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A review of types of risks in agriculture: What we know and what we need to know

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ABSTRACT

This study examines the scope and depth of research on the five major types of risks in agriculture, and the extent to which those studies have addressed the impacts of, and policies to mitigate individual types of risk as opposed to more holistic analyses of the multiple sources of risk with which farmers have to cope with. Risk is at the center of new paradigms and approaches that inform risk management initiatives and shape investments in many countries. Although the literature includes several substantive reviews of the methods available for risk analysis and their empirical applications have been extensively scrutinized, limited information exists about which types of risks have received sufficient attention, and which have not. This limited information is perplexing because farmers manage multiple risks at the same time and unanticipated events continue to have substantial impacts on farmers. We identify 3283 peer-reviewed studies that address one or more of the five major types of risk in agriculture (production risk, market risk, institutional risk, personal risk, and financial risk) published between 1974 and 2019. We conduct a literature search and then apply an eligibility criteria to retain eligible studies from the search. We then classify those eligible studies based on risk type and geographic focus. We placed no limit on the temporal scale, geographic focus, or study method for inclusion in our search. Results show that 66% of the 3283 studies focused solely on production risk, with only 15% considering more than one type of risk. Only 18 studies considered all five types of risk and those either asked how farmers perceived the importance of each risk or were focused on conceptual issues, rather than assessing how exposure to all the risks quantitatively affects farm indicators such as yields or incomes. Without more detailed analyses of the multiple types of risks faced by farmers, farmers and policymakers will lack the information needed to devise relevant risk management strategies and policies. A shift in research focus towards the analysis of multiple contemporaneous types of risk may provide a basis that gives farmers greater options for coping with and managing risk. We discuss some of the challenges for studying multiple risks simultaneously, including data requirements and the need for probability distributions and the role of simulation approaches.

1. Introduction

Farmers constantly cope with and manage different types of agricultural risks (Huirne, 2003).[1] Risk inherently involves adverse outcomes, including lower yields and incomes and can also involve catastrophic events, such as financial bankruptcy, food insecurity and human health problems, although higher expected returns are typically one of the positive rewards for taking risk. Farmers therefore cope simultaneously with and manage multiple risks that can have compounding effects (van Winsen et al., 2013; Wauters et al., 2014). The compounding effects may affect decisions and outcomes at scales well beyond the farmer. One initial cause of the 2007/08 world food price crisis was production risk related to severe droughts but the impacts of the ensuing price spikes were exacerbated by some governments imposing export restrictions (Headey, 2011). During this crisis farmers faced production risk (drought), market risk (price spikes), and institutional risk (unexpected changes in government policy) all within a short period. Thus, risk outcomes can have cascading effects where

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[1] In our study "farmer" refers to any person(s) involved in the production of crops or livestock or both, i.e., any person(s) involved in "farming". Farmers live and work in different social and business units that often overlap, including family farms, farm households, agricultural households, agribusinesses, or providing wage labor. The production of crops and livestock occurs on a "farm" and the "farm" is one component of the "farm household". The "farm household" can have both on-farm and off-farm activities.

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one type contributes to another type occurring—for example, excessive rainfall during harvest is an event that can engender another set of risks such as financial risks associated with being unable to repay loans (Pelka, 2015).

Given that multiple types of agricultural risks are likely to occur simultaneously, several policy-driven initiatives have begun to address these risks more holistically. These initiatives examine risk management issues and strategies that concentrate on multiple sources of risk. They include the Platform on Agricultural Risk Management, the World Bank's Forum for Agricultural Risk Management in Development (FARM-D), and programs in the Center for Resilience.[2] Funders of agricultural research are also beginning to support more projects that focus on the multiple risks that farmers encounter. Examples include the SURE-Farm project and the INFORM index for risk management (Bornhofen et al., 2019; Meuwissen et al., 2019). In addition, both academics and policy researchers are taking a more earnest focus on risk, such as the PIIRS Global Systemic Risk research community and the recent efforts by the OECD's risk management and resilience topic group. This new focus and reorganization of human and financial resources, often in the context of the resilience of farms and the agricultural sector to adverse events, suggests that a growing appreciation exists that multiple types of risk are important.

Farmers have always faced multiple risks; for example, in premodern Iceland major concerns for farmers included weather variability and personal illness (Eggertsson, 1998). Campbell et al. (2016) argue that the growing number of studies that focus almost exclusively on the link between weather variability and crop yields provide only marginal increases in knowledge and by only studying one risk we only gain an inadequate picture of all the types of risk farmers encounter. The implication of this argument is that analyses of multiple concurrent sources of risks are likely to generate more useful insights. The IPCC (2019) reinforces this view by discussing how diverse types of risks co-occur or reinforce each other and how such co-occurrence can limit the effectiveness of adaptation planning for climate change. The IPCC indicates a possible remedy may be policy-making that considers multiple risks. Other researchers have also argued that the risks associated with climate change, economic volatility, globalization, and political instability have become more pronounced and severe (Barrett and Constas, 2014; Darnhofer et al., 2016; Hansen et al., 2019). Whether farmers' exposure to risks, in general, has increased over time remains an open question as the quantitative evidence seems mixed and context specific, especially for weather and commodity prices (Rajeevan et al., 2008; Gilbert and Morgan, 2010; Wildemeersch et al., 2015). However, unanticipated events with considerable impacts on farmers continue to occur (Just, 2001), which suggests that the nature of risk has changed over time. The challenges to the agricultural sector from a growing world population, from changing diets with higher demand for animal-source foods, and from climate change, make managing multiple risks more important than ever.

Given this context, the objective of our study is to examine the extent to which the existing peer-reviewed literature provides sufficient support for a more holistic approach to risk management that includes examining multiple types of risk and evaluates their joint effects. The focus is on farmers and the types of risks relevant to them on their farms. Ideally, new initiatives that seek to promote and support holistic risk management should be underpinned by evidence on how farmers cope with multiple risks. However, the evidence from our study indicates that the existing literature may not adequately provide such support. Our study describes and synthesizes the trajectory and status of the peer-reviewed literature on the types of agricultural risks that researchers have examined. We use a literature search procedure in the Web of Science for all available years (1974–2019). We include five general types of risk in agriculture (Harwood et al., 1999; Hardaker et al., 2004): 1) production, 2) market, 3) institutional, 4) personal (also called human or idiosyncratic), and 5) financial. The first four of these risks are business risks and in important ways are independent of financial risks associated with how a farm may be financed.

Our current study complements earlier reviews that have examined the theoretical models and empirical methods used to examine specific types of risk (Just, 2003; Just and Pope, 2003; Marra et al., 2003; Barrett et al., 2010; Chavas et al., 2010). These reviews reinforce the importance of understanding risk, as for example, technology choices are strongly affected by risk-related issues (Marra et al., 2003). However, Just (2003) argues that agricultural risk research "has failed to convince the larger profession of the importance of risk averse behavior", that "agricultural risk research has focused too much on problems in which risk is less likely to be important", and that there has been an over emphasis on "characterization of the production problem that does not support risk research". Researchers have reflected that the treatment of multiple sources of risks appears limited in the literature (Chambers and Quiggin, 2004). Researchers have also reflected that the literature has often focused on the types of risk that are "easy" to study, such as weather shocks in Africa rather than market or institutional risks (Dercon, 2008). Managing these less "easy" risks possibly provides more opportunities for long-term livelihood improvement. Our study therefore examines these reflections in more detail through a literature review and analysis, in light of the recent initiatives on risk and because farmers face multiple risks simultaneously.

2. Methods

We conducted a literature search to identify an initial database of peer-reviewed studies that possibly examined type(s) of agricultural risk. Every one of these studies was then manually assessed for eligibility to retain in the database based on an eligibility criteria. After removing ineligible studies from the initial database, we arrived at our database. For each study in our database we recorded the type of risk(s) studied and the geographic focus.

2.1. Terminology for definitions of risk and risk types

To provide context to our literature search we first define risk and some of its interpretations, and then overview the five general types of risk in agriculture. There can exist multiple sources of risk within a type of risk, for example production risk is a type of risk and the source of risk that generates the production risk might be a drought or a pest outbreak. The risk management option could include crop yield insurance for a drought or integrated pest management for a pest outbreak.

To identify studies on types of risk we set a boundary on the words and terms associated with types of risk. Here definitions and interpretations of risk in the literature informed our choice of search strings (search 2 in Table 1). Knight (1921) defined risk as the case where the distribution of outcomes is known either a priori or statistically through experience, and uncertainty as the case where probabilities cannot be quantified. This definition implies that decisionmakers have imperfect information about whether a given outcome associated with a course of action will occur but act as if they know the probabilities of the relevant alternative states of nature that each lead to different outcomes. Nevertheless, probabilities used by decisionmakers are usually unavoidably subjective (Hardaker, 2016). Hardaker (2000) lists three common interpretations of risk: 1) the chance of a bad outcome, 2) the variability of outcomes (i.e., the converse of stability), and 3) uncertainty of outcomes. Building on the word stability in the second interpretation, other words that characterize risk include robustness, vulnerability, and resilience (Urruty et al., 2016). Finally, the Society for Risk Analysis has a Glossary of Risk-Related Terminology for key terms related to risk analysis. The preceding definitions, interpretations, and glossary informed our search.

[2] The Center for Resilience is part of the United States Agency for International Development's Bureau for Food Security. For farmers, resilience encompasses buffer, adaptive, and transformative capability (Darnhofer, 2014).

Table 1
Search strings in the literature search.

Search name	Search focus	Search number	Search string
Agriculture	Agriculture	1	TS = (agricultur* or farm* or pastoralist* or rancher* or smallholder*) and SU = (agriculture or business & economics) not WC = (forestry or fisheries)
Risk notion	Risk	2	TS = (ambiguity or hazard or uncertain* or risk* or variab* or volatil* or stabil* or vulnerab* or resilien* or robust*)
Risk types	Production	3	TS = (yield or quantity or production or climat* or drought* or flood* or temperature* or weather or rainfall* or precipitation* or salinity or "heavy metal*" or hurricane* or cyclone* or pest or pests or disease* or fungi or insect* or bacteria or virus* or nematode* or rodent* or vermin or hail or frost or weed*)
	Market	4	TS = (market* or price* or "trade" or cost)
	Institutional	5	TS = (regulation* or institution* or "property right*" or tenure or "land right*" or "policy change*" or "policy shift*" or "policy shock*" or "support polic*" or "support payment*" or "social norm*" or tax or taxation or taxes or corruption or "cooperative*" or "co-operative*" or "farmer organi$ation" or "rural producer organi$ation")
	Personal	6	TS = (injury or injuries or accident* or illness* or cancer* or "human disease*" or "human health" or "skin disease*" or sick* or death or divorce* or "property theft" or "property fire" or personal)
	Financial	7	TS = ("interest rate*" or "credit" or financ*)

Note: TS denotes Topic, SU denotes Research Area, and WC = Web of Science Category. TS indicates that either the title, abstract, or keywords contained the specified word(s) in the search string. An asterisk indicated a wildcard representing any group of characters, including no character. A dollar sign ($) captured both British and American spelling. Phrases enclosed in quotation marks searched for an exact phrase, with the asterisk still representing a wildcard.

The five general types of risk in agriculture are as follows:

1 Production risks stem from the uncertain natural growth processes of crops and livestock, with typical sources of these risks related to weather and climate (temperature and precipitation) and pests and diseases. Other yield-limiting or yield-reducing factors are also production risks such as excessive heavy metals in soils or soil salinity.
2 Market risks largely focus on uncertainty with prices, costs, and market access. Sources of volatility in agricultural commodity prices include weather shocks and their effects on yields, energy price shocks and asymmetric access to information are additional sources of market risk. Other sources of market risk include international trade, liberalization, and protectionism as they can increase or decrease market access across multiple spatial scales. Farmers' decision making evolves in a context in which multiple risks occur simultaneously, such as weather variability and price spikes or reduced market access (Holden and Shiferaw, 2004; Harvey et al., 2014; Lazzaroni and Wagner, 2016).
3 Institutional risks relate to unpredictable changes in the policies and regulations that effect agriculture (Harwood et al., 1999), with these changes generated by formal or informal institutions. Government, a formal institution, may create risks through unpredictable changes in policies and regulations, factors over which farmers have limited control. Sources of institutional risk can also derive from informal institutions such as unpredictable changes in the actions of informal trading partners, rural producer organizations, or changes in social norms that all effect agriculture. Farmers are increasingly supported by and connected to institutions, especially as farm production becomes more market focused.
4 Personal risks are specific to an individual and relate to problems with human health or personal relationships that affect the farm or farm household. Some sources of personal risk include injuries from farm machinery, the death or illness of family members from diseases, negative human health effects from pesticide use, and disease transmission between livestock and humans (Antle and Pingali, 1994; Lopes Soares and Firpo de Souza Porto, 2009; Masuku and Sithole, 2009; Arana et al., 2010; Tukana and Gummow, 2017). Health risks are a major source of income fluctuation and concern for farmers (Dercon et al., 2005). Farmers often cope with the interconnectedness of personal and institutional risks; for example, divorce or death of a husband can lead to the appropriation of land or livestock, due to institutional risks created by customary laws (Meinzen-Dick et al., 2014). In the literature, the words "personal", "human", and "idiosyncratic" generally refer to the same type of "personal" risks we considered.
5 Financial risk refers to the risks associated with how the farm is financed and is defined as the additional variability of the farm's operating cash flow due to the fixed financial obligations inherent in the use of credit (Gabriel and Baker, 1980; de Mey et al., 2016). Some sources of financial risk include changes in interest rates or credit availability, or changes in credit conditions.

2.2. Literature search and search strings

The literature search used a combination of search strings to retrieve studies in the Web of Science Core Collection (SCC). The SCC is part of the Institute for Scientific Information Web of Knowledge Database. The search covered all Citation Indexes in the Database. The Indexes included the Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, and the Emerging Sources Citation Index. The search included peer-reviewed English-language journal articles (called "studies" in our review) published between 1974 and 2019. The first available year in the Database was 1974. We conducted the search on August 5th, 2019 and the search included two Research Areas defined by the Web of Science: (1) agriculture and (2) economics and business. The literature search excluded studies in the Web of Science Category of Forestry and Fisheries because our primary focus was to identify studies on types of risks in agriculture relevant to crops and livestock. Table 1 displays the search strings used to identify the initial database of studies.

Our first search string specified words related to agriculture (search 1 in Table 1). Subsequent searches were composed of two inclusion terms linked by a proximity operator, following procedures in other agricultural-focused reviews (Kane et al., 2016). The string of words in the first inclusion term ensured the search results pertained to risk (search 2 in Table 1), guided by methods Section 2.1. The second inclusion term captured specific sources of risk for each type of risk—searches 3–7 in Table 1. The scale of the study was left unrestricted, and therefore included studies at the plot, farm, household, country, regional, and global scale.

We linked the inclusion terms for risk (search 2) with each type of risk (searches 3–7) using a proximity operator. The proximity operator was set to 2, which meant the two inclusion terms were within two words of each other. This approach was less restrictive than searching for exact phrases (such as "climate risk"). As a result, the search retrieved more studies than if we applied exact phrases, for example, we capture "risk of climate change" plus "climate risk". Setting the proximity operator to 2 also helped to reduce false hits that would have occurred by using the "AND" operator between the inclusion term for risk and the type of risk. For example, to retrieve production risk studies the Web of Science syntax (using the numbers in Table 1) was #1 AND (#2 NEAR/2 #3), where NEAR/2 is the proximity operator. We experimented with different words

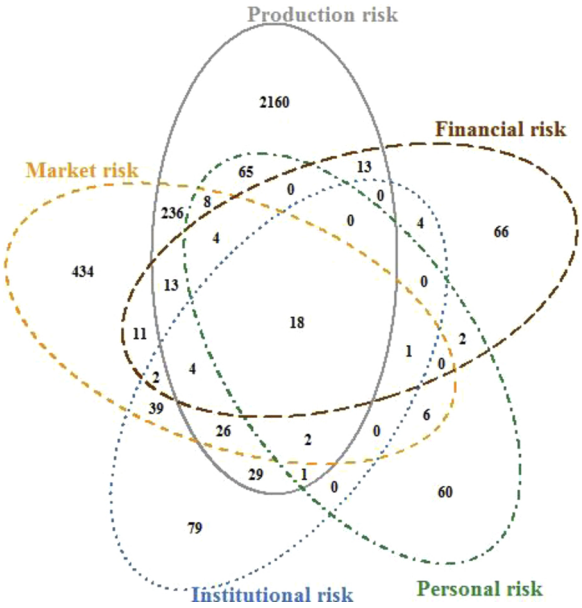

Fig. 1. Venn diagram for distribution of the number of studies across five types of risk between 1974 and 2019. Data from authors' literature search.

in the search strings and setting the proximity operators greater than or less than 2. The strings in Table 1 suited our study's objectives. Changing the search strings changes the number of studies in each category; however, the search strings described in Table 1, coupled with the proximity operator, produced an initial database that we believe reflects the literature between 1974 and 2019. We report data for all years but focused our analysis of temporal trends for the following decades: 1979–1988, 1989–1998, 1999–2008, and 2009–2018.

2.3. Eligibility criteria for retaining studies

The search retrieved an initial database of studies for which the study's title, abstract, or keywords indicated the study examined a type of risk. We then manually assessed every study against an eligibility criteria. The assessment involved examining the study's title, abstract, or keywords against an eligibility criteria. If the study's title, abstract, or keywords contained insufficient information to assess the study's eligibility we examined the full text of the study. We retained in our database only studies that met our eligibility criteria:

- The study provided a quantitative or conceptual analysis of a type(s) of agricultural risk. Examples of quantitative analyses included studies based on manipulative experiments (such as agronomic field trials or experimental trials with livestock), monitoring of sources of risk (such as weather variability or heavy metals in soil), scenario analysis with simulation models (such as cropping systems or bioeconomic models), statistical analyses, or studies that combined multiple methods. Statistical analyses included examining survey data on perceptions of risk types or the effect of risk types on farmer behavior, or econometric analysis of commodity price volatility. Conceptual analysis of types of risk included reviews and overview studies, theoretical studies, and qualitative assessments.
- The actual analysis or argument of the study earnestly included risk, i.e., a major part of the study covered a type of risk and risk was not only (or solely) mentioned in the framing or motivation of the study. For example, we excluded a study that writes "climate change is a growing problem" but then does not actually examine climate change (or any other type of risk). We also excluded a study that writes "Key uncertainties about price trends include" but then does not actually examine price uncertainty. A study, in general, earnestly included risk if the study's title or abstract listed an objective, research question or result related to a risk type.
- We excluded studies that were in the initial database for nomenclature reasons but were unrelated to a type of risk. For example, we excluded studies that included terms like "modelling uncertainty" or "aggregate stability" (of soil) but had no more details on a type of risk.
- The study focuses on crops or livestock or both. We excluded studies only on forestry or fisheries. Studies on integrated aquaculture (such as crop-livestock systems that also include fish) and agroforestry studies were eligible. If multiple commodities (like energy, agriculture, and metals) were studied for market risk, the agriculture commodity must be earnestly studied and not just part of the list of commodities studied. For example, we retained studies on how oil price shocks affect cereal grain prices.
- To be eligible the study focuses more on the agricultural production aspects of risk types than on the consumer aspects of risk types. We excluded studies on consumer choice of foods and excluded studies that provided a cursory mention to "human health" with no other focus on a type of risk.

2.4. Study classifications

After we assessed all the studies in the initial database for eligibility, we examined the eligible studies by recording the type of risk(s) the study focused on, and the geographic focus of the study. This involved examining the title, abstract, or keywords, or full text version if required. The geographic focus of the study was based on the United Nations Standard Country codes (UN, 2019). We listed the country or region(s) where the study focused. For theoretical studies, studies that presented stylized numerical examples without a geographic focus, or studies where the geographic focus was unclear, we listed the geographic location as Not Applicable (NA).

3. Results

Our literature search identified 5294 studies published between 1974 and 2019 that potentially examined risk. We then examined the studies in this initial database for their eligibility. Through this examination, we excluded 2011 studies from the initial database, resulting in a database of 3283 studies. Fig. 1 shows the distribution of the 3283 studies among all the combinations of risk types. A total of 2160 studies focused solely on production risks, accounting for 66% of the total sample. Among studies that examined only one of the five risk types, market and then institutional risks were the next most widely examined. Thirteen percent of the total sample (434 studies) considered only market risks, but only 2.4% of all studies (79 studies) considered only institutional risks. Only 1.8% of the studies in the total sample (60 studies) considered personal risks only and 2.0% of all studies focused solely on financial risks (66 studies). Fifteen percent (484 studies) of the studies in total sample examined at least two types of risk (Fig. 1). Among these 484 studies, 405 considered two risk types, 50 considered three types, 11 considered four types, and 18 considered all five types. Risks in production were the most likely to be examined in combination with another type of risk. The combination of production and market risk was the pair that occurred most frequently, consisting of 236 studies that was 7.2% of the total sample and 48.7% of the subsample of studies examining multiple types of risk. Production, market, and institutional risk was studied in 26 of the 50 studies on three types (52% of that subsample). Financial risks are only incurred by farmers who actually have financial obligations like a loan. These obligations are reflected in financial risks being least numerous in Fig. 1.

Fig. 2A shows the distribution of studies for each risk type over the past four decades. The number of studies in the dataset increased over time. The number of studies published between 1989 and 1998 was 284. However, between 1999 and 2008 the number of studies in our database increased by 120% to 626, and between 2009 and 2018 increased by 245% to 2158, also highlighting that the number of studies

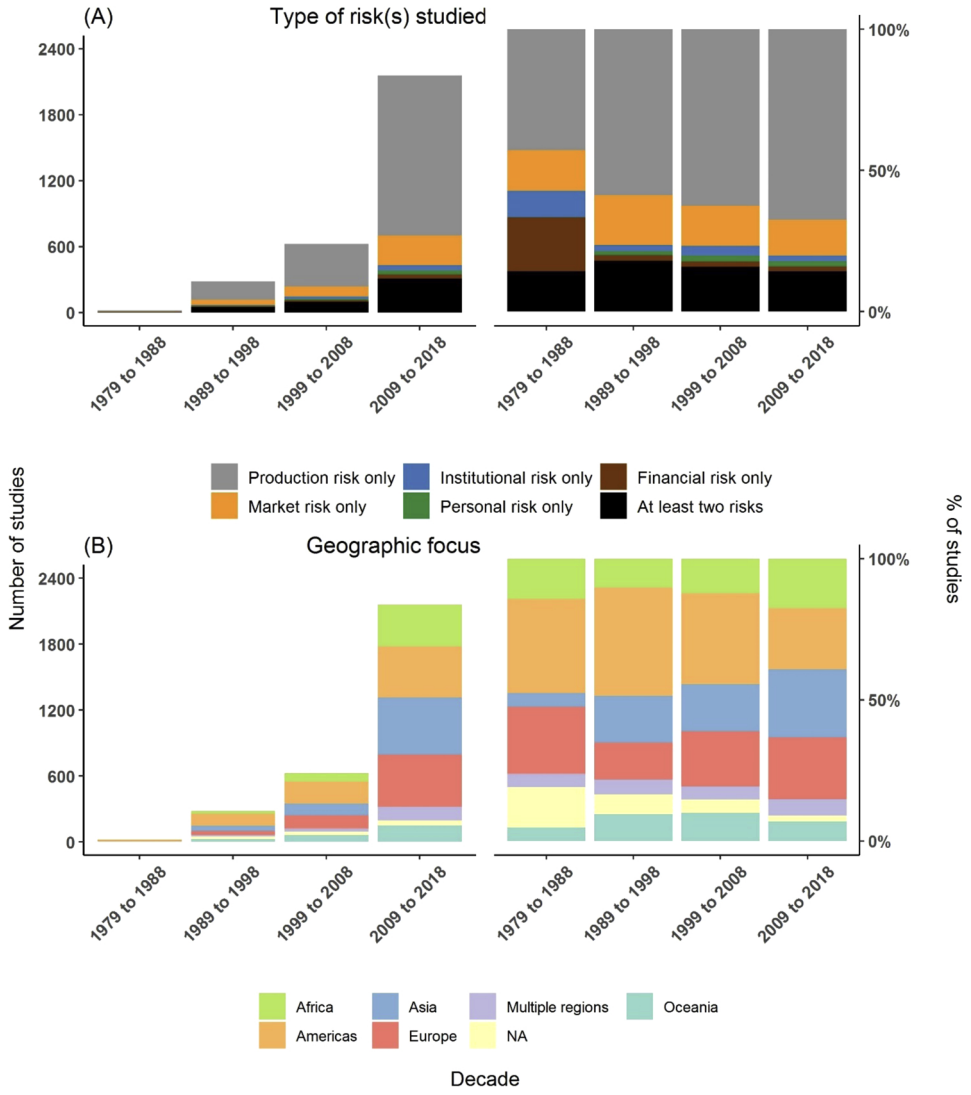

Fig. 2. Number and percentage of risk studies by decade for two categories: risk type (A) and geographic region (B). Left y axis represents the number of studies found in each subcategory. Right y axis represents the percentage of all studies in each subcategory. Table 2 reports the number of studies in each category for all years (1974–2019). Data from authors' literature search.

Table 2
Number of studies by risk type and geographic focus over time.

Category	Subcategory			Year			
		Total all years (1974 –2019)	1974–1978 and 2019	1979–1988	1989–1998	1999–2008	2009–2018
Risk type	**Total all risks**	3283	194	21	284	626	2158
	Production	2160	137	9	167	391	1456
	Market	434	20	3	50	89	272
	Institutional	79	3	2	6	22	46
	Personal	60	4	0	4	13	39
	Financial	66	7	4	6	12	37
	At least two risk types	484	23	3	51	99	308
Geographic focus	**Total geographic focus**	3283	194	21	284	626	2158
	Africa	526	38	3	29	77	379
	Americas	823	40	7	109	201	466
	Asia	726	54	1	47	105	519
	Europe	672	34	5	37	122	474
	Oceania	251	12	1	27	62	149
	Multiple regions	181	10	1	15	29	126
	NA	104	6	3	20	30	45

Note: Data from authors' literature search.

increased at an increasing rate. Changes occurred in the allocation of studies among the risk types over the past four decades (Table 2). The percentage of all studies on only production risk increased modestly from 59% in 1989–1998 to 63% in 1999–2008, and then 66% in 2009–2018. The increased prevalence of production only studies occurred together with a decline in the percentage of studies on only market risk. Eighteen percent of studies considered only market risks in 1989–1998, but this percent decreased to 14% in 1999–2008 and 12% in 2009–2018. The proportions of studies in the other categories remained relatively constant over the entire period. For example, the proportion of studies on at least two types of risk was between 14% and 18% in all decades. One notable change was that in the decade 1979–1988 4 of the 21 studies were on financial risk only (19%) and in all subsequent decades only 2% of studies were on financial risk only.

Seventy nine percent of all studies in the database (2759 from the 3283) included production risk and 2160 of those 2759 studies considered production risk only. To the extent that production risk features in studies from other risk types, we found 64% of all studies on multiple types of risk included at least production and market risk (311 from 484 studies). We observed no discernable change in the percentage of all studies considering multiple types of risk over time.

Market risks, in isolation from or in combination with other risks, were the next most widely examined. Forty six percent of all studies on market risk considered those risks in combination with at least one other type of risk, but, for example, only 16% of all studies on production risk considered production risks in combination with at least one other type of risk. Less studies included institutional, personal, or financial risks, compared with production and market risks. The percentage of studies that considered institutional risk was 6.2%, considered personal risk was 5.1%, and considered financial risk was 4.2%. Looking at studies of two or more risks, institutional risks were mostly studied in combination with market risks and personal risk with production risks. For example, 29 studies considered only production risk with institutional risk and 39 studies considered only market risk with institutional risk.

For the geographic focus of the 3283 studies, 823 were in the Americas, 726 were in Asia, 672 in Europe, 526 in Africa, 251 in Oceania, 181 were in multiple regions, and 104 we allocated to the NA category. Most of the studies listed as NA were theoretical studies or studies with stylized numerical examples without a geographic focus. The geographic focus changed over time, with the major trend among regions being a faster increase in the number of studies in Asia compared to the Americas. The percentage of all studies from Asia was 16.5% in 1989–1988, 16.8% in 1999–2008, and 24.1% in 2009–2018, and the percentage of all studies from the Americas was 38.4% in 1989–1988, 32.1% in 1999–2008, and 21.6% in 2009–2018. Across all years and for studies that were specific to one country (from the 117 unique countries in our database), the number of studies in the top ten countries by number of studies was United States of America 541, Australia 218, India 195, China 178, Canada 97, France 74, Germany 70, Brazil 67, Ethiopia 62, and Spain and the United Kingdom both with 59. Across all countries and years, the proportion of studies in developing countries increased over time, for example in 1989–1998 34% of country-specific studies were in developing countries, but in 2009–2018 this percent rose to 50%.

Table 3 summarizes the 18 studies that considered all five risk types. Thirteen of these studies used questionnaires to ask what types of risk farmers perceived as most important. The other five studies were qualitative or conceptual. Many of the questionnaire-based studies ranked the types of risk based on farmers scores from a 5-point Likert scale. The types of risk perceived as most important varied by context, for example famers in Europe reported institutional risks associated with policy uncertainty as a major concern. None of the studies on all five types of risk examined directly the effect of changes in sources of risk on farm indicators.

4. Discussion

Our literature search and subsequent database of eligible studies provides insights into the types of risks studied in agriculture between 1974 and 2019. Previous reviews highlight the extent to which agricultural studies focus on risk, for example, 29% of studies that used farm-scale models in the European Union between 2007 and 2015 included risk or stochasticity (Reidsma et al., 2018). Between 1957 and 2015 the topic “uncertainty and risk” had the greatest number of studies in the Australian Journal of Agricultural and Resource Economics (Polyakov et al., 2016). Our results, however, also indicate that studies have overwhelmingly clustered around production and market risks.

4.1. Types of risks studied

The focus on production risk is understandable given that productivity in agriculture is closely connected to biological processes and can be studied in relatively controlled experiments. These experiments permit a better understanding of cause and effect. For example, the analysis of long-term agronomic trials can help identify how weather variability affects crop yield stability. Moreover, farmers often perceived production risks as being one of the most important types of risk (Table 3), but this perception is context specific with surveys from farmers in Europe often suggesting policy uncertainty as a major concern. The focus on market risks is also reasonable. Markets, prices, and price volatility are at the center of theories and models developed in agricultural economics. Researchers have recognized the importance of risks beyond production risks (such as market prices), but the rate of increase in studies on multiple risks was less than the rate of increase in studies on single types of risk over the past two decades. The literature has focused less on institutional, personal, and financial risks, compared with production and market risks. The focus on production and market risks may also be related to the greater availability of open access data on weather and prices (Woodard, 2016; Coble et al., 2018). This focus has in turn shaped the methods available to study risk. Only a limited number of studies examined personal risk. One example was Zhen et al. (2005) who reported survey results from 270 farmers that implied cropping systems on the North China Plain are economically viable. These farmers also reported the over use and inappropriate handling of mineral fertilizer and pesticides, resulting in 20% of farmers reporting headaches and fatigue. These health problems are a concern for human welfare and may affect agricultural production through reduced work productivity. Quantifying these human health problems is a challenge, but identifying the risk is an important first step in quantifying the cost of the risk.

The extensive focus on production and market risks raises questions about whether the current literature adequately addresses the information needs of farmers, and the institutions and agencies working to assist them prioritize among all available options to cope with risk. These considerations suggest that a refocus of research towards studying strategies that address these additional sources of risk may be useful. This refocus would address concerns raised by several researchers about the limited focus on multiple sources of risk—see, for example, Chambers and Quiggin (2004) and Dercon (2008). Further, OECD (2009) argue because different types of risks are often linked, a holistic approach is needed to manage them. Without studying all the types of risks that farmers encounter, practitioners and policymakers will continue to have challenges identifying appropriate risk management options and policies. Yet, as discussed above, evidence seems limited about how multiple risks affect farm indicators and about the effectiveness of different risk management options. The few studies that jointly consider multiple sources of risk also suggests that the focus of the current literature is too narrow.

Many of the studies the examined multiple types of risk applied quantitative methods. For example, Lien (2003) examined the variability of gross margins on a Norwegian dairy farm and studied production and market risks through the examination of stochastic dependencies between prices and yields. Pacin and Oesterheld (2014) studied the combined effect of production and market risks on income stability of farmers in Argentina. Some studies have examined more than two risks jointly, often using simulation models that take a system view (Finger, 2012; Djanibekov and Finger, 2018). Taking a system (or

Table 3
Summary of studies that considered all five types of risk.

Reference	Geographic focus	Methods	Main activity	Main findings
Angelucci and Conforti (2010)	Grenada, Jamaica, Fiji and Vanuatu	Survey on perception of risk sources for stakeholders in value chains	Fruit, vegetable, and spices	Across the countries, price and production risks most important
Chand et al. (2018)	India	Survey on farmer perception of risk sources	Livestock	Increased feed costs greatest source of risk followed by extreme weather and delays in veterinary services
Girdziute et al. (2014)	Lithuania	Survey to construct a farm risk index using factor analysis	Mixed farming	Non-productivity sources of risk had highest loading in factor analysis
Glemarec (2017)	NA	Qualitative study on risk, climate-smart agriculture, and gender	Climate-smart agriculture	Structural barriers to gender equality are a source of risk for women, such as access to land
Flaten et al. (2005)	Norway	Survey on farmer perception of risk sources	Conventional and organic dairy	Uncertainty about the continuation of general government support payments most important source of risk
Iqbal et al. (2018)	Pakistan	Survey on farmer perception of risk sources	Cotton	Frequent changes in agricultural policies greatest concern followed by price of farm equipment and a lack of farm co-operatives
Jankelova et al. (2017)	Slovakia	Survey on farmer perception of risk sources	Mixed farming	Price risk greatest concern followed by production risk and then institutional risk
Karadas and Birinci (2018)	Turkey	Survey data and factor analysis to identify knowledge of risk sources	Bees	Financial risk is a concern in the presence of biotic stressors and theft
Lane et al. (2018)	United States	Qualitative perceptions of risk sources from farmer focus groups	Mixed farming	Non-climate risks more of a concern than climate
Lobos et al. (2018)	Chile	Survey on farmer perception of risk sources for managers and owners	Blueberry	Climatic events greatest concern followed by price and currency exchange rate fluctuations
Martin and McLeay (1998)	New Zealand	Survey on farmer perception of risk sources	Sheep and beef	Changes in government laws and policies most important source of risk
Meuwissen et al. (2001)	Netherlands	Survey on farmer perception of risk sources	Livestock	Price risk was the most important source of risk, followed by epidemic animal diseases and death of a farmer
Ndem and Osondu (2018)	Nigeria	Survey on farmer perception of risk sources	Cassava	Low rainfall greatest concern followed by lack of credit and then low prices
Thompson et al. (2019)	United States	Best-worst choice experiment with farmers for importance of risk types	Large commercial	Production, market, and financial risks a greater concern than personal or legal risks
Ullah et al. (2016)	NA	Narrative review on risk sources	NA	Importance of risks are context specific and influence adoption of risk-coping tools
Wauters et al. (2014)	Belgium	Survey on farmer perception of risk sources	Mixed farming	Major concern was policy and gap between expenses and receipts
Wauters et al. (2015)	Europe	Conceptual study	NA	Importance of off-farm employment for farm household risk balancing

Note: Studies retrieved from our literature search. NA means not applicable. Data from authors' literature search.

whole-farm) view through using simulation models has been considered one of the best approaches to examine risks since at least the 1970s (Hardaker and Lien, 2005). A recent example is the use of a recursive programming model to examine farmer responses to production, market, and institutional risks in Uzbekistan (Djanibekov and Finger, 2018). In this Uzbekistan example, production risks came from irrigation water variability and market risks stemmed from price fluctuations. Variability in irrigation water and prices were based on realized observations over time, and the institutional risks were considered using scenarios in the programming model. The institutional risk focused on farmers having land expropriated because of their failure to fulfill cotton production targets set by the government.

Among the 18 studies that considered all five major risk types, most examined how farmers perceive the importance of each type of risk using a ranking-based Likert scale. The importance of risk is context specific; for example market risks contributed more than production risks in explaining revenue variability among Californian and New Zealand farmers (Blank et al., 1997; Beukes et al., 2019). However, blueberry farmers in Chile were more concerned about production risk than market risk (sourced from price volatility) (Lobos et al., 2018). The studies on risk perceptions indicate that farmers make important distinctions between issues at the farm scale and farm household scale, with health risks for household members generating issues for the farm. Further, several studies reported that concerns about family relationships (including divorce) and the health condition of family members are important issues for farm households (Meuwissen et al., 2001; Lobos et al., 2018). Some of the 18 studies also canvassed the importance of risk management options. The farm scale versus farm household scale issue emerged again with off-farm income being one risk management option (Flaten et al., 2005). Using off-farm income is especially important in response to institutional risks, such as the hypothetical ending of all Common Agricultural Policy payments (Weltin et al., 2017).

4.2. Implications of the types of risk studied

The approach of initiatives by the World Bank and the International Fund for Agricultural Development aims to build the capacity to develop and implement comprehensive risk-related contingency plans and to promote the implementation of multiple strategies to manage risks. As Holling (1973) observed, these types of approaches do not require "a precise capacity to predict the future, but only a qualitative capacity to devise systems that can absorb and accommodate future events in whatever unexpected form they may take". Nevertheless, policymakers desire evidence on the joint effects of multiple risks and on the comparative efficiency of different risk management strategies. Therefore, studies that examine coping strategies and current and potential responses to multiple risks could supplement our understanding of decisions under risk and improve stakeholders' capacity to manage risk at the farm and policy scale. A retrospective look at responses by governments to the 2007/08 world food price crisis buttresses the need for more research on jointly managing multiple risks. Governments changed their storage and trade policies to help manage the price spikes during the crisis in a range of countries (including Brazil, South Africa, India, and China). In some cases, these policy changes stabilized domestic markets but destabilized global markets. One overall lesson from the crisis was that time could be spent between food price crises to generate evidence to help improve policy decisions (Pinstrup-Andersen, 2015).

Not all risks are equally important in specific contexts. For example, property rights are often more secure for land and water in developed countries, with Feder and Feeny (1991) arguing that institutions should be considered in developing countries when assessing how property rights effect resource allocations. Therefore, although we outline a need to examine multiple sources of risk jointly, the importance of each risk will differ by context. The effects of risk on farm indicators still need to be examined within specific contexts, if these effects remain unexamined the information available for prioritizing risk management options will remain limited. In addition, some sources of personal risks may be more relevant in developing countries because, for example, health insurance is often less available than in developed countries, and labor laws and occupational safety policies in developed countries are often more stringent and enforced. These laws and policies may result in farmers having less work-related injuries or less exposure to harmful levels of pesticides.

4.3. Challenges and opportunities for studying multiple types of risk

We advocate for a greater focus on studying multiple types of risk, but considerable challenges exist to further our understanding of the problem. Some of these challenges include access to relevant and reliable data, appropriate methods to account for the stochastic dependency between the different sources of risk, and how to obtain more relevant probabilities for risk research. Probabilities can come from either a frequentist view or a subjectivist view (Hardaker and Lien, 2010; Hardaker, 2016). The frequentist view considers probabilities as the limit of a relative frequency (Knight, 1921) and the subjectivist view sees a probability as the degree of belief in an uncertain proposition (Hardaker and Lien, 2010). Here we offer our thoughts on some of these challenges, mainly regarding data.

Often variance in gross margins, revenue, or income is an indicator of risk and this indicator is often examined as a single stochastic process (Lien, 2003; Delbridge and King, 2016), rather than as a joint distribution of separate stochastic variables for yields, prices, and costs. A single stochastic process is commonly used because greater levels of disaggregation can lead to an increase in the number of "messy" dependencies (Lien, 2003). As such one approach for examining production and market risk consists of using a time series of weather data to examine (often with a crop model) how weather variability affects farm production and then conduct a sensitivity analysis of the subsequent farm income to changes in prices or to use simulation models for scenarios related to risk types, such as institutional risk. However, the application of sensitivity analysis could be made more relevant for risk research if probability distributions for the risk types were specified (Pannell, 1997; Hardaker and Lien, 2005).

A priority for future research lies in developing databases that capture all five risk types and developing methods to account quantitatively for simultaneous changes in multiple types of risk. Databases available for risk research may be incomplete for the examination of all types of risks. For example, financial information at the household scale are absent in the main farm-scale accounting database in Europe (Wauters and de Mey, 2019), the Farm Accountancy Data Network (FADN), despite the FADN being a valuable source of panel data. Thus, the analysis of financial risk is impossible with data from the FADN. Improving data collection in agriculture is becoming a more visible issue, especially given the changing nature of the family farm and the increased complexity of the agricultural sector (National Academies of Sciences et al., 2019). Risk analysis is the "art of the possible" (Hardaker and Lien, 2005), and as such understanding which risks are important for farmers (not only for researchers) is a crucial step in risk analysis. Judging by the 18 studies that examined all five types of risk, farmers displayed a concern with all of them even though their importance is context specific.

Given the greater availability of open access data on weather and prices (Woodard, 2016; Coble et al., 2018), along with panel data tracking individual farms and farm households such as the FADN and the Living Standards Measurement Study, a possible path forward is to apply simulation models that have a core of production and market risk and conduct farmer-relevant "what-if" scenarios for institutional, personal, and financial risk. The coupling of these panel data that provide year-on-year variability in farm (and farm household) indicators with other data on risks, such as satellite data on weather or complementary surveys on institutional or financial risks and their probabilities, may help uncover trends between risks and indicators. These panel data often contain self-reported data on a range of risks, such as drought severity (production risk) and any deaths or major illnesses in the farm household (personal

risk). These trends could also provide data for the calibration and evaluation of simulation models and inform scenario design.

We recommend that "what-if" scenarios for risk analysis are informed by data on the probability distribution of the risk type, or at least the range of possible values for sources of risk are considered. Across the five types of risk, production and market risk data appear more readily available and could be viewed as having frequentist distributions, but data appear scarcer for institutional, personal, and financial risks where a subjectivist view may be more appropriate to generate probability distributions. When data are scarce, an option to develop probability distributions is to combine the frequentist and subjectivist views (Hardaker and Lien, 2010), here probability distributions are generated based on scarce data and expert judgments. Case studies that integrate the frequentist and subjectivist views are emerging (Bauermeister et al., 2018; Rojo-Gimeno et al., 2018). An understanding of Bayesian decision theory may also help researchers revise probability distributions after new information is obtained (Pannell, 1997), such as after the realization of an uncertain event.

5. Conclusion

Our study examines the trajectory of the literature on the types of agricultural risks studied since 1974. Starting with a literature search in the Web of Science, we identify 3283 studies on types of risk in agriculture. Unexpected events continue to effect farmers and we know that farmers manage multiple risks jointly. Thus, our study focuses on the distribution of studies by type of risk (production, market, institution, personal, and financial) and the number of studies that examined more than one type of risk. Our results reflect the types of risk that researchers have studied and do not necessarily reflect the importance of different risks as perceived by farmers. We found only a limited number of studies that examined multiple sources of risk. This limited number means that there may be opportunities to better align risk research with the needs of farmers who manage multiple risks jointly, and the agencies, institutions, and donors that work to support them. Adopting a multi-risk research agenda faces challenges, including the intense data requirements needed to understand how risks are connected. One pragmatic approach, among several options, is to use simulation models that combine observed data on weather variability and price volatility with the design of "what-if" scenarios related to institutional, personal, and financial risks. Some simulation models consider market risks through the use of a sensitivity analysis, but we require greater understanding of how to better account for the stochastic dependencies between types of risks and the probability distributions of variables for risk types, especially given the differences between the frequentist and subjectivist views on probabilities. Moreover, to use simulation models and conduct scenarios for combinations of types of risk, data on the effects of all the types of risk are required. Our results also highlight that the types of risk are often relevant at differing scales (farm versus farm household), with personal risks often stemming from the farm household scale (such as personal illness or changes in family relationships) but negatively effecting farm operations. This scale issue highlights the need for risk research to consider the interactions between on-farm production activities and household family members. Despite these challenges, our study raises the awareness of the apparent disconnect between risk research and the multi-risk realities encountered by farmers and policymakers. This greater awareness is a first step towards developing a research agenda that overcomes technical challenges in analyzing multiple risks, such as the stochastic dependencies between types of risk, and provides much needed information to farmers and policymakers regarding risk management priorities.

Data availability statement

The data and code required to replicate the figures and tables reported in the results section of this study are available online: http://dx.doi.org/10.17632/ppy2x4yy7k.1.

Declaration of Competing Interest

The authors declare no conflict of interest.

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