0.012	2.200*
Rural or urban	0.0039	0.268

F-statistic = 15.825**.
Adjusted $R^2 = 0.31$.
$n = 330$.
**Significant at $p < 0.01$.
*Significant at $0.01 < p < 0.05$.

consumers having stronger beliefs may not be more likely to pay more for cellulosic ethanol. The control variables of gender and income were statistically significant. However, whether a consumer was located in a rural vs. urban setting was insignificant.

Table 6 – Regression equation section – Fair share: cellulosic ethanol from forestry residues and paper mill wastes.

Independent variable	Estimated coefficient	t-Statistic
Intercept	0.0875	2.996**
Environment, Energy Consumption and Climate Change (Factor 1)	−0.0311	−4.582**
Concerns about Climate Change Impacts (Factor 2)	−0.0263	−3.812**
Inability to Stop Climate Change (Factor 3)	0.022	3.104**
Self-Perceived Lack of Familiarity with Climate Change (Factor 4)	0.002	0.443
Gasoline Prices and Consumption (Factor 5)	0.068	8.559**
Self-Perceived Lack of Knowledge About Climate Change (Factor 6)	−0.009	−1.209
Energy Security (Factor 7)	0.001	0.113
Gender	0.037	1.863
Income	0.011	1.893
Rural or urban	0.011	0.718

F-statistic = 15.46**.
Adjusted $R^2 = 0.31$.
$n = 330$.
**Significant at $p < 0.01$.
*Significant at $0.01 < p < 0.05$.

5.2.2. *Fair share – cellulosic ethanol from forestry residues and paper mill wastes*

The question posed was, "what is the most that you think your household should be charged extra per gallon as its "fair share" to purchase cellulosic ethanol from *forestry residues and paper mill wastes* if the fuel becomes available in your area?" The result model for cellulosic ethanol from forest residues and paper mill wastes resulted in an adjusted R^2 of 0.31 (Table 6).

The same relationships appear to hold true for the second multiple regression model, meaning the interpretation is the same with the signs on the regression coefficients being identical. However, the control variables were not statistically significant for cellulosic ethanol from forestry residues and paper mill wastes.

5.2.3. *Fair share – cellulosic ethanol from solid wastes*

The question posed was, "what is the most that you think your household should be charged extra per gallon as its "fair share" to purchase cellulosic ethanol from *solid wastes* if the fuel becomes available in your area?" The result model for cellulosic ethanol from solid wastes resulted in an adjusted R^2 of 0.33 (Table 7).

Based on these results, we fail to reject the null hypothesis for factors 4, 6, 7, and rural/urban, meaning that Self-Perceived Familiarity with Climate Change (Factor 4), Self-Perceived Lack of Knowledge about Climate Change (Factor 6), or Energy Security (Factor 7) were not statistically significant at the 5% level and have no impact on WTP for cellulosic ethanol from solid waste. Additionally, it should be noted that Factor 1: Environment, Energy Consumption, and Climate Change, and Factor 2: Concerns about Climate Change, have negative coefficients. This can be interpreted as those consumers having

Table 7 – Regression equation section – Fair share: cellulosic ethanol from solid wastes

Independent variable	Estimated coefficient	t-Statistic
Intercept	0.0817	2.849
Environment, Energy Consumption and Climate Change (Factor 1)	−0.035	−5.369**
Concerns about Climate Change Impacts (Factor 2)	−0.029	−4.309**
Inability to Stop Climate Change (Factor 3)	0.0193	2.882**
Self-Perceived Lack of Familiarity with Climate Change (Factor 4)	0.0047	0.913
Gasoline Prices and Consumption (Factor 5)	0.0641	8.613**
Self-Perceived Lack of Knowledge About Climate Change (Factor 6)	−0.011	−1.607
Energy Security (Factor 7)	−0.002	−0.230
Gender	0.045	2.367*
Income	0.013	2.282*
Rural or urban	0.005	0.379

F-statistic = 17.284**.
Adjusted $R^2 = 0.33$.
$n = 327$.
**Significant at $p < 0.01$.
*Significant at $0.01 < p < 0.05$.

stronger beliefs are unlikely to pay more for cellulosic ethanol. The control variables of gender and income were found to be statistically significant. However, whether a consumer was located in a rural vs. urban setting was insignificant.

6. Discussion and conclusions

A comprehensive analysis of upper Midwestern consumers' beliefs about climate change and how this impacts their WTP more for cellulosic ethanol from farming residues, forest residues and mill wastes, and solid wastes provides us with insights regarding consumers' behavior, though we must be cautious regarding the generalization of our sample since it was not fully representative of the general population in the region. PCA allowed for dimensionality reduction into factors or groupings with common meaning. The factors' scores were used as independent variables to learn more about the impact on WTP a "fair share" per gallon for cellulosic ethanol. These predictive models provide further explanation into the different considerations that consumers might use to evaluate their decisions on WTP more or extra per gallon of cellulosic ethanol when it becomes available. While our initial model was formulated into six distinct categories of variables, the PCA surprisingly resulted in seven factors. The PCA results thus differed from the initial question dimensions.

Four factors were significant explanatory variables in all three regression models: Factor 1: Environment, Energy Consumption, and Climate Change; Factor 2: Concerns about Climate Change; Factor 3: Inability to Stop Climate Change; and Factor 5: Gasoline Prices and Consumption Behavior. Conversely, Factor 4: Self-Perceived Familiarity with Climate Change, Factor 6: Self-Perceived Lack of Knowledge about Climate Change, and Factor 7: Energy Security, were not significant predictors of consumers' WTP their fair share for cellulosic ethanol in any of the models. As presented in Table 3, Cronbach's alpha ranges from a low of 0.65 on Factor 6: Self-Perceived Lack of Knowledge about Climate Change to a high of 0.79 on Factor 2: Concerns about Climate Change. Typically a value of alpha (α) in excess of 0.9 is considered a very good level of scale reliability and internal consistency; in many cases, a value of 0.7 is considered acceptable [32]. Thus, Factor 6 may be unreliable. There are various forms of regression that can be used for multivariate analysis and include multiple, stepwise, and robust regression techniques [30]. Robust regression provides an alternative to least squares regression that works with less restrictive assumptions [31]. When using robust regression, users must be familiar with the variables they are using to understand the impact of outliers and also final model outcomes [29].

Consumers may have preconceived notions regarding the different feedstocks used to produce cellulosic ethanol. In the survey, respondents were, therefore, asked about three different feedstocks and their WTP based on these different feedstocks. The reason it is important is because some consumers may be more adverse to purchasing cellulosic ethanol from farm or forestry residues than from solid waste, since some residues need to remain in the soil. The results of the robust regression models indicate that there may be only minimal differentiation made by consumers. Besides the four significant PCA factors used as explanatory variables, only gender and income were found to be statistically significant, and only in two of the three regression models. Thus, it can reasonably be inferred that there is no significant influence of the different types of feedstocks on consumer WTP more for cellulosic ethanol.

Our findings expand the preliminary research completed by Halvorsen and colleagues [6] that measured and modeled national-level public awareness of bioenergy, and Solomon and Johnson's [10] earlier research emphasizing the support for and consumer's WTP for biomass ethanol and promotion policies. This assessment of Upper Midwestern U.S. consumers' beliefs regarding climate change causes, impacts, and solutions provides further preliminary evidence for the linkage to their WTP for cellulosic ethanol development. Additionally, our findings demonstrate that the climate-change-related cultural models found by earlier authors [12] but not quantified in terms of their distribution or statistical interrelationships, indeed do appear to coalesce together into integrated models and to be widely distributed.

Given the market pull vs. the technology push operations strategies, it would appear that cellulosic ethanol is characteristic of technology push, with the anticipation that many consumers are willing to pay for mitigating the negative environmental impacts that can result from continuing growth and use of fossil fuels through higher fuel prices. However, these findings must be tempered by the lack of retail availability of cellulosic ethanol, and significant doubt among a minority of the population regarding the reality of climate change and its connection to fossil fuel consumption [10].

The research that forms the basis of this study allows for application beyond the Upper Midwestern U.S. region into other U.S. regions. The expansion of this research to cover more regions in the United States is critical to the understanding of the broader impacts of alternatives to fossil fuel and consumers' beliefs regarding their willingness to change and support the infrastructure required to move to commercialization and wider acceptability.

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