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Environmental Research Letters

TOPICAL REVIEW

Agricultural decision making and climate uncertainty in developing countries

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Abstract

In situations of uncertainty, people often make decisions with heuristic shortcuts or decision rules, rather than using computational or logical methods such as optimizing their behavior based on specific goals. The high level of uncertainty and complexity involved in adapting to climate change suggests that heuristics would be commonly used in this context rather than more structured decision methods. Through a systematic review of 137 articles, from 2007–2017 we explore the behavioral and cognitive assumptions used to examine agricultural decision-making related to climate change among farmers in developing countries. We find a strong orientation toward modeling behavior and decision making as a rational utility-maximizing process, despite decades of research demonstrating the prevalence of simpler heuristic choice when facing uncertainty and real-world constraints. Behavioral and cognitive approaches can increase our ability to predict or explain decisions being made in this realm, particularly in terms of how we understand decision making around information processing and risk assessment. In the following review, we highlight articles that have contributed to developing a more realistic decision-making framework for studying this problem on the ground. While there is a burgeoning literature using psychological insights to examine decision making under climate uncertainty, few studies consider the prevalence of simple heuristics, the presence of cognitive biases, and the salience of climate relative to other risk factors.

1. Introduction: climate uncertainty and agricultural decision making

A range of approaches are used to investigate agricultural decision making among farmers in developing countries, who are usually smallholder farmers. The fields of anthropology, cognitive science, economics, geography, political science, psychology, and rural sociology all address human decision making to some extent and in different ways. An interdisciplinary area of research has emerged that specifically examines agricultural decision making in response to climate change among farmers in developing countries. Previous research suggests that a variety of constraints can influence decision processes, so that people are likely to use simple rules or decision heuristics when facing situations which require decision making under limited time, limited knowledge, increasing complexity, and under uncertainty, rather than using utility-maximizing approaches that are traditionally considered rational (Kahneman *et al* 1982, Gigerenzer *et al* 1999). This implies that methods of evaluating decision making based on typical assumptions of rational preference ordering are not well suited to understanding how people make choices in complex and uncertain decision environments.

High levels of complexity and uncertainty cause people to use alternative decision-making rules and this phenomenon has been demonstrated in the case of climate-related decisions (Kunreuther *et al* 2013)

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and more generally with decisions characterized by uncertainty related to poverty and scarcity (Mani *et al* 2013, Schilbach *et al* 2016), which are commonplace among farmers in developing countries. Climate change is characterized by high levels of uncertainty, and this uncertainty can influence farmers' decision making. It is reasonable to expect smallholder farmers to use heuristics when making decisions in this context and therefore researchers studying climate uncertainty and agricultural decision making should look at both rational and heuristic decision making approaches. While this review focuses on agricultural decision making with respect to uncertainty related to climate change, the same could be said of environmental decision making more broadly as it applies to various resource domains. A few studies have demonstrated that assumptions of rationality do not adequately describe environmental behavior under uncertainty in other domains, for example, with respect to fisheries (Carrella *et al* 2020), more generally to land use change (see Groeneveld *et al* 2017 for a review) and common pool resource management (Schlager 2002).

There is a widespread perception among farmers in developing countries that the climate is changing and that weather variability is increasing but there is not necessarily widespread adaptive responses to these perceptions or observations (Mertz *et al* 2008, Osbahr *et al* 2011, Simelton *et al* 2013). The lack of inaction among farmers who perceived climate change may at least be partially explained by the more general cognitive issue of the persistence of status quo bias, a preference for the current state of affairs (Samuelson and Zeckhauser 1988). Regardless, it is clear that there is generally a lack of meteorological data and climate information in developing countries, there is variation in perceptions of climate change (Sutcliffe *et al* 2016), and not all climate perceptions translate into adaptive action (Rao *et al* 2011), all of which make it reasonable to expect that farmers do not make optimizing decisions. For this reason, focusing only on rational decision making in this context may not capture important descriptive dimensions of decision making including perceptions of risk from extreme weather events or variability, information asymmetry (weather and otherwise), cognitive biases related to climate observations, and the use of heuristics that are both commonplace among all humans or more cultural in nature. The result is that we may be systematically misunderstanding agricultural decision making in response to climate uncertainty in these contexts.

Making decisions that take climate change into account are particularly challenging because climate change is difficult to observe, and accurate climate information is often not accessible or existent in developing countries. Given the multidimensional nature of the climate, it is not cognitively easy to identify changes without extensive recording and processing of climate data. While research has found farmer perceptions to be well aligned with meteorological data in instances (Vedwan 2006, Ayanlade *et al* 2017) other studies have found there to be inconsistencies (Sutcliffe *et al* 2016, Osbahr *et al* 2011). These differences may in part be attributed to how people understand climate and how climate knowledge is constructed (Burnham *et al* 2016). Gradual shifts in the climate occurring over a long time period present a mismatch with human perceptions of time (Pahl *et al* 2014). The same information can lead two people to opposite conclusions about climate change based on how they personally experience temperature (Howe *et al* 2013) and climate impacts (Howe *et al* 2015). For example, people often judge the probability of environmental shocks occurring as higher the more recent or extreme they were (Hertwig *et al* 2004, Marx *et al* 2007, Morton 2007). Perceptions of climate change therefore may more often reflect recent weather events than long-term climate trends (Zaval *et al* 2014). People also tend to underestimate their personal exposure to extreme weather events and the probabilities associated with these (Freeman and Kunreuther 2002).

Perceptions of trends in the climate, various biases related to information and recall, and judgement of the probability of climate impacts, all complicate perceptions of climate risk. While normative models have been developed to include risk, they are generally less developed than descriptive models in terms of how risk is treated (Johnson and Busemeyer 2010). The development of prospect theory introduced the notion that risk can be perceived differently based on one's reference point (Kahneman and Tversky 1979), thus incorporating individual subjectivity of risk. Fox (1999) extended this notion by demonstrating that individuals in circumstances of uncertainty might estimate probabilities, which helps extend our understanding of decisions under risk where probability is known to situations where probability is unknown (i.e. uncertainty). While some studies of decision making and climate change among farmers in developing countries address risk, few address the more subjective nature of uncertainty.

What we can learn about the decision making of farmers in developing countries facing the uncertainty of climate change depends on the theories and methods used to study these decisions. The objective of this review is to characterize the nature of research on farmer decision making across different academic fields of study, considering the various frameworks used under different lines of investigation. We consider these differences through a systematic review of articles published about agricultural decision making associated with climate change among farmers in developing countries. The specific research questions are as follows: To what extent do articles in this domain consider assumptions about rationality in decision making and specifically how

uncertainty imposes a challenging decision environment for farmers? To what extent do the researchers consider the role of climate-related information in agricultural decisions and how do they treat perceived risk related to climate change? How do researchers establish a causal relationship between agricultural decisions and climate change? Finally, we identify research gaps and make suggestions for ways that behavioral science can enhance this area of research going forward.

2. Background: decision making theory

The study of agricultural decision making has historically been dominated by economists who tended to rely on normative mathematical models and behavioral theories driven by assumptions of human rationality that emphasized utility maximization (Camerer *et al* 2011). Characterizations of decision making tended to be normatively constructed (e.g. assuming farmers choose the option that maximizes their profit, yield or income) as opposed to descriptive or empirically derived, and were simply used as behavioral assumptions in models rather than experimentally tested (Anderson *et al* 1977). During the 'cognitive revolution' of the 1950s, normative assumptions about human decision making were supplanted by more empirically driven and descriptive theories about behavior, starting with modern portfolio theory characterizing risk aversion in investors (Markowitz 1952).

Psychologists and economists began to address anomalies stemming from mathematical theories of rationality and confront the theoretically-puzzling behavior of actual people engaged in economic activities (Camerer 2003). The genesis of behavioral economics, a subfield devoted to these topics, is often credited to psychologists Amos Tversky and Daniel Kahneman who demonstrated that humans frequently rely on heuristics or cognitive shortcuts to make decisions and violate basic economic assumptions in certain contexts (Kahneman and Tversky 1979). Behavioral economics has since been focused on developing more contextually specific assumptions about human behavior and how these contexts can lead to predictably irrational choices (Thaler 1980, Ariely 2010).

One of the problematic components of traditional decision theory is the assumption that people have 'perfect information' about the options available to them. Classic economic theory assumes that people draw on this information to make choices among various options thus articulating a rational transitive ordering of their utility-based preferences. Simon (1955) demonstrated that rational decision making is 'bounded' by the information people have, their cognitive limitations, and the finite time they have to make a decision. This eventually led to the use of subjective probabilities and consideration of relative choices through weighting of different choice alternatives. Kahneman *et al* (1982) demonstrated that people often choose among multiple options without ranking them or comparing them systematically.

Another line of research following Simon's concept of bounded rationality has pointed out that rather than being rampantly irrational, humans typically do make good decisions within their constraints of limited time, information, and cognitive resources (Gigerenzer *et al* 1999). This work has shown that bounded rationality is often advantageous for decision making under uncertainty and can lead to more efficient choice processes- provided that people use appropriate decision strategies in the particular decision environments they face. In other words, heuristics can lead to good decisions in common natural situations, even if they also can produce irrational behavior or systematic biases when tested in unexpected or artificially misleading settings. Simon (1990) proposed that rational behavior is shaped by the interaction of decision mechanisms in the mind and the structures of information in the environment, fitting together like the blades of a pair of scissors. This perspective emphasizes not only internal mental constraints, but also external environmental ones–a balanced emphasis captured in the study of *ecological rationality* which takes both aspects into account (Todd and Gigerenzer 2007). Studies find that people make 'good' choices within those constraints by employing specific simple decision processes that use little information, such as whether an option is recognized or surpasses a simple threshold of acceptability, rather than traditionally rational approaches requiring full information and extensive processing (Gigerenzer and Gaissmaier 2011).

Given that agricultural decision making is central to the economic livelihood of the farmers making these decisions, an economic approach is commonly used in studying this domain. Using a traditional economic framework, individuals are assumed to be rational actors with perfect information about choice alternatives that make decisions that will maximize their utility (or a related objective such as profit, income or yield), using all the information they can get to attain that goal. While some empirical work tests the impact of various policy interventions on farmer behavior or the influence of risk aversion on behavior, this is typically within a framework that assumes utility maximization. Despite advancements in our conceptualization of decision-making, many methods still explicitly or implicitly assume that decision makers have perfect information (Risbey *et al* 1999) which, for example, can overpredict climate adaptive behavior (Findlater *et al* 2018b, 2019a). Given that climate change is a paradigmatic example of uncertainty, which can render maximization impossible to achieve, it instead calls for the application of appropriate bounded rational

heuristics. According to Weber (2017), the challenging psychological characteristics of climate change represent a 'textbook example of bounded rationality'.

One example of a method economists use to empirically model agricultural decision making related to climate change is the use of discrete choice experiments (DCE). DCEs are based on the theory that people's preferences are shaped not by a good itself but by the characteristics the good embodies (Lancaster 1966). Consumers are assumed to maximize the utility they derive from each attribute, and their observed choices in the DCEs are used to estimate their marginal values for each attribute of a good, forming a vector of preference parameters mapping attribute levels into utility. Then choices between goods are predicted to follow whichever good has the greatest summed attributed-level utility. DCEs have been used to model preferences related to climate adaptive technologies in developing countries including early duration hybrid maize (Smale and Olwande 2014), drought tolerant rice (Ward *et al* 2014) and hybrid and perennial sorghum (Waldman and Richardson 2018). This method assumes an actor has information about the attributes of choices they are facing, has well defined preferences, and uses a computational method to maximize their utility.

In contrast, decision scientists and psychologists tend to view decision making with a focus on decisions as processes rather than just a set of well-defined preferences (Frisch and Clemen 1994). According to this view, human decision making applies cognitive and social skills that are expressed across different contexts in potentially similar ways (Hastie and Dawes 2010). This type of behavioral approach emphasizes the constraints that shape people's decisions and behavior including the selective use of information, reliance on heuristics or rules of thumb, and the role of perceptions, beliefs, emotions, and values (Payne and Bettman 2004). Emphasizing the process of decision making and more importantly the context of decision making is particularly relevant when examining decisions that are framed by risk and uncertainty. Various psychological models have been developed to understand these types of decision contexts, often involving consideration of risk perceptions, actual levels of risk and uncertainty, and the decision maker's capacity and desire to cope with various levels of risk (Grothmann and Patt 2005).

Assessing decisions without a maximization framework often involves consideration of how information is processed, for example, through fast (reactive) or slow (more controlled) systems of thinking (Payne and Bettman 2004). Rather than viewing decisions as maximizing one's utility by a transitive ordering of preferences, one might choose the first available option that meets basic criteria (e.g. satisficing) (Simon 1955) or simply choose an alternative with the best value for the most important attribute (e.g. lexicographic rules). Rather than assuming that choices reflect the marginal value of all attributes, a psychologically realistic decision process might simply assess a simple heuristic based on the importance of one attribute and the value of that attribute relative to other attributes through the process of elimination (Tversky 1972). Not accounting for the possible use of simple heuristics such as lexicographic rules by people in DCEs can lead to systematic errors in categorizing behavior and biased point estimates of parameters in the underlying decision models (Campbell *et al* 2006).

Simple heuristics are studied by analyzing the choices and decisions people make in the lab or in the wild. This typically involves having people make decisions among a defined set of options, and either controlling or finding out what people know about the options they are choosing between rather than assuming they are maximizing an objective. The collected choice data is then analyzed by seeing which of two or more decision strategies (which can be heuristics or more complex full-information models like regression) best fit the choices people made given the data they had (see Scheibehenne *et al* 2007, for an example with food choices). The results indicate the mix of decision strategies likely used by the particular population of people in that particular decision setting.

With these different theoretical approaches in mind, we review the literature on smallholder agricultural decision making and climate change. This is clearly an arena of decision making under uncertainty, both in terms of how people perceive climate change and the impact climate change has on agricultural systems. We pay particular attention to how researchers characterize decision making processes and whether and how they connect these decisions or related behavior to climate change. We do this through a systematic Web of Science literature review of peer reviewed articles published about farmer decision making and climate change.

This review is both timely and important, both for the urgency of responding to the uncertainty of climate change and the lack of attention to how decisions are actually made in this context of climate uncertainty. While elements of the descriptive behavioral dimensions of decision making arise in this literature, they are by no means common for understanding agricultural decision making. Misrepresenting how agricultural decisions are made may lead to a broader misunderstanding about best practices and policy for climate adaptation. This is increasingly critical as evidence of climate change in developing countries mounts, including changes in average and extreme temperatures, changes in rainfall amounts and spatiotemporal patterns, and changes in the frequency and intensity of extreme weather events (see Kotir 2011 for a review of evidence from Africa).

A more realistic understanding of farmer decision making related to climate uncertainty could improve preparation for and adaptation to climate change, which is expected to be most severe among farmers in developing countries (Jarvis *et al* 2011, Campbell *et al* 2016).

3. Search methodology

This article summarizes the findings of a systematic review, presenting quantitative analysis of coded data in addition to qualitative descriptions of specific decision-making approaches used in individual articles. We identified three primary concepts that capture the body of literature we are interested in: climate change, agriculture, and decision making. A list of these basic keywords was then expanded to include related search terms and derivatives of these terms that would be likely to appear in either the title, abstract, or keyword list of articles. We found that using variations of climate returned numerous articles that were not relating to the physical environment so chose iterations that captured a wide range of climate change related topics. We also wanted to capture articles across disciplines where norms are slightly different in terms of using the terms behavior, choice and decision so included each of these. The search was conducted using the Science Citation Index Expanded and the Social Sciences Citation Index from the Core Collection of Web of Science of English language peer reviewed articles from 2007–2017. We chose this date range to capture the emerging emphasis of research on agricultural decision making and climate change. The following keyword search was used:

> Topic=((agriculture OR farm*) AND ("climate change" OR "climate variability" OR "climate adaptation") AND (decision* OR behavior OR choice))

Boolean operators were used to ensure that we included articles that had one element from each of the three categories of relevant search terms (agriculture, climate and decision making) and we allowed for inclusion of any of the similar terms or a derivative of that word (indicated with an asterisk). This search yielded 1326 results. Four reviewers, each of whom had at least MS or PhD level training in a socio-environmental field conducted the article review and coding. One of four reviewers read the abstract of each of the articles to determine if the article met the basic criteria: (a) was about an agricultural decision, (b) related to climate change, and (c) involved farmers in a developing country. Articles were excluded for one or multiple of these reasons. We manually sorted whether articles were about developing countries based on whether a country was included in the International Monetary Fund's World Economic Outlook: Emerging and developing economies (IMF 2020). These articles were then coded using a Qualtrics survey instrument to create a database of responses, which was used for analysis and is included in the supplementary material (available online at stacks.iop.org/ERL/15/113004/mmedia).

The systematic nature of the search approach resulted in some potentially relevant literature being excluded from the final search results. For example, we only captured articles where the search terms appeared in the title, abstract, and author-assigned keyword list, and this excluded some articles that one might expect to be captured that did not include one of these terms. Rather than manually include additional articles that are seemingly related through a more synthetic review, for consistency we decided to limit the analysis to those articles returned from the search process as originally designed. This procedure should not have categorically excluded articles from relevant subfields that deal with the topic of this review.

In this process we also had to make a number of boundary decisions about inclusion and exclusion for each of the search terms. Regarding agriculture we excluded articles that dealt with decisions that were only related to forestry, livestock husbandry and pasture production, and decisions such as rural migration. We also excluded articles that did not explicitly mention some aspect of weather or climate in the abstract. We did not try to evaluate whether a paper differentiated between climate variability, climate change or extreme weather, but rather included all articles that referred to climate, broadly speaking. Additionally, we only included articles that were concerned with individual-level decision making, excluding articles that were about policy and institutional-level decision-making. Strictly physical science articles that were captured in our initial search, including topics such as life cycle assessments, were also excluded from the review.

Of the 1326 articles drawn from the Web of Science search, 209 articles met the basic criteria based on the abstract. Each paper that met the basic criteria was then read in full by one of the four reviewers. Only 137 articles contained a research question and analysis that met those basic criteria (ten articles were excluded because the research question addressed an agricultural decision but the actual analysis did not). The frequency of publication of the included articles over the 10 year period is presented in figure 1. The articles were drawn from 91 different journals—the top 10 journals where the articles were most frequently published is presented in table 1.

The studies included assessed decision making across a wide range of developing countries across the globe—43% of studies evaluated decisions in Africa and 43% of studies addressed decision making in Asia (see figure 2). 13% studied Central or South America and 4% covered the Middle East. The most studies on

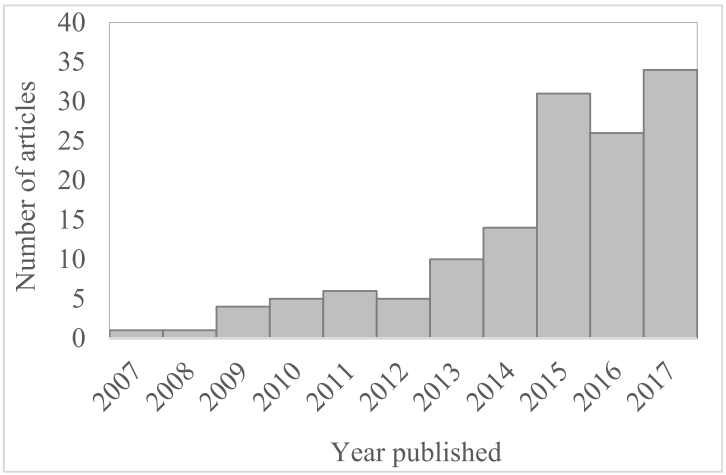

Figure 1. Frequency of included articles published per year (n = 137).

Table 1. Journals where included articles were most frequently published.

Journal	Count	Percent
Global Environmental Change	11	8.0
Intl. Journal of Climate Change Strategies and Management	10	7.3
Sustainability	7	5.1
Ecological Economics	7	5.1
Land Use Policy	6	4.4
Regional Environmental Change	6	4.4
Climatic Change	5	3.6
Environment Development and Sustainability	5	3.6
Environmental Management	4	2.9
International Journal of Disaster Risk Reduction	4	2.9

smallholder farming and climate change came from China and India.

Each of the 137 articles was coded by one reviewer in terms of basic descriptive statistics (year and location published, nature of data and methods used), the type and nature of the agricultural decision, explanatory variables related to the decision, the conceptual approach in terms of maximization versus heuristics, reference to cognitive constraints, characterization of risk, and the extent to which information was considered in the article. We also recorded up to three separate research questions for each paper, copying them directly from the text to the extent possible. For those articles that contained both a research question and analysis related to an agricultural decision, one of the reviewers coded each question as to whether it sought to *characterize* existing behavior or to *explain why* a behavior existed or occurred.

We performed intercoder agreement among the four reviewers in two stages, during the article inclusion phase and coding phase. Intercoder agreement is when multiple coders reconcile any coding discrepancies that arise through discussion of the text and codes assigned (Campbell *et al* 2013). Since inclusion was a critical component of the review that involved a larger number of evaluations, all four reviewers reviewed the first 20 articles drawn from the Web of Science search for inclusion. Sixteen of the 20 articles did not meet the criteria and there was 100% agreement among the four reviewers about exclusion. Due to the nuance in understanding the concepts related to decision making we conducted intercoder agreement prior to coding as opposed to testing for intercoder reliability after the coding of the manuscripts. This involved a training period where 20 manuscripts were coded stepwise individually. After four articles were coded, the reviewers compared responses and discussed differences to understand where coders differed in responses and understanding of the questions and categories. There were five phases of this process, where all four reviewers discussed any discrepancies in coding until there was a consensus about how to code each paper. The consensus responses were included in the final analysis. Our entire assessment survey instrument and database including articles and coded responses is available in the supplemental materials.

4. Results and discussion: agricultural decision making and perceptions of climate change

We investigate the conceptualization of decision making in a number of ways. First, in section 4.1, we assess how the framing of the research questions in each article reflect whether the researcher was interested in decision processes versus outcomes or determinants of a decision. In section 4.2, we further investigate the extent to which authors conceptualize the structure of decisions in terms of whether they were logical and ordered (including utility maximization) as opposed to descriptive, including the use

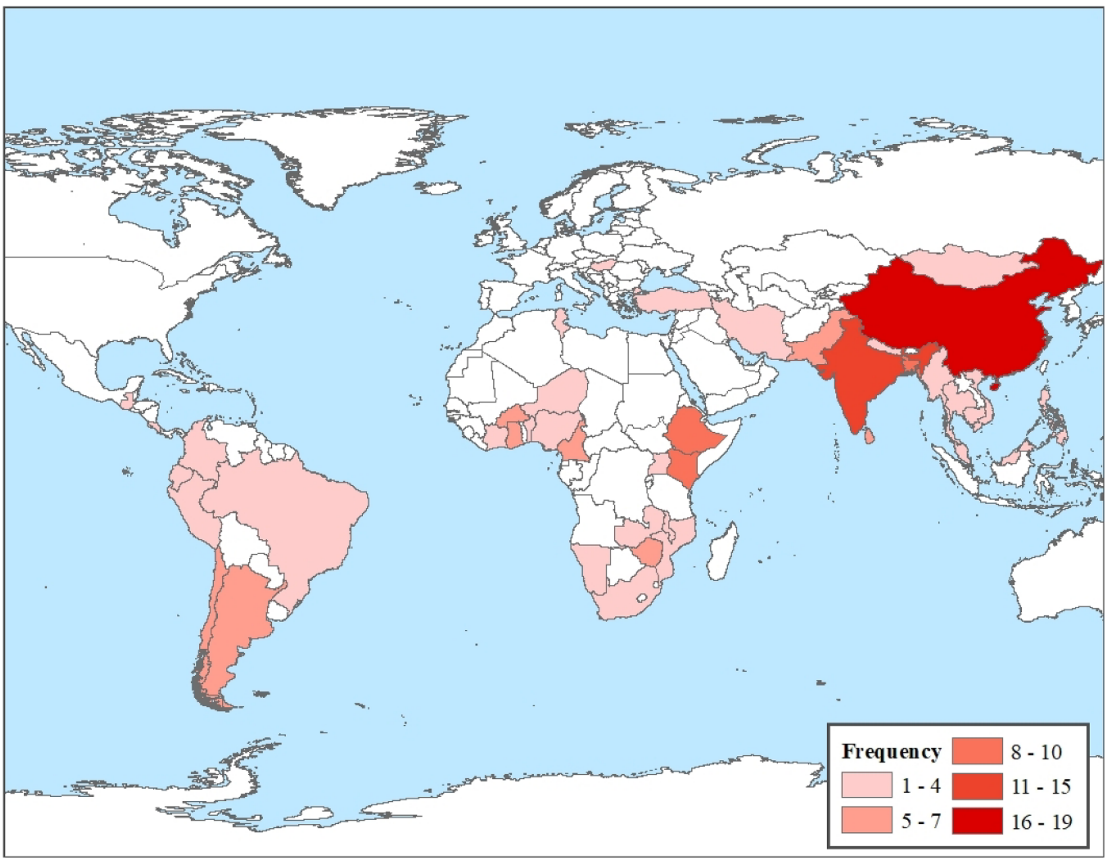

Figure 2. Locations of countries represented by included articles and frequency of occurrence.

of heuristics or mental shortcuts. When considering this distinction, we also look at the extent to which an article acknowledges cognitive constraints to optimal decision making (i.e. bounded rationality). In section 4.3 we examine the role of risk preferences and information availability in how decision-making is presented in each article. Finally, in section 4.4 we discuss the causal relationship between decision making and weather or climate data and the implications of this for understanding agricultural decision making and climate change.

4.1. Decision processes vs. decision outcomes

Examination of the research questions posed reveals that few articles seek to understand how decisions are made. We extracted 236 total research questions from the 137 articles, where some articles explicitly stated research questions, and in other instances research questions were assembled based on a reviewer's interpretation. For each paper the reviewer identified each of the stated or implied research questions and entered it into the Qualtrics form, verbatim or as closely as possible based on the authors text. A second reviewer then coded all of the research questions into three categories (a) whether they dealt with a decision, and if so (b) whether the question addressed a decision process or (c) whether they addressed an outcome of a decision. Of the 236 research questions, 78% were about behavior or decision making, but less than 3% of the questions that addressed a decision examine the process of making agricultural decisions. Questions that involved characterizing decision outcomes tended to use words or combinations of words such as 'determinants,' 'barriers,' 'factors,' and 'what,' while questions about decisions processes tended to use words such as 'process,' 'why,' or 'how.' Some examples of research questions that involve understanding decision processes include understanding how climate adaptation decisions arise (Ahmed and Schmitz 2015), and how farmers learn to adapt to climate changes over time (Meza and Silva 2009). The vast majority of research questions, tend to focus on determinants or outcomes of decisions, who was making those decisions, and the impact of decisions. Few research questions are specifically related to decision processes.

While it is important to understand *the nature of decisions*, it is also crucial to understand *how* those decisions are made. These data are much more intensive to collect but a focus on the process can tell us why different farmers faced with the same social or environmental conditions decide to change their behavior. To a certain degree, models that prioritize predictive power may attain higher levels of performance using analytical approaches that do not elucidate the decision-making *process* and thus do not provide

Table 2. Decision making conceptualization of included articles (n = 137 articles).

	Count	Percent
Clearly utility maximization or other optimization	43	29.1
Appears to be using utility maximization or other optimization	43	29.1
No decision-making theory	35	23.6
Clearly psychosocial or cognitive approach (includes heuristics, appraisal or process)	17	11.5
Appears to use psychosocial or cognitive approach	10	6.8
	148	100.0

Note: A paper could have included more than one framework (i.e. both utility maximization and psychosocial).

insight for policy interventions and building adaptive capacity.

4.2. Assumptions about the structure of decision making

Approaches to decision making among the surveyed articles vary from explicit and clear to unclear and nonexistent (table 2 displays the results). The largest portion of articles, 29%, approach decision making from a utility maximization perspective, most often in terms of profit or income maximization. Some of these articles do not explicitly state a utility maximization framework but it could be assumed from their methodological approach; for example, they use a method such as DCE, which implies maximization of utility in terms of attributes. A further 29% appear to use a utility maximization framework, although based on the description in the paper we could not conclude with confidence that a utility maximization framework was used. Only 11.5% of articles use a cognitive or psychological framework to examine decision making and 6.8% appear to use a cognitive approach but do not provide enough detail to conclude that with certainty.

A slightly smaller group of articles (23.6%) do not use any decision-making theory; most of these articles examine the statistical relationship between two variables or a set of variables and an outcome variable but without assumptions about how the decision was made. These articles largely address the underlying descriptive characteristics of decision makers or the determinants of a decision as opposed to the structure of the decision or decision process. Examples include looking at determinants of adapting various practices to mitigate climate change (Ndamani and Watanabe 2016) and evaluation of the likelihood of changing or not changing agricultural practices (Tesfaye and Seifu 2016).

Despite previous research characterizing climate change as a 'classic case of bounded rationality' (Weber 2017), few articles in this review explicitly evaluate decisions as other than rational behavioral expressions. Only 10% of the total coded articles acknowledge that the decision might be influenced by cognitive limitations, the tractability of the decision, the time it takes to make a decision, or mention anything that would lead to a 'boundedly rational' decision or satisficing. Among these 14 articles, the most common reason cited for bounded rationality in decision making, exemplified by 12 articles, was related to information asymmetry, information access or simply lack of information. It is surprising that only 12 articles mention information issues given how difficult it is to access weather or climate data in developing countries, particularly local weather information, which is often not measured or recorded. Only one paper cited cognitive limitations as a reason why decisions might be 'boundedly rational'; Gunda *et al* (2017) consider farmers' ability to interpret a seasonal forecast and their perceived effectiveness by the farmer. Another paper found that the complexity of the decision-making environment might influence decisions; Keshavarz and Karami (2014) model human decisions during a drought in three phases in terms of cognitive aspects (prior values, beliefs and experience), citing the complexity of the decision environment.

A substantial number of articles are descriptive of decisions and do not consider how decision are made (examples include Ogalleh *et al* 2012, Pauw 2013). This could reflect a behaviorist (non-cognitive) approach to decision making, assuming an action is a reflexive response to a stimulus, but most articles in this category are simply describing decision makers as opposed to the decision or decision-making process.

An analysis of the use of the various models of decision making over time reveals that the majority of the growth among articles involves those that take a maximization approach (see figure 3). While there has been a more increase in the literature based on psychosocial or cognitive conceptualizations of decision making there is problematically a larger group that do not address how they conceptualize decision making. Clearly the most growth, however, has been the increase in publications that use some form of utility maximization or optimization.

In the following sections we divide the articles that incorporate identifiable decision-making assumptions into two categories: (1) Articles that use an optimization or maximization approach, whether directly articulated or implicitly included; and (2) articles that implicitly or explicitly use a psychological or cognitive approach to decision making involving heuristics, cognitive steps, appraisal, etc. We consider both of these in turn in the next two subsections.

4.2.1. Approaches based on optimization or maximizationF

Among the articles that are explicit in their assumption that behavior reflects maximization of various

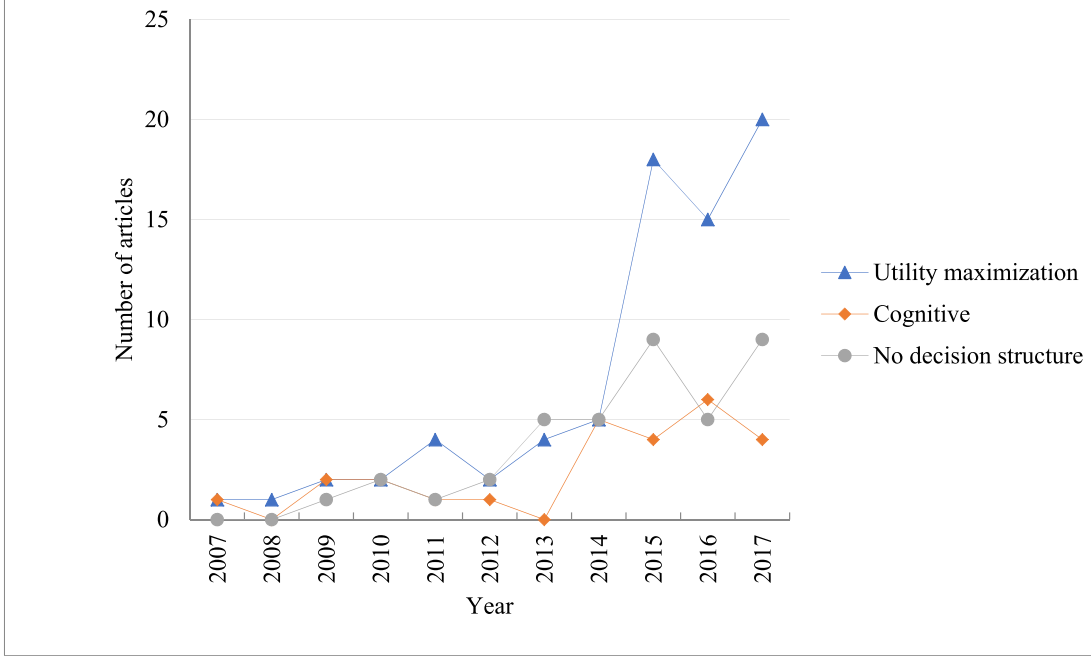

Figure 3. Decision making conceptualization used in reviewed articles.

objective functions, the tendency is to rely loosely on random utility theory, wherein each alternative is a function of various observed characteristics and farmers' decisions reflect the choice that has the highest utility (Sarker *et al* 2013). In most cases, the analyzed behavior was maximizing crop yield or agricultural income or minimizing labor or crop loss, although a few articles, such as Wineman and Crawford (2017), assume choices reflect maximization of other objectives, such as caloric production. Within this group of articles, some acknowledge that maximization objectives are impacted by constraints, such as (Asfaw *et al* 2016), where farming choices are modeled as 'the outcome of a constrained optimization problem by rational agents.' Other variations of modeling choice include accounting for risk such as Gomez (2015), who use stochastic frontier analysis to model technology adoption among risk-averse farm households who 'maximize the expected utility from final wealth at the end of the production period.' While these articles sometimes specify a caveat to maximization, including constraints such as risk aversion, their underlying conceptual framework is utility maximization.

Among the articles that do not articulate assumptions about behavior but appear to implicitly make assumptions, these assumptions are typically about rationality and often maximization. An example of this type of approach is when a 'right' decision is characterized as choosing between production alternatives based on a 'systematic approach for achieving maximum returns' (Kumar *et al* 2017). Similarly, Jain *et al* (2015), evaluate whether agricultural decisions led to higher yield and income, effectively assuming that the decisions were in response to the weather and that the decisions were taken in order to maximize yield. In other articles, it is simply not clear whether they used a utility maximization framework or something with a similar logical structure–e.g. farm households will adapt 'only if they perceive a reduction in the risk to crop production or an increase in expected net farm benefits' (Abid *et al* 2015). The informal presentation of decision making in these articles is in contrast to the typical highly structured assumptions used in traditional economic modeling, but they still often embed assumptions about rationality and or maximization.

In some of the articles that appear to be atheoretical, there are often subtle behavioral assumptions. For instance, one common assumption in articles about climate adaptation is that despite various barriers to climate adaptation, it is nonetheless rational to adapt to the climate if you perceive it is changing (for example Bryan *et al* 2009). This type of assumption appears to assert a correlational approach to analyzing decisions, but we cannot infer what underlying framework of decision making the authors may have in mind.

4.2.2. Approaches based on alternative cognitive models of decision making

A total of 17 articles (11.5%) use an alternative to maximization or optimization to model decision making related to climate change adaptation, in the sense that they consider aspects of the psychological or cognitive processes involved and the information

that goes into a decision. These articles tend to focus on the process of adaptation to climate change. We briefly discuss examples of the decision theories described in these articles including: Protection motivation theory (PMT), risk, coping and social appraisal models, theory of planned behavior, and theory of reasoned action.

The most common psychological or cognitive approach to decision making used was PMT, which conceptualizes behavior as an adaptive action taken in response to risks assessed through threat appraisal and coping appraisal. PMT applications propose that decision makers consider current behavior and future decisions in terms of the respective costs and benefits of making pro-environmental decisions (Keshavarz and Karami 2014), such as adapting to drought and climate change. Feng *et al* (2017) model adaptation decisions in terms of weighing the benefits of not adapting to drought (threat appraisal) and the perceived ability to avoid or reduce risks against the estimated costs of protective or adaptive actions (coping appraisal). Similarly, Dang *et al* (2014b) use structural equation modeling to test the applicability of PMT for understanding farmers' intention to adapt to climate change.

Further studies employ variations and extensions of PMT specifically to understand cognition about climate adaptation. Zheng and Dallimer (2016) use a 'model of private proactive adaptation to climate change' (MPPACC) first proposed by Grothmann and Patt (2005), to examine how two cognitive processes, climate risk appraisal and adaptation appraisal, underlie decisions to adapt. Burnham and Ma (2017) use a similar MPPACC model to draw out factors that influence farmers' perceived self-efficacy and adaptation intent. Gebrehiwot and van der Veen (2015) test the applicability of an integrated 'PMT-trans-theoretical stage model' in assessing drought risk vulnerability and examine how response efficacy, perceived risk severity, vulnerability, and subjective knowledge of drought predict the behavioral intention to adapt at various stages of the cognitive process. Truelove *et al* (2015) develop a risk, coping, and social appraisal model derived from PMT to predict the intention to adopt an activity based on perceptions of drought risk and appraisal in terms of social connectedness in the community.

Other articles focus on people's intention to adapt to climate change. The theory of planned behavior and the related reasoned action approach view intentions in terms of the perception that a given behavior will have the expected outcome given one's perception of the risks associated with that outcome. Arunrat *et al* (2017), for example, use the theory of planned behavior to guide selection of explanatory variables in climate adaptation decisions. Van Hulst and Posthumus (2016) use a 'reasoned action' approach to understand why farmers choose conservation agriculture or conventional farming. Both are modeling steps prior to making decisions.

One study by Letson *et al* (2009) specifically use a combination of utility maximization along with theory about the cognitive dimensions with respect to decisions under uncertainty. They examine the differences among simulated agricultural production decisions identified as optimal by maximization of the objective functions associated with expected utility and with prospect theory, the notion that people value gains and losses differently in risky situations. They demonstrate that the more realistic cognitive assumptions (i.e. prospect theory) lead to differences in the expected value of forecast information or how worthwhile it is to disseminate forecast information to farmers.

Only four articles investigate heuristics or decision rules related to agricultural decisions. Hochman *et al* (2017) use field experiments and simulation models of cropping and sowing generating different outcomes from various decision rules for choosing sowing time and frequency and use of irrigation as adaptive strategies. Similarly, Gunda *et al* (2017) simulate crop choices using system dynamics and experimental games which demonstrate the importance of heuristics related to trust in forecasts and the market on crop choice. Zheng and Dallimer (2016) examine the prevalence of the availability heuristic among farmers and how emotional reactions, such as fear, increase climate adaptation. Bharwani *et al* (2015) use a knowledge elicitation tool to identify decision rules, based on heterogeneous group attributes such as gender and household wealth. Overall, articles that involve attention to decision heuristics and rules are rare in this literature.

Understanding heuristics and alternative decision rules is one dimension of the fundamental question about how people respond to climate change that has been overlooked. In situations of uncertainty, the traditional rational economic approach to decision making based on optimal choices given known probabilities is no longer realistic or feasible (Gigerenzer *et al* 1999). Instead of gathering all the available information and optimally assessing it, people rely on simple rules of thumb or heuristics that use only a few pieces of important information (Gigerenzer 2007). There is no reason to believe this would not be the case with phenomena as complex as climate change or with decisions as critical as those related to climate adaptation. Simple heuristics can produce very good choices given the constraints of limited information and limited information processing—common with climate change. This could include mimicking observed successful decisions (Hoppitt and Laland 2013) or choosing a familiar option (Pachur *et al* 2011). Applied to farming this could include behavior such as mimicking a neighboring expert farmer or planting a traditional seed type. Cognitive approaches can thus tell us about whether satisficing or alternate

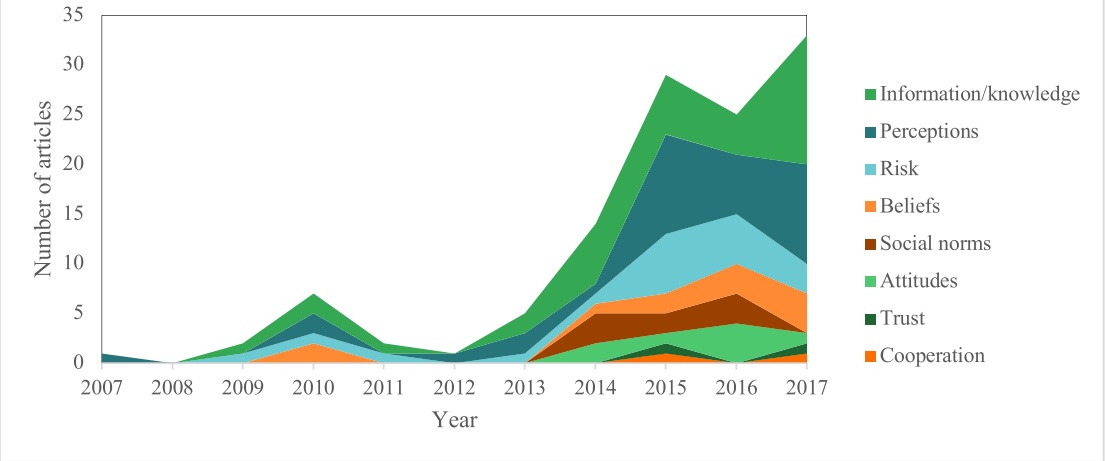

Figure 4. Cognitive variables included as determinants of climate adaptation.

Note: We did not account for whether the factors were statistically significant but rather whether the author included them in the analysis. Our intention here is to understand how decision making is modeled, not what drives decision making. Factors that were present in less than 5% of articles were dropped from the figure.

assumptions about decision making are appropriate in a given context.

The idea that heuristics are contextual also connects with the concepts of 'adaptive pathways', recognizing that various historical, environmental, and social contexts impact decision making (Fazey *et al* 2016) as do cross-scale processes (Feola *et al* 2015). This approach draws on cognitive concepts such as path dependency, the role of values in decision making, and the influence of social and institutional norms (Wise *et al* 2014). The framework of adaptation pathways can highlight where adaptation decisions might be inconsistent with social institutions or other risk management strategies (Burnham and Ma 2018). Adaptation pathways captures a similar sentiment to the concept of 'ecological rationality' in cognitive science—that people employ domain-specific simple heuristics that use information from the environments in which they are applied (Todd and Gigerenzer 2007).

Also related to the context of heuristics is the concept of traditional ecological knowledge (TEK) or knowledge practices and beliefs about humans and the environment handed down through cultural transmission (Berkes *et al* 2000). TEK produces heuristics that shape decisions and adaptation strategies with regard to agriculture and climate change (e.g. Granderson 2017, Leonard *et al* 2013). For example, farmers in Peru traditionally used the timing and presence of toads in their fields to estimate the onset of the rainy season although with rainfall variability the toads disappeared (Saylor *et al* 2017). This example highlights the limitations of heuristics in the context of climate adaptation but the importance of studying them—as the environment shifts so do the relevance of the heuristics based on generational and cultural knowledge.

We also looked at the extent to which various factors were used as determinants or independent variables in estimations relating to agricultural decision-making (see figure 4 for summary). Cognitive factors that were included were related to information and knowledge (28% of coded articles), perceptions and perceived behavioral control (27% of coded articles), and risk (15% of articles). Less than 14% of articles included cognitive factors such as beliefs, attitudes and social norms, despite previous research demonstrating the importance of these in forming environmental values (Stern 2000). Figure 4 displays the cognitive factors that were included as determinants of decision-making. These studies do not explicitly model or conceptualize decision making beyond controlling for the relative importance of these cognitive variables on a decision. This includes, for example, how perceptions of weather and climate, and related risk impact adaptation decisions (Esham and Garforth 2013; Li *et al* 2017).

4.3. The role of risk and information in climate decision making

Twenty-one percent of articles consider the role of risk in decision making and 15% consider risk as a determinant of a decision. This is surprisingly low given the centrality of risk and uncertainty in climate-related decisions for farmers. Of these articles, 14 examine decisions relating to the occurrence of extreme weather events, 10 relate to decisions about general risk aversion or tolerance, 7 relate to decisions about risk associated with crop loss, and 4 relate to decisions about adopting risk insurance. While some articles directly refer to climate risk, (such as Joshi *et al* 2017), more common is to include some basic measure of generalized risk as an independent variable in a

statistical model (Molua 2012). These general forms of risk aversion include estimating time preferences and time discounting (Akpalu and Bezabih 2015) or estimating risk aversion coefficients from an expected utility game (Jin *et al* 2016). When specific risks are considered in this literature, they are often related to climate change, but sometimes to other factors such as risk from price volatility (Tucker *et al* 2010) or food insecurity (Bhatta *et al* 2017). In general, authors acknowledge risk as a barrier to various behaviors or adoption of agricultural practices and/or technology, such as the decision to adapt new soil conservation practices (Alpizar *et al* 2011), rather than a cognitive factor directly related to one's perception of climate uncertainty. In other words, while some studies address climate change related risk among farmers in developing countries, few address the more subjective nature of uncertainty.

Rather than simply categorizing or describing someone's risk preferences, alternative cognitive models can tell us more about how risk is appraised and one's capacity to respond to it. We know that people may generally perceive risk differently and have different tolerance levels (Slovic 1987) and that risk is emotional (Loewenstein *et al* 2001). Risk is intertwined with bounded rationality too—research has demonstrated that humans have finite attention and processing capacity particularly for decisions that are close in time and space (Weber and Johnson 2009). In practice this means that we often leave risk assessment to scientists, despite the differences between public and technocratic assessments of risk (Weber and Stern 2011). One's perceptions of risk related to climate change are dampened by the time-delayed, abstract, and often statistical nature of the phenomenon, failing to alarm people sufficiently to act (Weber 2006). Using models that isolate the subjectivity of risk and investigate how risk contributes to or inhibits climate adaptation in developing countries is vital to understanding how to support climate adaptation.

The role of information is also a crucial cognitive component of agricultural decision making under climate change, where farmers rely on weather and climate for food security and their livelihoods. Thirty-two percent of articles consider the role of information in the decision-making process, including (a) what information is used, (b) whether information is available or accessible, and (c) the quality and credibility of the available information. Of these, 33 articles consider whether weather and climate influences were part of the process, 17 articles relate to decisions about the source of information (including whether they receive information from agricultural extension services), 12 articles relate to information about a new technology, and 7 articles relate to information about market prices, soil quality, or credibility of information more generally. An example of a paper that addresses the role of weather and climate information, is Chen *et al* (2014), who evaluate the provision of early warning information through a natural experiment. A common theme among articles that consider information access involves measuring decision makers' access to technical knowledge about climate adaptive measures (Dang *et al* 2014a, Wang *et al* 2015, Hou *et al* 2017). Other articles that address information access, explore how climate projections, including decadal climate information, positively influence decision makers towards anticipatory climate adaptation (Nyamwanza and New 2016). Examples of articles that focus on information quality, demonstrated how much people would be willing to pay for various attributes of climate information (Lechthaler and Vinogradova 2017) or calculate the expected value of forecasting information (Letson *et al* 2009).

A deeper understanding of climate information and related behavior can tell us about how to communicate about the complex, variable, and sometimes unreliable information about climate change (Swim *et al* 2011). Knowing about information sources, access, and quality is important, but contextualizing information issues in terms of processing can provide insight into how information can facilitate climate decision making (Marx *et al* 2007). A surprisingly large number of studies in this review entirely ignore the role of information or simply assume that decision makers have the relevant information needed to make informed decisions. This is in light of research that demonstrates that farmers in developing countries often do not have enough accurate information, in terms of geographically and temporally specific forecasts (Ingram *et al* 2002). In other climate decisions, such as choosing seed varieties, farmers are overloaded with too much information, some of which is not accurate (Waldman *et al* 2017). The availability of information about climate change is essential to understand climate adaptation but just as important is consideration of how information is or is not processed (Risbey *et al* 1999).

Overall, in the reviewed articles we see an increase in the inclusion of information and risk as elements of decision making over time (see figure 5). This is especially true with information as researchers increasingly recognize problems with information asymmetry, accessibility, and credibility related to weather and climate in developing countries. Other than the past few years risk has largely been ignored in this literature—and recent applications address more traditional conceptions of risk perceptions as barriers to adoption without considering uncertainty. The prevalence of studies addressing information and risk is greater than those accounting for bounded rationality in decision making yet the consideration of these factors would strongly suggest boundedly rationality would be a factor in decision making.

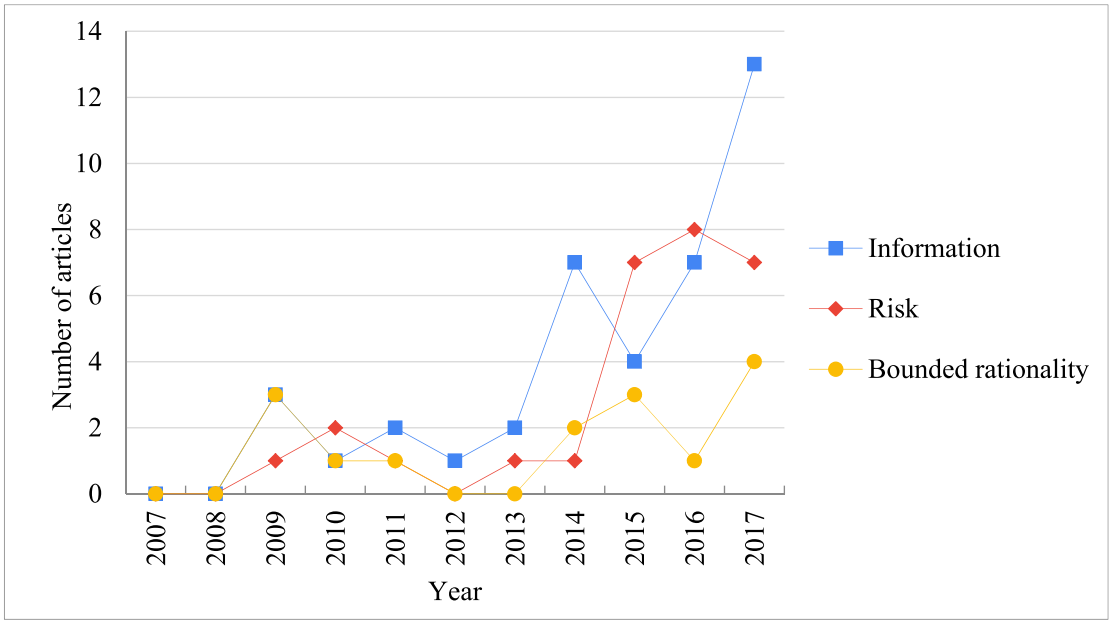

Figure 5. Inclusion of elements of information, risk and bounded rationality in analysis.

4.4. Limitations in connecting decisions to climate change

One limitation in the reviewed articles is clearly defining what aspect of the climate a decision is related to. Of the articles that clearly define a dimension of climate, they address decisions or perceptions related to increased dry spells or drought (51%), temperature increases (27%), increased flooding or excessive rainfall events (26%), and the change in onset or duration of the rainy season (23%). However, 34% of articles do not clearly articulate the dimension of the climate or climate impacts they are studying, similar to the findings of a review article on climate adaptation by Burnham and Ma (2016). These findings are also consistent with Findlater *et al* (2019b) who conclude that weather and climate variability are often assumed to be proxies for climate change in evaluating farmers' risk perceptions and predicting their adaptive responses, yet farmers treat them differently. We also found that the articles that take a cognitive approach were twice as likely not to provide clarity about the dimension of climate change they were assessing behavior in relation to (see figure 6). Almost one third of articles using a cognitive approach failed to articulate what dimension of climate they were addressing and articles using a cognitive approach were also the least likely to address climate change rather than extreme weather or weather variability.

Related to identifying the dimension of climate change being studied is the issue of connecting a behavior, choice, or agricultural decisions to climate change. We found 12% of coded articles do not establish any relationship between the agricultural decision being studied and the environment. This is often because the authors do not explicitly set out to establish this link but rather assume that climate-friendly behavior is a response to a perception about the climate. Problematically, this precludes an understanding of whether the motivation of the decision was related to environmental change or another factor.

Of the 120 articles that do establish a link between behavior and the environment, 57% establish the relationship by 'framing' or asking respondents directly. For example, a study design could include a dependent variable that is based on whether farmers reported specifically engaging in a previous climate adaptive behavior (e.g. Murage *et al* 2015, Yegbemey *et al* 2013, Wood *et al* 2014), such as constructing a reservoir or adopting a new cultivation technique in response to climate change. Eighteen percent of articles that establish a relationship between a behavior and the environment do so by statistically linking a perception of an environmental trend with a behavior or action. An example of this is where the authors use the farmers' perception of rainfall change as an independent variable predicting an adaptation action, such as constructing a reservoir (for example Dang *et al* 2014b; Nordhagen and Pascual 2013). Finally, 17% of articles that establish a link do so through a correlational relationship between a behavior and the environment using physical weather or climate data, such as temperature or precipitation data (for example Siderius *et al* 2016, Skoufias *et al* 2017, Moniruzzaman 2015, Waha *et al* 2013).

Previous research has highlighted the importance of identifying the relationship between a given decision and the appropriate climate context (Findlater *et al* 2019b). As Tucker *et al* (2010) explain,

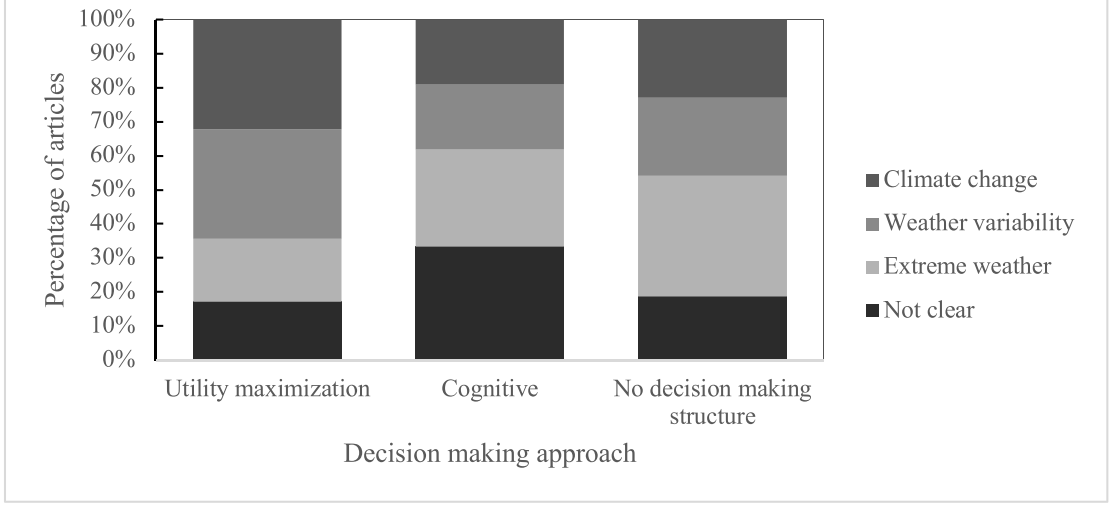

Figure 6. Dimension of climate changed addressed for each decision-making approach.

it is challenging to distinguish behavior that is in response to environmental risk from behavior addressing other forms of concurrent risk, such as those posed by market forces. In many studies there is a murkiness related to whether pre-existing strategies are interpreted as adaptation or whether the causality has been clearly isolated. It is challenging to identify behavior that is explicitly in response to physical environmental change over time, which could be why many articles examine perceptions of environmental change and indirect causal relationships between a behavior and an environmental change. This identification problem clearly speaks to the need for wholistic assessments of climate decisions such as those using an adaptive pathways framework (Wise *et al* 2014).

Additionally, the vast majority of articles (88%) do not consider how long the observed agricultural activity or behavior studied has been performed or whether it was a traditional farming practice. An example is the study of Salazar-Espinoza *et al* (2015), who examine whether interannual shifts in farmer cropping choices are in response to extreme weather events, or are traditional crop rotation practices. Without considering when the behavior arose, we cannot tell whether the behavior is new and for example whether it is an adaptation to climate change or simply an existing behavior that facilitates climate adaptation.

5. Conclusions

The vast majority of the literature on climate change and decision making among farmers in developing countries overlooks the nuances of human decision processes, and cognitive issues related to information availability and risk under uncertainty. Few of the articles in this review discuss the bounded nature of rationality related to decisions under climate uncertainty, or acknowledge that the decisions under study might be influenced by a cognitive constraint. Assuming that farmers are maximizing yield or profit or maximally adapting to climate change, implies that farmers have complete information about climate trends and appropriate agricultural adaptation measures to mitigate climate effects, which is often not the case. Using expected utility-based decision models assumes a decision-making structure being used by farmers that is not realistic given their cognitive and information constraints, their expectations and aversion to risk, and their subjective responses to that risk, that have been developed over time. Incorrect assumptions about behavior can lead to poorly designed policies, undermine adaptation, and even have the opposite of the intended effect (Findlater *et al* 2019a). Approaches that account for the high levels of uncertainty are likely to reflect alternative decision-making assumptions and the prevalence of heuristics and biases. Analyzing decisions within a broader framework of multiple sources of uncertainty and related risk are likely to generate a more accurate understanding of agricultural decisions in the context of climate change.

6. Future research

Future research should focus on the processes by which agricultural decisions are made in the context of climate change. This includes research investigating three primary areas: (1) the structure of decision making under climate uncertainty, (2) the role of cognition and cognitive biases as they relate to weather, climate, and adaptation and (3) the subjectivity of risk under climate uncertainty.

Alternative decision-making assumptions are appropriate in the climate change context including

partial optimization or satisficing, which are common with limited information or uncertainty (Findlater *et al* 2019c). Additionally, it is critical is to consider whether heuristics are at play—many farmers utilize some form of knowledge specific to their decision environment, often involving the use of heuristics. Investigations that consider how decision rules operate within the broader decision-making context are likely to be more effective, including connecting with the principles of ecological rationality, TEK or adaptive pathways. Simple heuristic-based decisions are appealing in complex decision environments because they are more efficient, ignoring part of the information can lead to more accurate judgments than considering all information computationally (Gigerenzer and Gaissmaier 2011). Central to understanding how different decision rules operate at different times for individuals is an understanding of the salience of climate change relative to other mitigating decision factors (Waldman *et al* 2019b). We need a better understanding of the extent to which farmers are making decisions to address multiple stressors and managing different forms of uncertainty and risk simultaneously (such as Burnham and Ma 2018, Eakin *et al* 2009).

Research has highlighted the prevalence of cognitive barriers when it comes to making sustainable decisions (Weber 2017). We know that our environmental decisions tend towards the status quo, our mind attends to some things more than others, and selectively interprets information that effects the sustainability of our behavior. Many of the cognitive biases relate to the uncertainty of climate change that exist among individual decision makers in developed countries are likely to be present among farmers in developing countries. There are numerous cognitive biases that have been found to be prevalent that have not been researched in developing countries. Additional research is needed on topics such as how cognitive biases relate to perceptions of climate and related farm decisions (such as Waldman *et al* 2019a) and in particular how cognitive biases might inhibit on-farm climate adaptive behavior.

Evidence from this review and elsewhere has demonstrated that climate change is often conflated with weather and climate variability yet they are often understood in terms of risk differently by farmers (Findlater *et al* 2018a, 2018b, 2019b). More care is needed when investigating climate-related risk with farmers and in particular in parsing what risk and uncertainty are related to. Local and global food systems are increasingly nested and interconnected (or teleconnected) and so are farmer's independent responses to the risks and opportunities associated with various changes (Eakin *et al* 2009). Further research is needed on how subjective assessments of risk impact agricultural decision making (such as Menapace *et al* 2013), but more specifically how different interrelated sources of risk influence the decision-making environment for farmers and come into play for different decisions and decision makers.

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Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: Waldman K 2020: ERL Manuscript Database. Figshare. Dataset. 10.6084/m9.figshare.12847325.

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