Journal of Environmental Studies and Sciences
https://doi.org/10.1007/s13412-019-00562-z

ORIGINAL ARTICLE

Activating values for encouraging pro-environmental behavior: the role of religious fundamentalism and willingness to sacrifice

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Abstract

A number of theories and hypotheses attempt to understand what influences pro-environmental behaviors. In social psychology, the values–beliefs–norms (VBN) theory is one of the most common approaches used to explain pro-environmental behaviors. But different sets of concepts have often been used in work based on large public opinion surveys. Here, we add to the VBN theory several variables—Christian religious fundamentalism, willingness to sacrifice, trust in scientists, biotechnology beliefs—that have been used in the public opinion literature in a step toward a more integrative theory. A sample of 518 U.S. adults completed an online questionnaire to provide data. Results confirm that, in the USA, biospheric altruism values had substantial indirect effects on pro-environmental behavior via willingness to sacrifice for biodiversity loss. But climate change beliefs and willingness to sacrifice for climate change did not exert direct or indirect effects on pro-environmental behavior. Interestingly, religious fundamentalism increased pro-environmental behavior net of other factors including political ideology, again acting primarily through biospheric altruism values. We hope that our findings encourage steps toward more integrated theory and the testing of more comprehensive models.

Keywords Pro-environmental behaviors · Values–beliefs–norms theory · Climate change · Biotechnology · Biodiversity loss

Introduction

Because most environmental problems can be thought of as a commons dilemma or public goods problem, a substantial literature has shown that altruism, including altruism toward other humans and toward the biosphere and other species, plays a central role in shaping environmental decision-making and pro-environmental behavior. The values–beliefs–norms (VBN) theory has become the most common framework in social psychology for examining the influence of altruism and other values on environmental decision-making (Dietz 2015; Steg 2016; Stern et al. 1993, 1999). In its general form, VBN theory posits a causal chain that begins with values, which in turn influence general beliefs about human harm to the environment. At the next step in the causal chain, values and general beliefs can influence beliefs about specific problems and about the role of individual action in shaping those problems and then beliefs and norms about taking pro-environmental action, with the norms viewed as causally proximate to pro-environmental behavior.

VBN is often used by itself to explain pro-environmental behavior. But recent progress has shown the benefits of linking VBN to other theories for a more holistic explanation of environmental decision-making. VBN is a complement to the theory of planned behavior (TPB) with VBN most distal from behaviors and the

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Published online: 15 August 2019

variables of TPB, which are quite specific to the behavior modeled, proximal to the behaviors (Ajzen 2012; Dietz 2015). Values have long been seen as a key component of identity, and Van der Werff and colleagues have shown a strong link between values and environmentalist identity (Van der Werff et al. 2013a, 2013b, 2014). VBN also has been used to complement TPB and the theory of diffusion of innovation in explaining adoption of residential photovoltaics (Wolske et al. 2017).

In this paper, we continue the effort to integrate the VBN theory into a more general approach to pro-environmental behavior by developing a model that combines VBN with several other influences on pro-environmental behavior. In particular, we examine the effects of Christian religious fundamentalism and willingness to sacrifice as factors that might predispose individuals in their decisions about the environment. We also consider two forms of general beliefs about environmental change, beliefs about climate change and beliefs about the benefits of biotechnology. Finally, we examine trust in scientists as a possible precursor to pro-environmental actions. These concepts do not form a coherent theory of pro-environmental behavior nor are they derived from an overall theory. Rather, we have selected two of them—religious fundamentalism and willingness to sacrifice—because they have often been used in studies of environmentalism in general public samples. The other measures—trust in scientists and general beliefs about climate change and about biotechnology—have been less extensively studied so we include them in as exploratory approach to see how they might contribute to a general theory of pro-environmental behavior. Thus, one purpose of our paper is to consider where these concepts would logically fit into an expanded VBN model. In the next section, we will discuss our rationale for adding each of these measures to a VBN model of pro-environmental consumer behavior.

Steps toward a more integrative theory

Since VBN is perhaps the most commonly used theory of pro-environmental behavior, we use it as the framework to which we append several other concepts that have found some traction in the literature. Our goal is to consider the degree to which these other concepts complement VBN, either by uniquely explaining variation in self-reported pro-environmental behaviors or by being intermediate in the causal chain between values and general beliefs and behavior. Recent efforts to link VBN to TPB and to diffusion of innovation theory benefited from all three approaches being relatively coherent theories (Wolske et al. 2017). In contrast, the theory justifying the measures we are adding to a VBN model has been somewhat ad hoc so part of our challenge is to consider how they might complement a VBN framework.

Religious fundamentalism In the USA, an ongoing literature has suggested that those with Christian fundamentalist religious orientation tend to be somewhat less pro-environmental than those with other religious views or those who are not religious (Boyd 1999; Clements et al. 2014a, b; Eckberg and Blocker 1996; Greeley 1993; Hand and Van Liere 1984; Schultz et al. 2000; Shao 2016; Smith and Leiserowitz 2013; Smith et al. 2017; Sherkat and Ellison 2007). The hypothesis stems from a controversial argument by White Jr (1967, 1973) that the degradation of the environment has its origin in Biblical assertions of human dominion over nature. Thus the typical approach to defining Christian fundamentalism in this literature is a belief that the Bible is the word of God (Smith et al. 2017). While the general theoretical prediction is that fundamentalism will lead to less environmental concern, empirical results vary and major reviews find the evidence inconclusive or mixed (Gifford and Nilsson 2014; McCright et al. 2016), although Peifer et al. (2016) found that fundamentalism may reduce effects of political conservatism on pro-environmental behavior. We treat fundamentalism as causally prior to values and all other variables save the social demographic variables representing position in the social structure. Of course, with cross-sectional data, we cannot resolve the causal direction of influence, so while we assume that fundamentalism influences values and other social psychological variables, some causation may flow in the other direction. This ambiguity about causal direction holds true for all variables in a cross-sectional model, but the causal ordering we posit follows standard practice in the literature and has been supported by some experimental and panel data evidence (Dietz 2015).

Willingness to sacrifice Many applications of the VBN theory include a personal norm supporting action as the variable most proximate to decisions and behaviors. However, a number of large, repeated national samples, such as the U.S. General Social Survey, while not including measures of a personal norm per se, do ask respondents if they would be willing to pay higher prices or taxes or accept a lower standard of living in support of environmental protection. Indeed, these measures may be among the most commonly used in analyzing survey data on the environment where they are usually interpreted as a "willingness to sacrifice" to protect the environment (Boyd 1999; Chaisty and Whitefield 2015; Dietz et al. 1998; Haller and Hadler 2008; Hunter 2000; Hunter and Toney 2005; Macias 2015; Marquart-Pyatt 2012;

Nawrotzki 2012; Nawrotzki and Pampel 2013; Olofsson and Öhman 2006; Oreg and Katz-Gerro 2006). Thus, they are quite similar to the personal norm ("I feel a responsibility to take action to protect the environment.") often used in VBN studies. We include willingness to sacrifice in our model with the intent that embedding this concept in a fuller social psychological model will help bridge the gap between the literature based on omnibus surveys and the environmental psychology literature. We also note that the willingness to sacrifice conceptualization can also be interpreted as a hypothetical behavioral intention. We chose to consider it a norm rather than an intention because the typical form of the questions in surveys, which we have replicated, is quite abstract. We have examined willingness to sacrifice to address two environmental problems: biodiversity loss and climate change. Below we will discuss the relationship between these two in our data.

In addition to these two concepts that have been frequently examined in the public opinion literature on environmentalism, the survey we are using included measures of three other concepts that are plausibly related to environmental concern: trust in scientists, beliefs about climate change, and beliefs about biotechnology. These concepts have been used far less often in the literature than religious fundamentalism and willingness to sacrifice. Nonetheless, we decided to include them in our model on an exploratory basis since the costs of including them in our models is primarily the loss of a few degrees of freedom and some risk of increased collinearity.

Trust in scientists Since information about environmental problems generally flows from the public accounts of scientists, trust is scientists may influence an individual's assessment of environmental problems and their willingness to take action to protect the environment. Public trust in science and in scientists has been broadly studied in public opinion surveys and has sometimes been invoked to explain public acceptance or rejection of technologies and of environmental risks (Hamilton et al. 2015; Priest et al. 2003; Slovic 1993; Xiao and McCright 2015). Some studies find that trust in science or scientists influences views of climate change, while others do not, so that in a comprehensive overview, McCright et al. (2016) conclude that there is no consistent effect.

Climate change beliefs Many applications of VBN operationalize beliefs only as a generalized belief that humans can have adverse effects on the environment and typically use a modified measure of the New Ecological Paradigm scale (Dunlap et al. 2000) to measure those general beliefs. However, the VBN theory allows beliefs about specific environmental problems to be casually subsequent to general beliefs and have effects on pro-environmental behavior beyond those of generalized beliefs. Here, we explore that possibility by including in our model beliefs about climate change, perhaps the most prominent contemporary environmental problem.

Biotechnology beliefs Biotechnology is sometimes suggested as offering potential solutions to many environmental problems, for example by leading to plant and animal species that require less water and fertilizer and pesticides, and that are overall more productive. But biotechnology in food crops remains highly controversial—it is widely accepted in the USA, albeit with some public resistance but is viewed with skepticism by many Europeans (Lucht 2015). We conjecture that those who are highly accepting of biotechnology may be less motivated to engage in individual actions to protect the environment, while those who are skeptical of the benefits of biotechnology may be more inclined to take action.

A modified VBN model

Like most social psychological models, VBN implies a causal chain in which variables theorized as somewhat distant from behavior can have direct effects but also indirect effects through their influence on variables more proximate to behaviors. Here, we outline the path model implied by our theoretical arguments (Fig. 1).

Position in the social structure

Pro-environmental behavior often is strongly influenced by a variety of sociodemographic factors that represent position in the social structure. These factors are indicators of constraints and possibilities for carrying out such actions and also serve as surrogates for elements of culture not fully captured by the social psychological variables in a model. We follow typical practice in modeling these factors as most causally distant from pro-environmental behaviors.

Race There is ample evidence that race/ethnicity drives exposure to environmental risks (Downey 2015; Holifield et al. 2017; Mascarenhas 2016). However, because race/ethnicity is linked not only to exposure to risk but also to opportunities and constraints in taking pro-environmental action, race has an inconsistent relationship with pro-environmental behaviors (Allen et al. 2015; Gifford and Nilsson 2014).

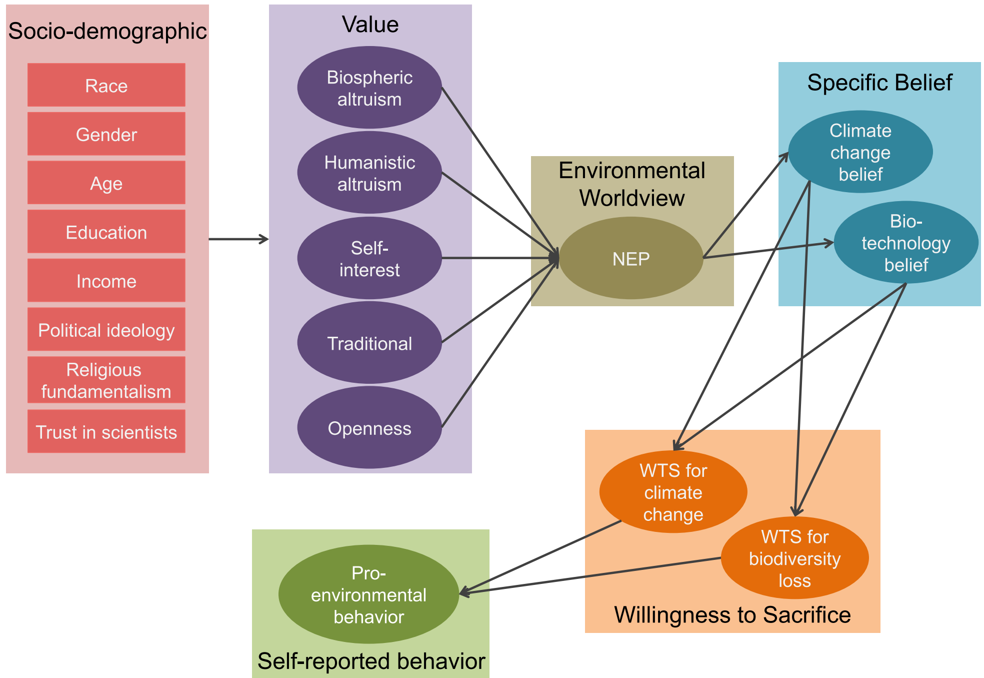

Fig. 1 Values–beliefs–norms theory for pro-environmental behavior: Although all direct effects (e.g., the direct effects of sociodemographic factors on pro-environmental behavior) are included in the final model, they are not drawn so as not to overcrowd the figure

Gender Gender has been a central concept in VBN theory since its inception (Stern et al. 1993). An ongoing literature shows that women are more likely to engage in pro-environmental behaviors than men (Davidson and Freudenburg 1996; Hunter et al. 2004; Luchs and Mooradian 2012; McCright and Xiao 2014).

Age/cohort In a cross-section survey, age is confounded with cohort and both may have an influence on pro-environmental behavior through social psychological mechanisms and through opportunities and constraints (Pampel and Hunter 2012). There is some evidence that older cohorts are more likely to engage in pro-environmental behaviors than younger cohorts (Gifford and Nilsson 2014; Gilg et al. 2005).

Education There are multiple pathways through which education can influence pro-environmental behavior. Education undoubtedly influences awareness of and concern with environmental problems and plausibly influences views about the efficacy of personal action. Reviews suggest that while the effects of education are often evident, they are usually of modest size (Bronfman et al. 2015; Dietz et al. 1998; Gifford and Nilsson 2014; Oreg and Katz-Gerro 2006).

Income Income is a rough surrogate for social class, is related to altruism, and reflects both interests that might be influenced by environmental protection and the costs, benefits, and constraints associated with pro-environmental behavior. Many but not all studies find income effects on pro-environmental behavior although the effects are often modest (Bronfman et al. 2015; Dietz et al. 1998; Dietz and Whitley 2018; Gifford and Nilsson 2014; Oreg and Katz-Gerro 2006).

Political ideology In the USA, political ideology has become one of the strongest predictors of environmental concern and pro-environmental behavior (Dietz et al. 2013; Fielding and Hornsey 2016; Gromet et al. 2013). Following standard practice, we include political ideology, religious beliefs, and trust in scientists in a block with sociodemographic variables and model them as most causally different from pro-environmental behaviors.

Religious fundamentalism Because for many religious beliefs are formed early on and remain relatively stable, we have chosen to include religious fundamentalism with our measures of position in the social structure and thus as an exogenous variable.

Trust in scientists While trust in institutions and professions might be modeled further down in the causal chain, we have no specific hypotheses about what drives it and thus have included it with the causal block of exogenous variables.

Values, beliefs, and willingness to sacrifice

Values We use the five value orientations most commonly examined in the literature: biospheric altruism, humanistic altruism, self-interest, traditionalism, and openness to change (Dietz 2015). We model values as causally subsequent to the sociodemographic values but causally prior to all else in the model.

Beliefs Following common practice, we use the New Ecological Paradigm scale as modified by Stern et al. (1995) as a measure of general belies. Note that we have also included two more specific beliefs: belief in climate change as a serious problem and beliefs that biotechnology may be beneficial. We model general beliefs as causally subsequent to values and sociodemographic values but causally prior to specific beliefs, norms, and pro-environmental behaviors, while the specific beliefs are subsequent to sociodemographic variables, values, and general beliefs but causally prior to norms and self-reported behaviors.

Willingness to sacrifice As discussed above, we are substituting willingness to sacrifice to protect biodiversity and to mitigate climate change for personal norm for action typically used in VBN models. Again, our goal is to incorporate willingness to sacrifice measures that are commonly used in large representative surveys into a model driven by social psychological theory. Willingness to sacrifice is proximate to self-reported behaviors but subsequent to all other variables in the model.

Pro-environmental behaviors

We follow the common practice of combining a number of self-report items into a scale to enhance reliability and to average across the idiosyncratic constraints individual respondents may face regarding any particular behavior (Arnold et al. 2018; Bronfman et al. 2015; Frick et al. 2004; Kaiser and Wilson 2000). In particular, we asked respondents to self-report on 12 pro-environmental behaviors (see the "Materials and methods" section for a more detailed description). We acknowledge that there are several issues with self-report scales. First, while Kormos and Gifford (2014) note that their meta-analysis reveals a "positive and nominally large" effect size linking self-reports to actual behaviors, there is still a great deal of variance in actual behavior that is not explained by self-reported behavior. Second, there is some evidence that different factors drive self-reports and actual behavior so that a model of self-reports or intentions may not identify the same influences as a model of observed behavior. For example, Allen et al. (2015) found that the general beliefs version of the NEP scale was a strong predictor of intentions to donate to an environmental NGO, while altruism predicted actual donations. Third, there is a reason to believe that the drivers of pro-environmental behavior may differ across specific behaviors so that using a scale provides insights in to what might be thought of as an "average" response across behaviors, whereas modeling the individual behaviors would reveal such differences. Of course, an advantage of the use of a scale is that the measurement error associated with individual behaviors is reduced via the potentially higher reliability of the scale and further that the reliability of the latent variable can be used in structural equation modeling to provide more accurate estimates of standard errors. Conceptually, we are assuming, and testing that assumption with confirmatory factor analysis, that a common pro-environmental behavior latent variable underlies the specific pro-environmental behaviors reported and are modeling that latent variable. Since our goal is to consider possible additions to the standard VBN model, we will use the scale based on the idea of the general latent variable as a dependent variable while noting that the key variables influencing a behavior undoubtedly differ to some degree across behaviors and that analyses intended to unpack specific sorts of consumer behavior (e.g., greenhouse gas emissions reductions, water use reductions) might be well served by modeling specific behaviors rather than a composite scale.

Material and methods

Sample

Data were collected through from a Qualtrics sample targeted at U.S. respondents over the age of 18 in March 2017. Quotas were used to insure a sample that matched the U.S. adult population on race/ethnicity. The questionnaire was in English and was introduced as a research project on "perceptions of important social issues in the U.S." The instrument and methodology were approved by the Institutional Review Board of Michigan State University.

We received 521 responses and excluded three participants who had substantial missing data; thus, 518 responses were used for data analyses. Table 1 presents demographics for our sample. The gender distribution in the sample was 32.8% of male (compared to 49.2% in the U.S. population). The median age was 48, which was higher than the median age of 37.9 in the U.S. population. The average household income of the sample was $54,829 per year, which was similar to the average household income of $55,322 per year in the general population of the USA. In our sample, 36.8% have at least Bachelor's degree compared to 30.3% in the general population of the USA. So, overall, the sample has more women, is somewhat older, and somewhat better educated than the U.S. adult population. In

Table 1 Descriptive statistics of questionnaire participants ($N = 518$)

Variable	Mean	SD
Race ("white" = 1)	0.714	0.452
Gender ("male" = 1)	0.328	0.470
Age (years)	47.846	16.286
Education (1–6 scale: "11 years of education or less" to "graduate or professional degree")	3.830	1.480
Income (1000 dollars)	54.829	37.990
Political Ideology (1–7 scale: "very liberal" to "very conservative")	3.826	1.765
Religious Fundamentalism (1–5 scale: "strongly disagree" to "strongly agree")	3.108	1.420
Trust in scientists (1–5 scale: "strongly disagree" to "strongly agree")	3.176	0.918

general, Qualtrics samples are seen as more representative of the U.S. population than convenience samples but also deviate from full representation in some ways.

Statistical procedures

MPlus Version 7.4 was used to estimate structural equation models (SEM) while Stata Version 14.2 was used for all other analyses (Muthén and Muthén 2012; StataCorp 2015). Our SEM model includes measurement models for each of the variables we are treating as latent variables and estimating using observed indicators. We have also examined each of these latent variables using alpha scaling and, thus, report simple additive reliabilities in the text below and in Tables 2 and 3, while the factor loadings for the SEM are included in Tables 2 and 3. The SEM models were estimated via maximum likelihood. Because some respondents had missing data on some items in the model, the final sample size for estimates reported below is 518. The advantage of the SEM approach is that it allows estimation of direct, indirect, and total effects and their standard errors while taking account of the reliability of latent variable estimates (Kline 2011).

Survey measures

Here, we detail the way we operationalized the concepts in our model. Note that within each group of questions with the same response categories (e.g., values, views of biotechnology, and general beliefs), the order in which specific items were presented to respondents was randomized to minimize response set effects.

Engagement in pro-environmental behaviors The survey included 12 self-reported behaviors tapping four areas/forms of pro-environmental behavior (Table 2): energy conservation, green consumerism, water conservation, and biodiversity protection. The items were modified from Allen et al. (2015) and Bronfman et al. (2015). Respondents were asked to indicate "how often do you do" each item on a 4-point scale ranged from "Never" (1) to "Always" (4). "Not applicable" responses were recoded to missing values and dropped

Table 2 Pro-environmental behavior items: standardized factor loadings from confirmatory factor analysis, scale reliability (Cronbach's alpha), means, standard deviations, and preferences ($N = 518$)

Pro-environmental behavior items	Factor loadings	Mean	SD	Participating always (%)	Participating never (%)
Pro-environmental behavior (alpha = 0.841)		2.952	0.608		
Make gas mileage and reduction in pollution the major considerations for my next vehicle	0.663	2.923	1.033	37.64	12.02
Turn down the thermostat at home in the winter	0.508	3.096	0.951	43.65	6.76
Limit my air-conditioner use at home in the summer	0.610	2.904	1.014	35.58	11.45
Take my own shopping bags when purchasing groceries at the store	0.531	2.649	1.133	30.94	21.76
Utilize reusable water bottles	0.494	3.060	1.025	45.27	10.29
Purchase housecleaning products that are marked "eco-friendly"	0.673	2.671	0.976	25.50	10.96
Conserve water or use water efficiently	0.608	3.247	0.844	47.53	3.35
Turn off the faucet when I brush my teeth	0.400	3.218	0.997	54.56	8.33
Turn off the water when shampooing and soaping	0.543	2.335	1.240	27.92	37.62
Reduce my consumption of meat	0.554	2.448	1.082	23.03	23.03
Respect nature when I go outside	0.468	3.655	0.635	73.35	1.00
Reuse and recycle to reduce my consumption of paper and cardboard	0.615	3.195	0.951	49.90	6.90

Participation frequency scale: 1 = never, 2 = sometimes, 3 = often, 4 = always, NA = not applicable

**All estimated factor loadings have $p < 0.001$

Table 3 Environmental values, beliefs, and willingness to sacrifice: standardized factor loadings from confirmatory factor analysis, scale reliability (Cronbach's alpha), means, and standard deviations

Predictor variables	Factor loadings	Mean	SD
Biospheric altruism (alpha = 0.849)		4.190	0.779
Respecting the earth, harmony with other species	0.849	4.276	0.857
Protecting the environment, preserving nature	0.820	4.255	0.876
Unity with nature, fitting into nature	0.760	4.041	0.933
Humanistic altruism (alpha = 0.741)		4.334	0.737
Equality, equal opportunity for all	0.738	4.340	0.945
Social justice, correcting injustice, care for the weak	0.677	4.185	0.933
A world at peace, free of war and conflict	0.675	4.477	0.840
Self-interest (alpha = 0.747)		3.402	0.956
Influence, having an impact on people and events	0.781	3.720	1.083
Authority, the right to lead or command	0.734	3.365	1.198
Wealth, material, possessions, money	0.667	3.120	1.232
Traditional values (alpha = 0.721)		4.421	0.648
Family security, safety for loved ones	0.511	4.593	0.724
Honoring parents and elders, showing respect	0.652	4.481	0.831
Self-discipline, self-restraint, resistance to temptation	0.631	4.189	0.863
Openness to change (alpha = 0.771)		3.915	0.813
An exciting life, stimulating experiences	0.727	3.847	1.010
Curiosity, interest in everything, exploring	0.659	4.021	0.930
A varied life, filled with challenge, novelty, and change	0.742	3.876	1.005
NEP scale (alpha = 0.661)		3.691	0.858
If things continue on their present course, we will soon experience a major ecological catastrophe	0.805	3.734	1.040
Humans are severely abusing the environment	0.742	4.060	0.967
The so-called ecological crisis is greatly exaggerated*	0.429	3.280	1.302
Climate change belief (alpha = 0.819)		3.757	0.913
Over the LAST 50 years, the earth's climate has been changing very quickly	0.684	3.747	1.072
Over the NEXT 50 years, the earth's climate has been changing very quickly	0.776	3.774	1.011
The earth's climate is changing primarily because of human activities	0.760	3.751	1.112
Biotechnology belief (alpha = 0.859)		3.375	0.851
I believe "Biopharmaceuticals" is beneficial	0.723	3.608	0.951
I believe "Herbicide-resistant crops" is beneficial	0.771	3.369	1.072
I believe "Biofortified crops" is beneficial	0.770	3.392	1.103
I believe "Horn free dairy cattle" is beneficial	0.690	3.095	1.123
I believe "Gene drive" is beneficial	0.742	3.413	1.059
Willingness to sacrifice for climate change (alpha = 0.865)		3.573	1.055
In deciding who to vote for in elections, consider efforts to address problems of climate change	0.765	3.820	1.108
Pay somewhat higher prices to support efforts to address problems of climate change	0.844	3.417	1.239
Make a donation to a nonprofit to support efforts to address problems of climate change	0.842	3.483	1.215
Willingness to sacrifice for biodiversity loss (alpha = 0.827)		3.468	0.936
In deciding who to vote for in elections, consider efforts to address biodiversity loss	0.703	3.617	0.980
Pay somewhat higher prices to support efforts to address biodiversity loss around the world	0.809	3.347	1.158
Make a donation to a nonprofit to support efforts to address biodiversity loss around the world	0.823	3.438	1.114

*Reversed scale

**All estimated factor loadings have $p < 0.001$

them. Energy conservation behaviors were measured with three items: "Make gas mileage and reduction in pollution the major considerations for my next vehicle," "Turn down the thermostat at home in the winter," and

"Limit my air-conditioner use at home in the summer." Green consumer behaviors included three items: "Take my own shopping bags when purchasing groceries at the store," "Utilize reusable water bottles," and "Purchases housecleaning products that are marked eco-friendly." Water conservation behaviors were measured with three items: "Conserve water or use water efficiently," "Turn off the faucet when I brush my teeth," and "Turn off the water when shampooing and soaping." Biodiversity protection behaviors were measured with three items: "Reduce my consumption of meat," "Respect nature when I go outside," and "Reuse and recycle to reduce my consumption of paper and cardboard." Note that our categorization of items into these four groups is somewhat arbitrary. Our goal in using the categories was simply to insure that we sampled widely across a variety of types of items, so the categories play no further role in the analysis since we find that the 12 items can reasonably be seen as a single latent variable.

We scaled all 12 items together. The scale formed a reliable general measure of pro-environmental behaviors ($\alpha = 0.841$). Cronbach's alpha was not substantially improved by deleting any of the 12 behavior items. Internal consistency with Cronbach's alpha is a necessary but not sufficient condition for a single dimension of pro-environmental behavior (Tavakol and Dennick 2011; Whitmarsh and O'Neill 2010). The confirmatory factor analysis embedded in the SEM indicates that all 12 behavior items have moderate to strong standardized loadings on a single factor ($\lambda > 0.4$) and all were significant at $p < 0.001$ (Table 2). Together the high internal consistency of behavior items and the results of confirmatory factor analysis support treating the 12 behavior items as a single scale in subsequent analyses although again we note there might be variation in what drives specific behaviors over and above what is captured by the model of the latent variable summarizing all behaviors.

Willingness to sacrifice Participants rated how they feel about their willingness to take actions on climate change and biodiversity loss. Respondents were asked about their willingness to take action, with responses on a 1–5 scale from "Very unwilling" to "Very willing." Willingness to sacrifice for climate change were measured with three items: "In deciding who to vote for in elections, consider efforts to address problems of climate change," "Pay somewhat higher prices to support efforts to address problems of climate change," and "Make a donation to a nonprofit to support efforts to address problems of climate change." The resulting scale has $\alpha = 0.865$, and all item loadings had $p < 0.001$ (Table 3). Willingness to sacrifice for biodiversity loss was measured with three items: "In deciding who to vote for in elections, consider efforts to address biodiversity loss," "Pay somewhat higher prices to support efforts to address biodiversity loss around the world," and "Make a donation to a nonprofit to support efforts to address biodiversity loss around the world." The resulting scale had $\alpha = 0.827$, and all item loadings had $p < 0.001$ (Table 3).

We have chosen to model willingness to sacrifice for protecting biodiversity and for climate change as two separate latent variables although there is an argument for combining them into a single scale. The two scales have relatively high correlation ($r = 0.834$). This leads to the highest variance inflation factors in a simple ordinary least squares regression of the independent variables on the behavior scale, using additive scales as surrogates for the latent variables in the SEM. For willingness to sacrifice to prevent climate change, the VIF = 4.41; for willingness to sacrifice for biodiversity, the VIF = 3.80 (see Table 6 in Online Appendix 1). However, neither of these VIF values is deemed problematic by conventional benchmarks. As we will see below, when we include both scales, willingness to sacrifice for biodiversity has a significant positive effect on behaviors, while willingness to sacrifice for climate change has an insignificant negative effect. While a combined measure of willingness to sacrifice has good reliability ($\alpha = 0.831$), it does not have a significant effect when we use a combined measure in the SEM. Thus, it appears that there are some collinearity problems with these measures, ones not resolved by combining them into a single scale. We believe the use of the two scales provides the most information, and thus, have used that as our approach. But we highlight that the willingness to sacrifice concept, while commonly deployed in large surveys, clearly needs further theoretical and methodological development.

Specific beliefs about biotechnology Five items were used to tap beliefs in the benefits from biotechnologies, each with reference to a specific application of biotechnology (Azodi and Dietz 2018). The applications were described in a few sentences, then respondents were asked whether or not they thought the technology was beneficial on a 1–5 scale from "Strongly disagree" to "Strongly agree" (The brief description is provided in Online Appendix 2). The five applications were "Biopharmaceuticals," "Herbicide-resistant crops," "Biofortified crops," "Horn free dairy cattle," and "Gene drives." The order in which the technologies were presented to a respondent was randomized across respondents. While this is a diverse set of technologies, respondents seemed to respond as if the items were tapping a general view of biotechnology ($\alpha = 0.859$; all $\lambda > 0.690$ with $p < 0.001$) (Table 3).

Specific beliefs about climate change Specific beliefs on concern about climate change were measured with three items: "Over the LAST 50 years, the earth's climate has been changing very quickly," "Over the NEXT 50 years, the earth's climate has been changing very quickly," and "The earth's climate is changing primarily because of human activities" ($\alpha = 0.819$; all $\lambda > 0.684$ with $p < 0.001$) (Table 3).

General beliefs General beliefs that humans can harm the environment were captured with three items, each rated on a 1–5 scale from "Strongly disagree" to "Strongly agree": "If things continue on their present course, we will soon experience a major ecological catastrophe," "Humans are severely abusing the environment," and "The so-called ecological crisis is greatly exaggerated (reversed in scoring)" ($\alpha = 0.661$; all $\lambda > 0.429$ with $p < 0.001$) (Table 3).

Environmental values Following common practice, we used three items to tap each of the five values used in our model (Dietz 2015). Respondents were asked to indicate how important each item was as "a guiding principle in your life" on a 1–5 scale, ranging from "Not at all important" (1) to "Extremely important" (5). Each value measure has adequate alpha reliability and every observed variable has a significant ($\lambda > 0.511$ with $p < 0.001$) loading on the appropriate latent value variable (Table 3). Biospheric altruism values were measured with: "Respecting the earth, harmony with other species," "Protecting the environment, preserving nature," and "Unity with nature, fitting into nature" ($\alpha = 0.849$). Humanistic altruism values were measured with: "Equality, equal opportunity for all," "Social justice, correcting injustice, care for the weak," and "A world at peace, free of war and conflict" ($\alpha = 0.741$). Self-interest values were captured with: "Influence, having an impact on people and events," "Authority, the right to lead or command," and "Wealth, material, possessions, money" ($\alpha = 0.747$). Traditional values was measured with: "Family security, safety for loved ones," "Honoring parents and elders, showing respect," and "Self-discipline, self-restraint, resistance to temptation" ($\alpha = 0.721$). Openness to change values were measured with: "An exciting life, stimulating experiences," "Curiosity, interest in everything, exploring," and "A varied life, filled with challenge, novelty, and change" ($\alpha = 0.771$).

Sociodemographic and other background variables We created a dummy variable scored 1 for respondents who reported their race/ethnicity as non-Hispanic white and 0 for all others. Gender was captured with a dummy variable scored 1 for men and 0 for all others. Age is a continuous variable in years. Education is scored as a continuous variable ranging from 1 for those with less than a high school education to 6 for those reporting graduate or professional degrees. Political ideology was measured on 7-point scale ranging from "Very liberal" (1) to "Very conservative" (7). We used a standard question on Biblical literalism to measure religious fundamentalism, asking on a 5-point Likert-like scale ranging from "Strongly disagree" (1) to "Strongly agree" (5) if the respondent felt that "The Bible is the actual word of God and is to be taken literally." The trust in scientists scale was measured by three items scored on a 1–5, "Strongly disagree" to "Strongly agree" scale: "Most scientists working for business act in the best interests of the public," "Most scientists working for government act in the best interests of the public," and "Most scientists working for universities act in the best interests of the public" ($\alpha = 0.795$, all $\lambda > 0.689$ with $p < 0.001$ for all three factor loadings).

Model building strategy

Figure 1 displays the causal logic of our model. For simplicity, we do not include the measurement models for the latent variables. The sociodemographic variables, political ideology, fundamentalism, and trust in scientists are treated as exogenous. The five environmental values—biospheric altruism, humanistic altruism, traditional values, self-interest, and openness to change—affect general environmental worldview. Then general worldview causes specific belief on concerns about climate change and specific belief on the benefits of new biotechnologies. These two specific beliefs influence willingness to sacrifice for climate change and willingness to sacrifice for biodiversity loss that might lead pro-environmental behaviors to alleviate environmental degradation. Finally, the two willingness to sacrifice variables are seen as direct causes of pro-environmental behaviors.

While these direct causal paths structure the model, we have simultaneously estimated both direct and indirect effects of hypothesized variables on pro-environmental behaviors. For example, in the model, we allowed direct and indirect paths from sociodemographic factors to pro-environmental behaviors. Although all direct effects (e.g., the direct effects of sociodemographic factors on pro-environmental behavior) were included in the final model estimated, for

Table 4 Standardized estimations of direct, indirect, and total effects of model variables on pro-environmental behavior

	Direct effects	Indirect effects	Total effects
White	− 0.039	0.039	0
Male	− 0.012	− 0.033	− 0.045
Age	0.095	− 0.027	0.068
Education	0.100*	0.034	0.134*
Income	0.083	0.013	0.096*
Political ideology	0.065	− 0.230*	− 0.165**
Religious fundamentalism	0.122	0.015	0.137*
Trust in scientists	0.016	0.171*	0.187**
Biospheric altruism	0.320	0.160	0.480**
Humanistic altruism	0.226	0.185	0.411
Self-interest	0.037	− 0.004	0.033
Traditionalism	− 0.261	− 0.223	− 0.484
Openness to change	0.113	0.075	0.188
NEP	0.030	0.061	0.091
Climate change belief	0.092	0.019	0.111
Biotechnology belief	0.020	0.048	0.068
WTS for climate change	− 0.255	0	− 0.225
WTS for biodiversity	0.371*	0	0.371*

*$p < 0.05$; **$p < 0.001$

simplicity, they are not displayed in Fig. 1. In addition to direct and indirect effects (Table 4), in Table 5, we display five SEM models corresponding to adding each block of variables to the model of pro-environmental behaviors. Thus, model 1 shows the total effects of the exogenous variables not controlling for intervening variables, and model 2 adds controls for values and so on to model 5 which is the full set of direct effects. Again we note that while the causal order we are positing is consistent with theoretical logical and general practice in the literature, we cannot test it with cross-sectional data. However, even if we are incorrect about the flow of causation, the estimates we report are still accurate assessments of partial association among the variables.

Following standard practice, we used the χ^2, the root mean square error of approximation (RMSEA), and the comparative fit index (CFI) to assess model fit. For a good model fit, the RMSEA would be less than 0.06 with a 90% CI, and the CFI would be near or greater than 0.90 (Hooper et al. 2008). Modification indices explain covariance errors among variables. The modification indices give the expected drop in chi-square if the parameter in question is freely estimated rather than constrained (Muthén and Muthén 2012).

Table 5 Unstandardized (standardized) coefficients of separate SEM models predicting pro-environmental behavior

	Model 1	Model 2	Model 3	Model 4	Model 5
White	− 0.009 (− 0.006)	− 0.065 (− 0.044)	− 0.067 (− 0.044)	− 0.067 (− 0.045)	− 0.059 (− 0.039)
Male	− 0.055 (− 0.038)	0.005 (0.004)	0.015 (0.010)	− 0.001 (− 0.001)	− 0.017 (− 0.012)
Age	0.003 (0.068)	0.002 (0.048)	0.002 (0.058)	0.002 (0.056)	0.004 (0.095)
Education	0.062* (0.134)	0.062* (0.136)	0.061* (0.133)	0.058* (0.127)	0.046* (0.100)
Income	0.002 (0.089)	0.002* (0.119)	0.002* (0.116)	0.002* (0.103)	0.001 (0.083)
Political ideology	− 0.066** (− 0.170)	0.038 (0.098)	0.037 (0.096)	0.029 (0.076)	0.025 (0.065)
Religious fundamentalism	0.068* (0.140)	0.101 (0.212)	0.092 (0.192)	0.083 (0.173)	0.058 (0.122)
Trust in scientists	0.137** (0.184)	0.029 (0.040)	0.030 (0.041)	0.000 (0.000)	0.012 (0.016)
Biospheric altruism	–	0.466* (0.499)	0.401* (0.429)	0.408* (0.436)	0.298 (0.320)
Humanistic altruism	–	0.438 (0.448)	0.357 (0.364)	0.311 (0.319)	0.220 (0.226)
Self-interest	–	0.029 (0.035)	0.024 (0.030)	0.013 (0.016)	0.030 (0.037)
Traditionalism	–	− 1.027 (− 0.536)	− 0.847 (− 0.441)	− 0.734 (− 0.381)	− 0.501 (− 0.261)
Openness to change	–	0.186 (0.195)	0.184 (0.193)	0.155 (0.161)	0.107 (0.113)
NEP	–	–	0.075 (0.092)	− 0.017 (− 0.020)	0.025 (0.030)
Climate change belief	–	–	–	0.108 (0.115)	0.086 (0.092)
Biotechnology belief	–	–	–	0.068 (0.069)	0.020 (0.020)
WTS for climate change	–	–	–	–	− 0.185 (− 0.225)
WTS for biodiversity	–	–	–	–	0.368* (0.371)
MR^2	0.130	0.326	0.328	0.326	0.349
χ^2	241.337	1226.11	1529.828	1932.863	2431.609
df	127	459	550	842	1089
CFI	0.928	0.859	0.842	0.874	0.885
RMSEA (95% CI)	0.042 (0.034–0.050)	0.057 (0.053–0.061)	0.059 (0.055–0.062)	0.050 (0.047–0.053)	0.049 (0.046–0.051)

Values in parentheses are standardized coefficients

*$p < 0.05$; **$p < 0.001$

Results

We begin by examining the direct, indirect, and total effects of the variables in our model, as displayed in Table 4. These estimates are from the full model that includes sociodemographic and background factors, values, general beliefs about the fragility of the environment, specific beliefs about climate change and biotechnology, and willingness to sacrifice as predictors of pro-environmental behavior. The model fit indices are reasonably good with the exception of the χ^2 value ($\chi^2 = 2431.6$; $df = 1089$; RMSEA = 0.049 compared to a norm of < 0.06; CFI = 0.885 compared to a norm of > 0.90). The χ^2 of our final model was significant ($p < 0.001$) rejecting the model as "adequate" for the data. However, any model with large sample size is frequently rejected as the χ^2 statistic is sensitive to sample size (Hooper et al. 2008). Model improvement statistics suggest that most of the lack of fit comes from not including correlations among error terms in the model. Since these are not of substantive importance for our analysis, we have not iteratively re-estimated the model simply to reduce χ^2 since other fit indices are adequate. The final model accounts for 34.9% of the variance in the latent pro-environmental behavior variable (Table 5).

Only education and willingness to sacrifice for biodiversity have significant direct effects on environmental behavior scale when all other variables are included in the model. The direct effect of willingness to sacrifice for biodiversity is expected since we posited willingness to sacrifice as similar to norm activation in the traditional VBN model. The lack of significance and negative sign of willingness to sacrifice for climate change is surprising. It might be attributed in part to the high correlation between the two willingness to sacrifice measures discussed above. The effects of education are consistent with the literature that shows frequent but moderate effects of education.

The total effects demonstrate the importance of a wider array of the variables we have modeled as exogenous. While the total effect of education is stronger than the direct effect, we also find that income has a modest tendency to increase pro-environmental behavior. Not surprisingly, conservative ideology decreases such behavior, with ideology acting primarily through values. Given that we cannot disentangle causal direction between ideology and values, we simply note that they seem strongly linked and that ideology and values are influential on pro-environmental behavior via indirect paths. Interestingly, religious fundamentalism increases pro-environmental behavior net of other factors including political ideology, again acting primarily through values. This is consistent with the results of Peifer et al. (2016), who found religious beliefs moderated the effects of ideology. As hypothesized, trust in scientists increases pro-environmental behavior through its links to values and through its influence on specific beliefs, again through its relationship to values. Finally, biospheric altruism has the strongest total effects in the model even though the direct effects do not reach significance. The strong total effects of biospheric altruism are consistent with many other findings that demonstrate its influence on pro-environmental behavior. While in some studies other values have influence on pro-environmental behavior and on the intermediate variables in our model, here only biospheric altruism matters.

Table 5 shows the paths by which indirect influence is exerted by estimating a series of SEM models that add intermediate variables. The model fit indices of the five models were generally acceptable (CFI near or greater than 0.90 and RMSEA less than 0.06 with a 90% CI). Entering values into the model attenuates the significance of political ideology, religious fundamentalism, and trust in scientists but reduces the standard error of income sufficiently to make it significant. The effects of income and altruism persist as variables are added to the model until the full model includes willingness to sacrifice. As noted, once willingness to sacrifice is controlled, education is the only other variable to have an effect on pro-environmental behavior.

Notable are the lack of significant direct, indirect, or total effects for any of the belief variables. While the generalized beliefs scale has often been significant in VBN-based models, here it does not seem to predict pro-environmental behavior over and above the effects of values and our exogenous variables. It is strongly predicted by both biospheric and humanistic altruism (see Table 7 in Online Appendix 1). Specific beliefs about climate change and about biotechnology have no effect on behavior, although beliefs that biotechnology may be beneficial do predict both measures of willingness to sacrifice.

Conclusions

Our goal was to build on the often-used framework of the VBN theory but to add several variables that have been found to influence environmental concern or pro-environmental behavior in parts of the literature not based directly on the VBN theory. In drawing conclusions, we first note the limits of the study. Perhaps the most compelling limit is that, like much of the literature, we do not have observed behaviors but self-reports. While the best literature review available, that of Gifford and Nilsson (2014), concludes that self-reports are generally related to actual behavior, it is always preferable to have observed behavior measures. Second, we have created a scale of behaviors based on a broad set of items. While we have noted the advantage of this common approach, there is much to be said for targeting high consequences of behaviors such as, for example, home weatherization or adoption of more efficient technologies. We did not pursue that strategy here because focusing on specific high impact behaviors requires assessing the contraints and opportunities faced by respondents and thus is best a follow-on to the more general approach we use. Third, our sample is an Internet quota sample. This approach is generally accepted as more representative than a convenience sample but still is not as representative as a full probability sample. Fourth, while our measures of variables we have added to the VBN model have good reliability and are consistent with standard practices, it is always possible that the failure of many of them to add much to VBN might reasonably be attributed to inadequate operationalization of the underlying concepts rather than the limits of the theorized relationships.

The strongest message in our results is that biospheric altruism remains a strong overall predictor of pro-environmental behavior. But, as in many other studies, its effects are mostly indirect, in our model acting through willingness to sacrifice (Dietz 2015). If, as we suggested, willingness to sacrifice is conceptually similar to ascription of responsibility to self, the penultimate variable in the VBN causal chain, then this result is consistent with the VBN theory.

Perhaps the most puzzling result is the lack of significance of willingness to sacrifice for climate change, and indeed the negative, albeit insignificant effect of this variable when willingness to sacrifice for biodiversity is controlled. This may be a methodological artifact given the collinearity of the two; however, a scale that combines them no longer significantly predicts pro-environmental behavior. All this suggests that willingness to sacrifice warrants further theoretical and empirical investigation because it has been so extensively used in large nationally representative samples. Understanding where it fits in a theoretically driven model could help link the social psychological literature to the literature based on nationally representative samples.

As noted, the literature has shown inconsistent effects of religious beliefs on pro-environmental behavior. Here, we replicated the intriguing finding of Peifer et al. (2016), with fundamentalism having a positive effect on pro-environmental behaviors acting through values, net of political ideology. Here again, further theoretical explication and more empirical works are certainly warranted.

Our paper was motivated by a perceived gap between social psychological theories of pro-environmental behavior, and in particular the VBN theory, and common practice in many studies of environmental concern and behavior based on public opinion surveys. The latter literature can be a bit ad hoc with regard to the variables posited as influencing pro-environmental behavior. We have examined a few of them: religious beliefs, trust in scientists, specific beliefs, and willingness to sacrifice are often deployed as explanatory variables. While our results are certainly tentative, we hope that they encourage steps toward more integrated theory and the testing of more comprehensive models and ultimately a better link between the social psychological theories of environmental decision-making and the design and analyses of large public opinion surveys that include environment modules.

Acknowledgments We thank Christina Azodi for the use of the biotechnology belief items she developed.

Funding Funding is provided by the National Science Foundation, NASA, Environmental Science and Policy Program at Michigan State University, Sustainable Michigan Endowment Project, and Michigan AgBioResearch.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Appendix 1VIF and SEM results

Table 6 Variance inflation factor (VIF) for variables used in SEM

	VIF	1/VIF
White	1.11	0.898
Male	1.16	0.865
Age	1.31	0.761
Education	1.19	0.841
Income	1.24	0.808
Political ideology	1.44	0.693
Religious fundamentalism	1.36	0.733
Trust in scientists	1.63	0.615
Biospheric altruism	2.56	0.391
Humanistic altruism	2.41	0.415
Self-interest	1.81	0.554
Traditionalism	1.98	0.505
Openness to change	1.88	0.532
NEP	2.82	0.355
Climate change belief	3.01	0.332
Biotechnology belief	1.49	0.670
WTS for climate change	4.41	0.227
WTS for biodiversity	3.80	0.263

Table 7 Unstandardized (standardized) coefficients of all variables predicting pro-environmental behavior in the final structural equation model

	Biospheric altruism	Humanistic altruism	Self-interest	Traditionalism	Openness to change	NEP	Climate change belief	Biotechnology belief	WTS for climate change	WTS for biodiversity	Pro-environmental behavior
White	0.102 (0.064)	0.075 (0.049)	–0.050 (− 0.027)	0.040 (0.052)	0.142 (0.090)	0.028 (0.017)	− 0.034 (− 0.023)	0.073 (0.048)	− 0.024 (− 0.010)	− 0.030 (− 0.018)	− 0.059 (− 0.039)
Male	− 0.236* (− 0.152)	− 0.194* (− 0.130)	− 0.037 (− 0.021)	− 0.126* (− 0.168)	− 0.029 (− 0.019)	− 0.115 (− 0.064)	− 0.018 (− 0.014)	0.291** (0.199)	− 0.121 (− 0.065)	− 0.020 (− 0.011)	− 0.017 (− 0.012)
Age	0.004 (0.092)	0.008** (0.187)	− 0.009** (− 0.176)	0.003* (0.161)	− 0.003 (− 0.076)	− 0.006 (− 0.119)	0.000 (0.007)	0.000 (0.004)	− 0.006* (− 0.124)	− 0.008* (− 0.181)	0.004 (0.095)
Education	0.012 (0.025)	0.014 (0.030)	0.040 (0.070)	0.022 (0.094)	0.054* (0.112)	0.010 (0.017)	0.014 (0.028)	0.012 (0.026)	0.025 (0.047)	0.044 (0.094)	0.046* (0.100)
Income	0.000 (0.020)	− 0.001 (− 0.058)	0.002* (0.096)	0.000 (0.049)	0.001 (0.071)	0.000 (0.012)	0.001 (0.030)	0.002* (0.105)	0.002 (0.102)	0.002* (0.119)	0.001 (0.083)
Political ideology	− 0.066* (− 0.159)	− 0.075** (− 0.189)	0.011 (0.022)	0.033* (0.166)	− 0.027 (− 0.066)	− 0.025 (− 0.061)	0.054 (0.140)	− 0.051 (− 0.131)	0.070 (0.156)	0.051 (0.129)	0.025 (0.065)
Religious fundamentalism	0.045 (0.088)	0.023 (0.046)	0.164** (0.279)	0.079** (0.318)	0.056* (0.113)	0.097 (0.170)	0.075 (0.147)	− 0.045 (− 0.094)	0.088 (0.165)	0.111 (0.226)	0.058 (0.122)
Trust in scientists	0.140** (0.177)	0.131* (0.173)	0.264** (0.292)	0.054* (0.140)	0.174** (0.225)	0.007 (0.013)	0.113* (0.139)	0.323** (0.430)	0.078 (0.088)	0.009 (0.005)	0.012 (0.016)
Biospheric altruism	–	–	–	–	–	0.793** (0.698)	− 0.014 (− 0.002)	− 0.302 (− 0.320)	0.600* (0.532)	0.605* (0.638)	0.298 (0.320)
Humanistic altruism	–	–	–	–	–	0.933* (0.771)	0.254 (0.276)	− 0.220 (− 0.224)	0.814 (0.697)	0.676 (0.674)	0.220 (0.226)
Self-interest	–	–	–	–	–	0.026 (0.031)	0.049 (0.053)	0.061 (0.074)	0.037 (0.050)	− 0.020 (− 0.024)	0.030 (0.037)
Traditionalism	–	–	–	–	–	− 2.000 (− 0.842)	− 0.724 (− 0.381)	0.680 (0.351)	− 1.826 (− 0.792)	− 1.593 (− 0.800)	− 0.501 (− 0.261)
Openness to change	–	–	–	–	–	0.008 (0.007)	0.167 (0.164)	0.079 (0.081)	0.181 (0.152)	0.221 (0.221)	0.107 (0.113)
NEP	–	–	–	–	–	–	0.837** (0.941)	0.079 (0.096)	0.299 (0.309)	0.036 (0.011)	0.025 (0.030)
Climate change belief	–	–	–	–	–	–	–	–	− 0.053 (− 0.061)	0.022 (0.067)	0.086 (0.092)
Biotechnology belief	–	–	–	–	–	–	–	–	0.193* (0.170)	0.225* (0.228)	0.020 (0.020)
WTS for climate change	–	–	–	–	–	–	–	–	–	–	− 0.185 (− 0.225)
WTS for biodiversity	–	–	–	–	–	–	–	–	–	–	0.368* (0.371)

Values in parentheses are standardized coefficients

*$p < 0.05$; **$p < 0.001$

Appendix 2 Short description of biotechnologies

The five biotechnology applications were developed by Christina Azodi (Azodi and Dietz 2018): "Biopharmaceuticals," "Herbicide-resistant crops," "Biofortified crops," "Horn free dairy cattle," and "Gene drives." The short descriptions of these applications are as follows:

1. "Biopharmaceuticals" are medical drugs produced by genetically modified bacteria to produce synthetic insulin more affordable.
2. "Herbicide-resistant crops" are genetically modified to be resistant to certain kinds of herbicides that allow farmer to increase productivity with lower costs.
3. "Biofortified crops" are genetically modified to increase their nutritional values such as a vitamin-A–enriched rice for undernourished children.
4. "Horn free dairy cattle" are genetically modified to suppress their natural horn growth, which eliminates the need for painful and expensive horn removal procedures in calves.
5. "Gene drive" is a way to introduce a gene or trait into a population and ensure it spreads to the whole population. For example, a genetically modified mosquito with a sterilization gene could be used to kill populations of mosquitoes carrying the Zika virus.

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