Weather and Climate Variability May Be Poor Proxies for Climate Change in Farmer Risk Perceptions^①

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ABSTRACT

Despite long-standing assertions that climate change creates new risk management challenges, the climate change adaptation literature persists in assuming, both implicitly and explicitly, that weather and climate variability are suitable proxies for climate change in evaluating farmers' risk perceptions and predicting their adaptive responses. This assumption persists in part because there is surprisingly little empirical evidence either way, although case studies suggest that there may be important differences. Here, we use a national survey of South Africa's commercial grain farmers ($n = 389$)—similar to their peers in higher-income countries (e.g., North America, Europe, Australia), but without subsidies—to show that they treat weather and climate change risks quite differently. We find that their perceptions of climate change risks are distinct from and, in many regards, oppositional to their perceptions of weather risks. While there seems to be a temporal element to this distinction (i.e., differing concern for short-term vs long-term risks), there are other differences that are better understood in terms of normalcy (i.e., normal vs abnormal relative to historical climate) and permanency (i.e., temporary vs permanent changes). We also find an interaction effect of education and political identity on concern for climate change that is at odds with the well-publicized cultural cognition thesis based on surveys of the American public. Overall, studies that use weather and climate variability as unqualified proxies for climate change are likely to mislead researchers and policymakers about how farmers perceive, interpret, and respond to climate change stimuli.

1. Introduction

The conceptual literature on climate change adaptation has long asserted that climate change creates new challenges

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for farm-level decision-making (Meinke and Stone 2005; Meinke et al. 2009; Risbey et al. 1999), yet many adaptation studies continue to use weather and climate variability as unqualified proxies for climate change, either explicitly or implicitly, in studying farmers' responses. This approach implies that farmers will adapt to climate change risks using the same decision-making and risk management strategies that they use for weather, and that they have little need to adapt differently or proactively to abnormal, permanent, and long-term changes. Some researchers make these assumptions implicitly (e.g., Ash et al. 2012; Jain et al. 2015;

Reidsma et al. 2010; Truelove et al. 2015; Wreford and Adger 2010); for instance, Abid et al. (2016) use the term “climate-related risks” as synonymous and interchangeable with “climate change risks” in studying past farmer responses to climate variability in Pakistan and as predictive of future adaptation. While their research goals are laudable and the methods appear to be rigorous, the implications of the research for adaptation to climate change are muddled by the unqualified conflation of past weather and climate variability with future climate change. Other researchers are more explicit (e.g., Bryant et al. 2000; Mendelsohn and Dinar 1999; Reidsma et al. 2010; Smit and Skinner 2002); for instance, Reidsma et al. (2010) use past climate variability, adaptive responses, and crop yield data to understand climate change adaptation in European agriculture across diverse income levels, comparing spatial to temporal variability, farm-level to regional responses, and crop model predictions to on-farm outcomes. They contextualize the paper with evidence of Europe’s changing climate and their datasets are large. The analysis provides useful information about the variability of impacts along various dimensions (e.g., income, farm type, region) and the risk-mitigating benefits of adaptive responses to prevailing conditions. However, their analysis does not differentiate between stationary and nonstationary climates, consistently referring to “climate change and variability” while analyzing only the variability and not the change.

Meanwhile, adaptation experts have encouraged farmers and other climate-vulnerable decision-makers to integrate (or “mainstream”) climate change risks into pre-existing decision-making processes so that climate risk management is coordinated with other objectives (Porter et al. 2014). Although adaptation is sometimes framed as a distinct process of deliberative adjustment to a new hazard, researchers argue that it is inseparable from the ongoing management of other cross-scalar and multi-causal risks (Bassett and Fogelman 2013)—for example, those related to family, finances, politics, pests, weeds, labor, markets, etc. (Findlater et al. 2019b). Even when farmers express disbelief in climate change or ambivalence toward mitigation, they may be supportive of government adaptation programs and receptive to adaptation messages (Arbuckle et al. 2015; Findlater et al. 2018a; Prokopy et al. 2015). As a whole, the literature therefore appears to suggest that farmers *ought* to mainstream climate change risks with their management of other risks, like weather (e.g., Howden et al. 2007), and that they are *likely to do so* intuitively and autonomously, whether or not they believe in climate change, because some aspects of those risks will manifest in similar ways (e.g., Mertz et al. 2009). Under such circumstances, weather and climate variability risks may be good proxies for climate change.

However, there is considerable evidence that *institutional* decision-makers (usually conceptualized as more deliberate) have difficulty incorporating climate change risks into pre-existing decision-making and risk management processes (Kunreuther et al. 2013). The uncertain, incremental, and often long-term nature of climate change risks is widely thought to create new and potentially intractable challenges for risk management (Dittrich et al. 2016), including technological, informational, economic, and social barriers to adaptation (Adger et al. 2009; Porter et al. 2014). For example, the high degree of uncertainty in projected local changes—their direction, amplitude, impacts, and the effectiveness of specific adaptive responses—make it difficult to include climate change risks in conventional risk assessments, cost-benefit and cost-effectiveness analyses, and multicriteria decision-making (Dittrich et al. 2016). Further, different ways of framing “resilience” to weather or climate change may imply different objectives and therefore necessitate different resilience-building strategies (Rodina 2019a,b). In parallel, nonagricultural surveys of experts and broader publics provide strong evidence that politics, culture, identity, and psychological distance play different roles in individuals’ perceptions of climate change risks than they do for weather (Clayton et al. 2015; Hornsey et al. 2016; Wolf and Moser 2011).

In contrast, there is surprisingly little empirical evidence for how individual decision-makers (and particularly farmers) perceive, interpret, and integrate responses to climate change stimuli, and how this may differ from weather and climate variability (Clayton et al. 2015). There is a small but growing body of evidence suggesting that farmers are sensitive to weather and climate change as related but distinct risks, and that this distinction might have important repercussions for farmers’ behavior (Eakin et al. 2016; Kenny 2011). Eakin et al. (2016), for instance, find that farmers in Arizona who otherwise consider themselves highly adaptable to a wide variety of risks may nonetheless express a lack of agency in responding to climate change risks; those farmers perceive climate change adaptation to require greater flexibility than weather, and better access to information, finance, and technology. Meanwhile, in a much larger-scale study of agriculture in the United States, Burke and Emerick (2016) find that farmers’ short-term responsiveness (i.e., to weather) masks a lack of longer-term adaptation (i.e., to decadal climate variability). They argue that this difference in short- versus long-term responsiveness will lead to greater future losses from climate change than found in studies that assume perfect adaptation or that assume similar short- and long-term responsiveness.

To help understand differences in weather and climate-driven behaviors, we first conducted four mixed-methods

analyses (Findlater et al. 2018a,b, 2019a,b) of the risk perceptions and risk management strategies of commercial grain farmers in South Africa's Western Cape province. South Africa's commercial grain farmers are uniquely positioned to adapt proactively to highly uncertain and long-term risks. They practice modern large-scale grain farming in a highly variable and largely semiarid climate vulnerable to climate change (Davis-Reddy and Vincent 2017) and are immersed in a culture that reveres multigenerational farming heritage (Devarenne 2009). They are relatively well educated, with good access to informational, financial, and institutional resources (Wilk et al. 2013). However, as many are historically privileged white beneficiaries of South Africa's apartheid legacy, they generally receive little explicit support from government (e.g., subsidies and government-backed crop insurance) (Bernstein 2013). They are therefore more exposed to the financial harms of weather and climate risks than their peers in higher-income countries (e.g., the United States, Canada, Europe, and Australia).

Their ongoing, but uneven, adoption of conservation agriculture (CA) practices widely recognized as being climate resilient is among the most important trends in the country's agricultural sector (DEA 2013; Findlater et al. 2019a). CA is a set of three climate-resilient principles (advanced crop rotations, minimum soil disturbance, and permanent soil cover) advocated by the Food and Agriculture Organization of the United Nations as part of their Climate-Smart Agriculture and Sustainable Intensification foci (Giller et al. 2015; McCarthy et al. 2011). With a long implementation period and established benefits across an array of climate and nonclimate risks (Niang et al. 2014), the adoption of CA by South African farmers suggests that these farmers are willing and able to undertake substantial and proactive changes in practice to manage uncertain long-term risks (Findlater et al. 2018b). This population therefore resembles the archetypal autonomous actor foundational to the adaptation literature, and may bookend the range of possible farmer responses to climate risks. Other populations that are less climatically, financially, and politically incentivized to adapt proactively may respond more slowly and more reactively.

To investigate how these farmers manage weather, climate variability, and climate change among the many other risks that they face, we conducted 90 in-depth mental model interviews. Mental modeling approaches attempt to capture the internal representations of reality, understood to be imperfect abstractions, that people use to understand and respond to specific problems (Jones et al. 2011; Morgan et al. 2002). This kind of analysis originated in psychology and has since been widely applied in risk perceptions research. We began

each interview with a rapport-building section and a lengthy risk elicitation exercise. This allowed each participant to set the stage in their own words, describing the landscape of risks that they face in the farming enterprise. The balance of each interview then followed an indirect mental modeling protocol with a typical "broad-to-narrow" structure intended to limit the amount of information introduced by the interviewer. Discreet prompts encouraged participants to elaborate causal relationships (i.e., causes, problems, effects, responses, and mediators of response) around weather- and climate-related risks, in particular.

The ability of mental modeling approaches to predict actual behavior is crucially dependent on the elicitation technique (Jones et al. 2011). Our in situ, in-depth, and indirect approach, which included rapport-building and allowed the participant to frame the conversation, was intended to make the elicitation conditions as similar as possible to those under which the participant normally makes risk management decisions. Here, we use these qualitative and quantitative data to contextualize the survey findings at hand, helping to overcome a common challenge in survey research: understanding participants' interpretation of the questions and extrapolating from their responses. These studies do not conceptualize adaptation as being limited to processes of deliberative planning and rational adjustment to hazards (a common framing in the adaptation literature; Bassett and Fogelman 2013), but rather as a combination of naturalistic and deliberative decision-making. For instance, in Findlater et al. (2019b) we find that these farmers make a variety of more deliberate business-oriented decisions and less deliberate personal decisions; however, across all kinds of decisions, they use naturalistic decision-making techniques, including two broad strategies that we call hazy hedging and cognitive thresholds, to make practical choices under pervasive uncertainty.

The triangulation afforded by this earlier work is particularly important in understanding how this group of farmers parses terms like weather, climate variability, and climate change, since they may mean different things to different people. We find virtually no misunderstanding and very little variation among our participants of the differences between these terms. "Weather" is understood to encompass short-term variability (from intraseasonal to seasonal), and "climate variability" encompassed medium-term variability (from annual to decadal), *consistent with historical conditions*. In contrast, "climate change" comprises those conditions *inconsistent with historical conditions*, which include both ongoing and future effects, as well as effects spanning the full range of short to long timeframes.

There is therefore a temporal element to the distinction, in that “normal” weather and climate variability do not typically include timeframes longer than decadal cycles; however, this temporal distinction is incomplete, because most of these farmers are already seeing and responding to changes (like shifting planting and harvesting dates, or intensified rainfall) that they associate with climate change, and they may experience some events associated with “normal” long-period climate variability only once in their working lives.

These farmers therefore tend to cluster weather and climate variability, as normal, and to distinguish them from climate change, as abnormal (Findlater et al. 2018a). Their descriptions of risks stemming from weather and climate variability are consistent with experts’ understanding of local historical risks (e.g., rainfall variability, intra- and interseasonal drought, wind, fire, flooding, and erosion). In contrast, climate change is characterized by permanent changes in weather and climate variables inconsistent with historical patterns, including increasingly variable rainfall with more intense rainfall events, longer droughts, hotter summers, colder winters, stronger windstorms, and shifts in the seasonality of rainfall (e.g., starting and ending later). These are again broadly consistent with experts’ understanding of anticipated local changes in climate. In analyzing these farmers’ mental models of weather and climate risks, we found that they isolate climate change from their otherwise highly integrated mental models of farm-level risk management. Their logics of climate change risk management are structurally (Findlater et al. 2018a) and linguistically (Findlater et al. 2018b) distinct from those around weather and climate variability. They tend to respond to weather and climate variability based on experiential and social learning, whereas they have little experience of climate change risk management and rely heavily on imparted expert knowledge (Findlater et al. 2018a).

Here, we build on these earlier findings to answer complementary and confirmatory questions in a broader sample. We use a risk ranking exercise in a national survey of South African commercial grain farmers to quantitatively test two hypotheses derived from common assumptions made in the adaptation literature: 1) that these farmers prioritize weather and climate change risks similarly, and 2) that their prioritizations of these two risks are driven by similar independent variables (i.e., their demographic position, farm characteristics, and farming practices). We contextualize these survey results with findings from the above mental models studies.

2. Methods

a. Design

To evaluate the relationship between farmers’ weather and climate change risk perceptions, we conducted a national survey of South Africa’s commercial grain farmers. Of 13 categories of risk identified in the earlier interviews, survey respondents were asked to select the five that posed the “greatest threats to the future success” of their farming businesses. They then ranked those five from highest to lowest priority. The ranking procedure was thus split into two steps to reduce the cognitive difficulty of the task (i.e., because there were many risk categories). The resulting rankings were reordered during analysis so that higher numbers were associated with greater priority (5 being the highest ranked; 1 being the lowest). The unselected risks (those each participant left out of the top five) were assigned a ranking of zero. These data were therefore amenable to ordinal and rank-based statistical analyses as described below. The survey was designed and piloted with input from Grain SA, the national commodity organization representing South African commercial grain farmers. Grain SA disseminated the final survey link to its members by e-mail. Our approach is similar to a recent study of drought risk perceptions among farmers in the Netherlands by van Duinen et al. (2015), which examined drivers of perceived weather risk; however, our analysis emphasizes the differences between weather and climate change.

b. Analysis

To assess overall climate risk perceptions, we first compared the proportions of respondents who selected weather and climate change as high-priority risks, alongside their explicit belief in climate change and concern for its impacts as expressed in five Likert-scale questions. The weather and climate change rankings were then each analyzed as dependent variables using ordinal logistic regression (i.e., a generalized linear model with a cumulative logit link) with a common set of demographics, farm characteristics, and farming practices as predictors. Since we were primarily interested in demonstrating that there are important differences between weather and climate change risk perceptions, we have not shown the nested regression models in the body of the paper (e.g., those that include only crop cluster or only farming practices as independent variables). These may be found in the online supplemental material. Further, we do not intend that the odds ratios be compared among independent variables—only that their signs and significance be compared between the two dependents. Note that the “education” variable represents the highest level of formal education (e.g., high

school, four-year undergraduate degree) that the respondent has completed, and does not capture informal learning.

To analyze the drivers of differences between weather and climate change risk perceptions, a dissimilarity measure was defined as the distance between the weather and climate change rankings assigned by each respondent. This was calculated by subtracting the weather rankings (0–5) from the climate change rankings (0–5). The resulting dependent variable ranged from +5 (when climate change was ranked highest and weather was not selected) to –5 (when weather was ranked highest and climate change was not selected). This variable, constructed to reflect differences in climate change and weather risk perceptions, was used as the dependent variable in a multivariate linear regression model (i.e., a generalized linear model with an identity link) with independent variables identical to those in the above ordinal regressions. We used linear, rather than ordinal, regression for this 11-point scale because the greater number of levels in the scale made it impossible to satisfy critical ordinal regression assumptions.

c. Population and sample

Our sampling frame consisted of South African commercial grain farmers who were dues-paying members of the national commodity organization, Grain SA. This frame captured more than half of the country's commercial grain farmers, both by internal (Grain SA) estimates and those provided during expert interviews in advance of the survey design. Grain SA members were thought to be broadly representative of the larger population of commercial grain farmers, although with fewer very large and very small farms. From a contact list containing 4757 entries, 441 farmers (9%) responded to the survey; while low, this response rate matches that reported by [van Duinen et al. \(2015\)](#) in the Netherlands. Researchers have previously found that late responders tend to resemble nonresponders and are therefore useful in detecting nonresponse bias ([Lindner et al. 2001](#)). Because there was little reliable population-level data for South African commercial grain farmers against which to compare our sample, we tested for nonresponse bias by comparing late responders to early responders. Across all variables in the analysis, the only measure on which late responders differed significantly from early responders was in the percentage of their farm profit that came from grain farming. Late responders tended to be less focused on grain than early responders, which makes sense—the invitation made clear that the survey would ask about the respondent's grain farming activities.

On the advice of local experts who had previously surveyed commercial farmers in South Africa, only a small number of survey questions were made mandatory, resulting in a higher frequency of missing data. Of the total, 246 farmers entered complete information for all questions relevant to the regression analyses; however, the sample sizes for the simpler analyses are higher (up to 383 farmers) as noted in the results. The missing data lowered the sample sizes of the regression analyses, but multiple imputation did not substantially change the results or improve the models and has therefore not been included. The questions with the highest proportion of missing data were about total farm profit (21.1% missing) and political identity (11.6% missing). There may therefore be some bias in the sample related to these two variables; however, there was no notable drop in participation following these questions, so these participants tend to be included in the simpler analyses. The survey was offered in both English and Afrikaans, although the vast majority of respondents (92%) chose to answer the Afrikaans version.

3. Results

We find that these farmers do not perceive and prioritize weather and climate change risks similarly. There are clear differences in their selection of weather and climate change as high-priority risks, and the independent variables often had opposing effects on the rankings of the two risks—for example, independent variables that were associated with higher concern for weather risks tended also to be associated with lower concern for climate change risks. These results are in keeping with the divergence in weather and climate change risk management reported in [Findlater et al. \(2018a\)](#).

a. Selection of weather and climate change as high-priority risks

To assess the level of priority that farmers give to weather and climate change, respondents were asked to select and rank five factors that posed the “greatest threats to the future success” of their farming businesses from 13 options. Weather and climate change were among six categories of risk selected by at least half of respondents ([Fig. 1](#)). Similar proportions of farmers selected weather (63%) and climate change (60%); however, only a minority of respondents (37%) selected both ([Fig. 2](#)). Roughly equal proportions selected only weather (26%) or only climate change (23%), and a small minority (14%) selected neither. That is, half of respondents (49%) selected one of the two risks—weather or climate change—as a high-priority threat, while excluding the other. Therefore, based simply on

FIG. 1. Percentage of survey respondents who selected each category of risk as one of the five “greatest threats to the future success” of their farming businesses ($n = 389$).

these binary choices (initial selection of five high-priority risks), half of individual farmers prioritized weather and climate change differently. As detailed above, our earlier qualitative interviews suggest that this difference is not a result of definitional confusion. In those discussions, participants were clear in distinguishing between “weather” and “climate change.” Further, this distinction is not simply a temporal dichotomy of short-term weather risks versus long-term climate change risks (Findlater et al. 2018a); these farmers recognize long-term risks from weather and climate variability (e.g., decadal cycles that drive periodic, multiyear droughts), as well as short-term risks from the climate change impacts that they are already observing (e.g., shifted seasons, increased rainfall intensity). It is rather a distinction between the “normal” risks and temporary changes associated with historical climate, the understanding of which is primarily driven by experiential learning and intergenerational knowledge transfers, and the “abnormal” risks and permanent changes in climate that are inconsistent with historical climate and are addressed using imparted expert knowledge.

Furthermore, a chi-square test showed no relationship between the selection of weather and the selection of climate change [$\chi^2(1, n = 378) = 0.320, p = 0.572$]. Therefore, farmers who selected one were no more or less likely to select the other. Similarly, Spearman’s rho showed no correlation between the rankings assigned to weather and to climate change [$r_s(376) = 0.011, p = 0.830$]. While they were selected as high-priority risks at about the same rate, a Wilcoxon signed-ranks test showed that individual farmers tended to rank weather ($M = 1.88, SD = 1.837$) slightly higher than climate

change ($M = 1.58, SD = 1.58$) ($Z = -2.333, p = 0.020$). In answering subsequent Likert-scale questions about climate change (Fig. 3), more than 70% of participants agreed or strongly agreed that climate change is already occurring, that it is of serious concern for South African agriculture and for their farming businesses, and that they need to account for it in planning for the next 5–10 years (i.e., in the medium term). The lowest rate of agreement was 59% with the statement that human action is the primary cause of climate change, suggesting that most farmers were explicitly sensitive to the threat of climate change even when they were uncertain of its cause. Fully three-quarters (75%) of respondents agreed or strongly agreed that they would need to consider the effects of climate change on their farms in planning for the next 5–10 years. As would be expected, the prior selection of climate change as a high-priority risk was well correlated with agreement with these statements of concern. For instance, respondents’ level of agreement with the final statement (consider climate change in planning) was well correlated with their selection of

		Weather	
		Selected	Not Selected
Climate Change	Selected	37%	23%
	Not Selected	26%	14%

FIG. 2. Participants’ selection of weather and climate change as high-priority risks. Percentage of survey respondents who selected weather and/or climate change as among the five “greatest threats to the future success” of their farming businesses ($n = 380$).

FIG. 3. Likert-scale climate change risk perceptions. Survey responses to direct questions about respondents' belief in climate change and concern for its impacts ($n = 383$).

climate change as a high priority risk [$r_s(376) = 0.390$, $p < 0.001$], as well as the ranking that they assigned to it [$r_s(374) = 0.370$, $p < 0.001$]. Overall, these Likert-scale questions confirmed that the risk ranking data were broadly consistent with other expressions of concern for climate change risks.

b. Drivers of weather and climate change rankings

To evaluate drivers of weather and climate change risk perceptions, the rankings that farmers assigned to weather and climate change were both analyzed as dependent variables in ordinal logistic regression using the same set of independent variables. The results are here presented with little interpretation, while their possible implications are elaborated in the discussion section below. The results in Fig. 4 show that weather and climate change were generally driven by different independent variables (i.e., the farm and farmer characteristics that were significantly associated with weather were generally different from those significantly associated with climate change). Furthermore, all of the variables that were significantly associated with both risks had effects on weather that were of opposite sign to their effects on climate change (i.e., if they tended to increase concern for weather, they tended to decrease concern for climate change). No independent variables had significant effects of the same sign on both dependents.

Both of the ordinal regressions provided significant results overall, as indicated by the likelihood ratio test [for weather rankings, $X^2(19) = 44.101$, $p < 0.001$; for climate change rankings, $X^2(19) = 53.622$, $p < 0.001$].

With respect to specific drivers and as elaborated below, the weather rankings were significantly associated with main or interaction effects of age, education, crop cluster, rainfall variability, and crop residue burning (a practice that is indirectly discouraged in the CA framework). Most conspicuously, farmers who primarily grew irrigated crops were far less likely to prioritize weather (Fig. 5). Rainfed maize farmers were more likely to prioritize weather in areas with more variable rainfall. Rainfed wheat farmers displayed the opposite tendency, but the effect was small. Farmers with more formal education were more likely to prioritize weather, but there was a significant interaction between age and education (see Figs. S1–S5 in the online supplemental material for more detail on the interaction effects). Specifically, middle-aged farmers were equally likely to prioritize weather regardless of education. Farmers who reported never burning their crop residues tended to give weather a lower ranking.

In contrast, the rankings assigned to climate change risk were significantly related to political identity, education, and crop residue burning (Fig. 4). Respondents who self-identified as politically liberal were more likely to prioritize climate change, overall, but this pattern was complicated by the interaction of political identity with education. Education did not have a significant main effect, but its interaction with political identity was significant. Among conservative farmers, those who were more educated were significantly more likely to prioritize climate change, whereas the opposite was

FIG. 4. Odds ratio estimates for independent predictors of climate change rankings (red) and weather rankings (blue). These estimates were obtained using ordinal regression (i.e., a generalized linear model with cumulative logit link) ($n = 246$). An odds ratio greater than 1 indicates that the independent variable had a positive effect on the ranking, while an odds ratio less than 1 indicates a negative effect. The dark lines show the mean estimates, while the shaded bars show the 95% confidence intervals. When the shaded bar does not cross the dashed line [$\text{Exp}(B) = 1$], the associated effect is statistically significant ($p < 0.05$). Interaction terms are indicated by an “x”. For each respondent, rankings were reordered from highest (5) to lowest (1) and nonselected risks were assigned a ranking of zero (0). Independent variables and their descriptions are as follows (labeled with superscript letters a–j). Letter a: age is an ordinal variable with three levels (recoded from six). Because its relationship with the dependent variables was nonlinear, it was entered as a categorical variable, with “Older” as the reference category. Letter b: education is an ordinal variable with three levels (recoded from five), with values of –1 (no postsecondary), 0 (short postsecondary), and +1 (long postsecondary). It was entered as a continuous variable. Letter c: political identity is an ordinal variable with three levels (recoded from five), with values of –1 (conservative), 0 (moderate), and +1 (liberal). It was entered as a continuous variable. Letter d: crop cluster is a categorical variable with four categories, derived from a cluster analysis of major crops grown with and without irrigation. “Rainfed maize farming” is the reference category. Letter e: rainfall variability [coefficient of variation

FIG. 5. The effect of crop cluster on the rankings assigned to weather and climate change. Error bars indicate 95% confidence intervals ($n = 389$).

true for liberal farmers (Fig. S2). No other major risk (i.e., those selected more than 50% of the time) had such a clear pattern of interaction between education and political identity (Fig. S3). Farmers who reported never burning their crop residues were more likely to prioritize climate change. Farmers in the “mixed” crop cluster were significantly more likely to prioritize climate change (Fig. 5), but the number of farmers in this category was too small to produce a significant effect for the crop cluster variable overall.

c. Drivers of the distance between weather and climate change rankings

To explore possible reasons for the observed differences in the prioritization of weather and climate change, the distance between the rankings assigned to each was modeled using multivariate linear regression. The regression model was significant overall, as indicated by the likelihood ratio test [$\chi^2(19) = 43.110$,

$p = 0.001$]. Most of the independent variables that were significant in predicting the rankings assigned to weather and climate change in the above ordinal regressions were also significant in predicting the distance between their rankings (Fig. 6). For instance, irrigation farmers were more likely to rank climate change risks as having a higher priority than weather risks. Higher levels of formal education were again significantly associated with a higher ranking for weather risks over climate change risks among younger and older farmers, but not among middle-aged farmers. However, political identity and its interaction with education were not significant in predicting the distance between rankings, despite being significant in the separate analysis of climate change. Similarly, rainfall variability and its interaction with crop cluster were not significant in predicting the distance between weather and climate change rankings, though they were significant in the separate analysis of weather.

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(CV)] is a continuous, standardized variable. Letter f: smaller farm is a binary variable, indicating that arable land area is less than 500 ha. “Larger farm” is the reference category. Letter g: total farm profit is an ordinal variable with eight levels. It was standardized and entered as a continuous variable. Letter h: number of crops in rotation is an ordinal variable with four levels. It was standardized and entered as a continuous variable. Letter i: no-till score is an ordinal variable with five levels. It was standardized and entered as a continuous variable. Letter j: never burn crop residues is a binary variable. “Sometimes or always burn crop residues” is the reference category.

FIG. 6. Parameter estimates for independent predictors of the distance between the rankings assigned to climate change and weather. These were obtained using multivariate linear regression (i.e., a generalized linear model with identity link) ($n = 246$). The dark lines show the mean estimates, while the shaded bars show the 95% confidence intervals. When the shaded bar does not cross the dashed line ($B = 0$), the associated effect is statistically significant ($p < 0.05$). See Fig. 4 for notes on the independent variables, indicated by letters in superscript. Interaction terms are indicated by an “x”.

The effects of individual predictor variables on climate change rankings were often opposite to the effects of the same variables on weather rankings. Of the 19 main and interaction effects, only five were of the same sign for both dependent variables, none of which were significantly associated with both risks. Further, differences that were observed in the drivers of weather rankings and climate change rankings, when analyzed separately, persisted and were often amplified when they were analyzed together. For variables whose coefficients had opposite signs, the net effect was greater when predicting the distance between weather and climate change rankings. For instance, the effect of farm size was not quite significant in the separate regressions ($B = -0.56$, $p = 0.09$ for climate change; $B = 0.54$, $p = 0.09$ for weather); however, it had opposite effects on weather and climate change, and it was therefore significant in predicting the distance between their rankings ($B = -0.94$, $p = 0.01$). Farmers with smaller arable land areas (less than 500 ha) were more likely to prioritize weather and less likely to prioritize

climate change, whereas the opposite was true for those with larger farms. Similarly, the effect of crop residue burning was amplified in the joint analysis because of its divergent effects in the separate analyses. Farmers who reported never burning their crop residues were far more likely to prioritize climate change over weather than those who sometimes or always burned their residues.

4. Discussion

Rather than being equivalent and therefore substitutable, perceptions of climate change risks among these South African commercial grain farmers appear to be distinct from and, in some regards, oppositional to those of weather risks. Individual farmers do not similarly prioritize climate change and weather risks, these risk perceptions are driven by different factors, and all of the variables that are significantly associated with both risk rankings have effects of opposite sign on the two (i.e., positive for weather and negative for climate

change, or vice versa). These apparent differences persist and are often magnified in the linear regression model predicting the distance between their assigned rankings. These findings are consistent with Findlater et al. (2018a,b), where we find that farmers in South Africa's Western Cape province treat climate change separately (both linguistically and structurally) from weather and climate variability in their mental models of farm risk management.

The apparent climate change/weather dichotomy results, undoubtedly in part, from temporal differences, in that weather is more likely to comprise short-term risks and climate change to comprise long-term risks. Burke and Emerick (2016), for instance, find that American farmers differ in their management of short- and longer-term vulnerability and are less adept at mitigating longer-term climate risks. However, the range of elicited weather, climate variability and climate change risks in Findlater et al. (2018a) suggests that the dichotomy of weather and climate variability on one hand, and climate change on the other, is more complex. In that study, South African commercial grain farmers seemed to differentiate climate change impacts on the basis of their abnormality relative to historical climate. Most of them noted climate change effects that were already occurring, like shifting seasons and more intense rainfall, and these were therefore framed as short-term risks to which the farmers were already responding. In contrast, climate variability—which they grouped with weather—was considered normal by historical standards, and included long-term risks associated with decadal cycles that might only occur once or twice in a farmer's working lifetime. Further, fluctuations associated with weather and climate variability were recognized as regular, temporary changes, while the effects of climate change were characterized as permanent changes.

Observed differences in weather and climate change risk perceptions may also result, in part, from the different kinds of information that farmers use to interpret the two kinds of risk, as argued in Findlater et al. (2018a) and consistent with Eakin et al. (2016). In the present study, some factors associated with farmers' prioritization of weather risk appear to stem from their personal experiences growing rainfed crops in a highly variable climate, including the greater salience of weather risks in districts with higher rainfall variability and the buffering effect of irrigation. In contrast, climate change risks are more theoretical and prospective; farmers have less practical on-farm experience with climate change, despite recognizing its early signs, and their understanding is informed more by outside knowledge imparted by experts, politicians, and the media. The temporal and spatial immensity of the climate change problem and its cascading impacts through global systems also make

it difficult to grasp (Morton 2013). Further, weather and climate variability are inseparably interlinked with other kinds of agronomic, economic, political, and personal risks in farmers' perception, understanding, and management (Findlater et al. 2018b). Farmers do not therefore necessarily seek to minimize weather risks, for example, but to manage them "well enough" toward various objectives in a complex landscape of risk (Findlater et al. 2019b).

The interaction effect of political identity and education on climate change risk perceptions is notable, in that it contradicts well-publicized cultural cognition findings in Kahan et al. (2012) and Kahan (2015). In the context of the American public, those studies suggest that concern for climate change is more an expression of cultural identity than a reflection of people's rational understanding of climate change risks. Kahan (2015) further finds that the effect of education differs by cultural identity: liberals become more concerned about climate change the greater their scientific literacy, whereas conservatives' perceptions of climate change are disconnected from their scientific literacy. The results of the present study instead show that conservative South African farmers become more concerned about climate change the higher their education, whereas liberal farmers become less concerned. There are no obvious patterns in the rankings of other risks that might explain this result, and it is not explained by differences in farming practices. It may well be that the cultural cognition thesis is simply less relevant to climate change in South Africa. These farmers express stronger belief in climate change and more willingness to adapt than most commercial farmers in higher-income countries (Prokopy et al. 2015). More widespread belief in climate change, overall, may make climate risk perceptions less partisan and therefore less rigid. These farmers are weather-sensitive actors directly exposed to climate change risks. They have strong incentive to account for the possibility of positive or negative climate change impacts, regardless of their personal beliefs. Speculatively, education may have a tempering effect on highly concerned liberal farmers as they learn more about potential climate-adaptive behavior, whereas increased exposure to the science and anticipated impacts of climate change may amplify the concerns of previously dismissive conservative farmers. Alternative explanations include problems with the cultural cognition thesis more broadly, incomparability across diverse contexts, and different mental models of "liberal" and "conservative" political worldviews in South Africa.

Personal experience with rainfall variability (and thus more frequent and more extreme weather events) does not seem make these farmers any more or less

concerned about climate change, on average. Farmers in districts with higher rainfall variability were more likely to prioritize weather risks, but rainfall variability did not affect the climate change rankings. This suggests that extreme weather events that are nonetheless consistent with historical climate variability may not necessarily be good proxies for climate change when studying farmers' risk perceptions, despite the popularity of this approach in the literature. Further, irrigation farmers appear to be insulated from weather risks, likely because their crop production is not restricted by short-term water shortages; however, they are as equally concerned about climate change as nonirrigation farmers, perhaps because they recognize the potential for longer-term hydrological changes to their water supplies (Findlater et al. 2018a). This finding reinforces that of Eakin et al. (2016) among irrigation farmers in Arizona, countering previous concern that climate change risks would be less salient for such farmers.

The effect of farm size is also notable. Farmers with smaller arable land areas (less than 500 ha) were more likely to prioritize weather, while those with larger land areas were more likely to prioritize climate change. This may reflect the temporal element in the climate change/weather dichotomy; it is important to note that the regression model included total farm profit, but not cash flow or income diversification, both of which are likely to be important in responding to short-term risks. Farmers who burn their crop residues were more likely to prioritize weather, while those who do not burn their residues were more likely to prioritize climate change. This is consistent with our further survey data (Findlater et al. 2019a) showing that when controlling for other CA-related practices and political identity, farmers who refrain from burning their crop residues (a practice that is implicitly discouraged in the CA framework) perceive themselves to be more agriculturally progressive and, by extension, forward thinking. Farmers who are more educated are more likely to prioritize weather, while those who have less education are more likely to prioritize climate change—except for middle-aged farmers, for whom the effect is negligible. This effect of education is as yet unexplained and warrants further study.

Scholarly debates about how best to understand climate risk perceptions remain unsettled. Kahan and Carpenter (2017) argue for more field studies to place laboratory-based evidence in context. In response, van der Linden et al. (2017) critique their narrow focus on cultural cognition, calling for more diverse studies of climate change cognition and for an emphasis on cross-cultural fieldwork. Our findings suggest that both efforts hold merit, but we are concerned that the focus of most such work remains limited to the risk

perceptions of broader publics, not those of climate-vulnerable decision-makers (e.g., farmers) per se. The differences that we have demonstrated in farmers' perceptions of climate change and weather, using a mixed-methods approach, strongly suggest the need for more in situ research on decision-making toward climate change adaptation. Further study of climate-vulnerable actors is certainly warranted to better understand how these actors differ from the general public and how the American context differs from others. Whether climate change is truly a risk that is separate from weather and climate variability, or simply a concept nested within some broader definition of weather or environmental risk, is perhaps moot; if farmers perceive and plan for them differently, as suggested by these results and those from our earlier studies, we will misunderstand climate change adaptation by using unqualified weather and climate variability proxies.

5. Conclusions

These results provide further evidence that farmers, broadly, may perceive and process climate change risks differently than they do those stemming from weather and climate variability. Although this study was limited to South African commercial grain farmers, this group is particularly informative; they practice modern large-scale farming in a climatically vulnerable region, with high adaptive capacity but few subsidies. They are more vulnerable to the financial harms of both weather and climate change than their peers in higher-income countries; they may therefore bookend the range of possible climate change responses, in that they closely resemble the archetype of the autonomous and responsive private actor foundational to the climate change adaptation literature.

These findings suggest that experts should be cautious in assuming that farmers will respond to climate change risks in the same ways that they respond to weather and climate variability, or that the distinction between the two categories is purely temporal. Adaptation researchers should, at minimum, qualify their use of weather and climate variability as proxies for climate change. Since many of the farmers in our study have recognized and are already responding to the early impacts of climate change [as with those in Belay et al. (2017) and Kenny (2011)], researchers may no longer need proxies for near-term effects. And for longer-term effects, selected proxies should account for the abnormality and permanency of climatic changes—one potential example being the post-apartheid deregulation of South Africa's agricultural sector that

made these farmers more vulnerable to the financial harms of weather- and climate-related risks (Bernstein 2013; Findlater et al. 2018a). Alternatively, it may be useful to study decadal climate cycles that manifest only once a generation (e.g., Burke and Emerick 2016), where farmers understand that the negative impacts will recur but have little personal experience of them and are uncertain of their timing and magnitude. Further, farmers will anticipate and plan for each such recurrence under new socioeconomic circumstances and using knowledge and technologies that were previously unavailable.

Some climate change impacts are expected to first manifest as increases in the magnitude and frequency of extreme weather. Overall, however, the climate-vulnerable farmers in our study seem unlikely to anticipate and respond to ongoing and future climate change impacts in the same way that they respond to weather and climate variability that are nonetheless consistent with historical climate. Whether or not specific climatic events are scientifically attributable to climate change may be less important than whether farmers perceive them to be historically abnormal and indicative of permanent changes in their environment. These findings suggest a crucial and underrecognized analytical challenge for adaptation researchers and policy-makers that warrants more widespread investigation across a wider variety of farming types and contexts. At minimum, researchers may increase the utility of their otherwise valuable empirical results by qualifying their conclusions in light of the potential distinction between climate change and weather. Overall, studies that use weather and climate variability as unqualified proxies for climate change are likely to mislead researchers and policymakers about how farmers perceive, interpret, and respond to climate change stimuli. Such approaches deny the agency and forethought that farmers have demonstrated in responding proactively to other abnormal, permanent, and long-term changes, and are therefore likely to generate inadequate policy prescriptions in support of farmers' adaptation to climate change.

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