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2020-08-17

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http://hdl.handle.net/10026.1/15353

10.1080/00207543.2020.1725684
International Journal of Production Research
Taylor & Francis

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Risk analysis of the agri-food supply chain: A multi-method approach

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Abstract

Agri-food supply chains (AFSCs) are becoming more complex in structure, and thus more susceptible to different vulnerabilities and risks. Therefore, to enhance performance, we need to manage the risks in AFSCs effectively and efficiently. This study analyses various AFSC risks using a multi-method approach, including thematic analysis, total interpretive structural modelling (TISM) and fuzzy cross-impact matrix multiplication applied to classification (MICMAC) analysis. Based on the empirical data collected from experienced AFSC practitioners, eight categories of risks and 16 risk factors have been identified as important following thematic analysis. Further, the interrelationships among the identified risks were built using TISM. Finally, the identified risks were classified into various categories according to their dependence and driving power using fuzzy MICMAC analysis. The research results indicate that the weather-related and political risks have the highest driving power and are located at the lowest level in the TISM hierarchy. These risks have a high tendency to disturb the whole flow of AFSC, therefore, should be managed effectively. This study advances existing literature on identifying risk factors, defining interrelations between different AFSC risks, and determining the key risks. The risk analysis results can help AFSC practitioners in AFSC to identify, categorise and analyse the risks.

Keywords: agri-food supply chain; risk identification; thematic analysis; total interpretive structural modelling; fuzzy MICMAC

1. Introduction

Agri-food supply chains (AFSCs) are the linked events in the agricultural production of food, which involves all stages of production, processing, trading, distribution, and consumption, namely, "from farm to fork" (Food and Agriculture Organization 2018). Since these supply chains are responsible for providing sustainable, affordable, safe, and sufficient food, feed, fibre, and fuel to consumers, it is critical to ensure that these supply chains operate smoothly and successfully in the increasingly volatile business environment (KPMG 2013). However, designing such smooth and stable AFSCs is extremely difficult for operation managers due to the involvement of various risks and risk driving factors (Diabat et al. 2012; Esteso, Alemany, and Ortiz 2018).

An AFSC risk is defined as "the possibility of breakdowns, operational difficulties, and credit loss and economic losses due to various uncertain factors during the operation process of each and every nodal enterprise along the food supply chain" (Septiani et al. 2016, 52). Because of the increased complexity of international supply network relationships along the greater uncertainty in supply and demand, customer preference shift to higher quality products, more strict quality and safety standards, short shelf-life of agri-food products, and cost, and dependency on climatic conditions, the number of risks has been increasing (Baryannis et al. 2019; Leat and Revoredo-Giha 2013; Siddh et al. 2017; Vanalle et al. 2019). In an AFSC, risks are mostly related to weather, biological/environment (e.g., excess rainfall, pests, and diseases), logistical/infrastructure, market (e.g., labour shortage and volatile customer demand), policy/regulation, financial, and operational/managerial (Nyamah et al. 2017; Behzadi et al. 2018). These risk sources could disrupt the flow of goods and services, reduce the quantity of agri-food products, interrupt the access to international markets, and further threaten the performance of AFSC. To address the AFSC vulnerabilities and risks, various academics and practitioners have emphasised the management of AFSC risks from different perspectives such as risk identification, risk assessment, decision analysis, risk mitigation and contingency planning (Tang and Tomlin 2008; Ge et al. 2016). Mitigating AFSC risks will aid farmers, processors, distributors, wholesalers, and retailers to increase product freshness and the reliability of distribution services and decrease stock-outs and inventory levels (Ahumada and Villalobos 2009). However, most of the existing literature focuses on technical methods and capability to perceive, prevent, mitigate, and avoid diverse vulnerabilities and risks (Bachev 2017), with little research evaluating the interrelationships among different AFSC risks (Ho et al. 2015).

The study analyses AFSC risks comprehensively by identifying various risk factors, structuring interrelationships among them, and distinguishing key risks. Thus, three research questions are formulated: (1) What are the main risk categories and risk factors in the AFSC? (2) How are the identified risk factors interrelated? (3) What are the risks most adversely influencing the AFSC? By answering these research questions, this study provides insights into risk identification, classification, and factor analysis. The contributions of this study are as follows. First, it enriches the AFSC risk management literature by serving as a systematic guideline for academics and practitioners to identify, categorise, and analyse AFSC risks. Second, it will help AFSC practitioners to formulate different strategies to mitigate risks based on their classification and interrelationships. Third, some key risk management decisions could be made based on the identified key risks.

The remainder of this paper is organised as follows. In section 2, AFSC risks are identified through a comprehensive review of the literature. Then, the research methodology is discussed in section 3. Further, the data collection is presented in section 4 followed by data analysis and findings in section 5. Sections 6 and 7 are dedicated to the discussion and contributions, respectively. Finally, we draw conclusions and future research directions in section 8.

2. Literature review

Generally, there are risks hidden in all business activities (Pfohl, Gallus, and Thomas 2011), with AFSCs facing more challenges due to their unique characteristic such as perishability. Namely, AFSCs' managers need to coordinate management activities efficiently and effectively to maintain the quality and other performance standards (Moazzam et al. 2018). However, it is a difficult task for them, as risks may arise from diverse factors. For example, defective and risky products may be recalled because of contamination, with such recalls being costly and detrimental to firms' reputation and service quality (Marucheck et al. 2011). Simultaneously, risks may happen in different AFSC stages before the consumption of the final products such as production, storage, processing, and distribution (Nakandala, Lau, and Zhao 2017; Zhou et al. 2019), with significant and adverse effects on the supply chain performance (Blackhurst et al. 2005; Yang and Yang. 2010; Macdonald et al. 2018). The production process is associated with biological production, which is affected by weather variability, pests and diseases, seasonal factors, and price variability (Weintraub and Romero. 2006). In the processing stage, there are special risks associated with food quality and safety (Esteso, Alemany, and Ortiz 2018). For example, food contamination is the most serious of food safety-related risks that may occur in the production and processing stages, and may involve incidents that could constitute a public health emergency of domestic or international concern (Dani and Deep 2010). In the distribution stage, the agricultural market is particularly volatile, heterogeneous, and extremely sensitive to economic and financial fluctuations (Borodin et al. 2016). Further, the seasonality, supply spikes, and perishability attributes of agri-food products may cause substantial loss of product value if not properly handled in the packing, storage, and transportation processes (Behzadi et al. 2018). Therefore, developing a typology with a structured and detailed collection of risks is crucial for risk analysis and management.

The literature provides various definitions of supply chain risks (Wagner and Bode. 2006; Bogataj and Bogataj. 2007), with most of them either focusing on a specific function (Juttner, Peck, and Christopher 2003) or an element of the supply chain (Zsidisin 2003; Ellis, Henry, and Shockley 2010), and not considering the whole chain. This study uses the supply chain risks definition proposed by Ho et al. (2015, 5035) to identify risks in the AFSC: "the likelihood and impact of unexpected macro and/or micro level events or conditions that adversely influence any part of a supply chain leading to operational, tactical, or strategical level failures or irregularities." Potential risks in supply chains can be classified into different categories following different perspectives (Rao and Goldsby 2009; Rangel, Oliveria, and Leita 2015) such as low/high probability risks, high/low consequence risks, and internal/external risks (Kleindorfer and Saad. 2005; Kumar, Tiwari, and Babiceanu 2010). Besides, some studies have divided risks into three categories, namely, internal, network-related, and external risks (Lin and Zhou 2011). A further categorisation of risks is provided by Mason-Jones and Towill (1998) and Christopher and Peck (2004). Risks are classified into five types: (1) internal to the focal firm, which are process and control risks; (2) external to the focal firm, but internal to the supply chain network, which are demand and supply risks; and (3) external to the supply chain network, which are environmental risks. While all of these risks are relevant to the AFSC, operational and disruption risks of supply/demand are particularly pertinent (Behzadi et al. 2018). Considering the aforementioned arguments, three steps are followed to categorise the risks. First, we adopt a broad view on supply chain risk management (SCRM) to build a generic understanding of the risk categories and match various risk factors with appropriate categories. Second, we focus on AFSCs and add new categories to evaluate which risk factors should be incorporated or removed, and why. Third, we conduct pilot interviews with experts to further refine the results. Thus, the identified AFSC risks are categorised into nine categories: supply, demand, biological and environmental, political and macroeconomic, weather-related, logistical and infrastructure, policy and regulatory, financial, and management and operational risks (Jaffee, Siegel, and Andrews 2010; Nyamah et al. 2017).

Table 1 AFSC risks identified from literature

Risk types	Risk factors	References
Supply risks	(1) supplier bankruptcy; (2) volatility in fertiliser cost; (3) delay in securing financial support; (4) poor planning; (5) yield uncertainty; (6) supplier quality problem; (7) capacity fluctuations/shortages in the supply market;	Anton et al. (2011); Leat and Revoredo-Giha. (2013); Nyamah et al. (2017); Behzadi et al. (2018);
Demand risks	(1) insufficient information from customers; (2) volatile of customer demand; (3) market price volatility; (4) changes in food safety requirements;	Dani and Deep. (2010); Nyamah et al. (2017); Behzadi et al. (2018);
Biological and environmental related risks	(1) pests and diseases risk; (2) contamination related to poor sanitation and illnesses; (3) contamination affecting food safety; (4) contamination and degradation of production and processing processes;	Nyamah et al. (2017); Leat and Revoredo-Giha. (2013);
Political and macroeconomic related risks	(1) political instability, war, civil unrest or other socio-political crises; (2) interruption of trade due to disputes with other countries; (3) nationalisation/confiscation of assets, especially belonging to foreign investors; (4) changes in the political environment due to introduction of new laws or stipulations;	Nyamah et al. (2017); Yeboah et al. (2014);
Weather-related risks	(1) periodic deficit/excess rainfall; (2) extreme drought; (3) Flooding; (4) extreme wind; (5) cold weather; (6) hailstorms;	Nyamah et al. (2017); Leat and Revoredo-Giha. (2013);
Logistical and infrastructure related risks	(1) poor infrastructure and services; (2) volatility in fuel price; (3) unreliable transport; (4) changes in transportation; (5) lack of infrastructure and service units; (6) poor performance of logistics service providers; (7) lack of effective system integration; (8) labour disputes;	Nyamah et al. (2017); Yeboah et al. (2014);
Policy and regulatory risks	(1) stricter food quality and safety standards; (2) animal welfare legislation negatively affecting the competiveness; (3) potential restrictions on waste disposal; (4) weak institutional capacity to implement regulatory mandates;	Nyamah et al. (2017); Jaffee et al. (2010);
Financial risks	(1) uncertain trade, market, land and tax policies; (2) Inadequate financial support; (3) delay in payment and even possible non-payment; (4) change in exchange rate; (5) insufficient credit;	Anton et al. (2011); Bachev (2017); Nyamah et al. (2017);
Management and operational risks	(1) poor management decisions on asset allocation; (2) use of expired seeds; (3) poor quality control; (4) poor decision making in use of inputs; (5) farm and firm equipment breakdowns; (6) inability to adapt to changes in cash and labour flows (7) forecast and planning errors;	Yeboah et al. (2014); Anton et al. (2011); Nyamah et al. (2017);

Furthermore, various quantitative and qualitative research methods are applied to assess, control, and mitigate the negative effects of AFSC risks, including mathematical programming (Laeequddin et al. 2009), quantitative survey analysis (Wagner and Bode 2006), interpretive structural modelling (ISM) (Diabat et al. 2012), analytic hierarchy process (AHP) (Guan, Dong, and Li 2011), and case analysis (Leat and Revoredo-Giha 2013). Although all these methods have their advantages in analysing AFSC risks, yet each one has its own limitations. For example, AHP cannot effectively evaluate risk and uncertainty because it presumes the relative importance of risks (Chan and Kumar 2007), while ISM only assists in providing answers to the “what” and “how” questions and unable to answer the “why” in theory building (Jena et al. 2017). However, it is interesting to note that though total interpretive structural modelling (TISM) has an advantage over ISM in answering the “why” question, and has been applied in different areas such as cloud computing (Amma et al. 2014), construction (Sandbhor and Botre 2014), flexible manufacturing systems (Jain and Raj 2015), and smartphone manufacturing ecosystems (Jena et al. 2016). However, there is no existing study on the agri-food industry that has used TISM to identify the interrelationships among different AFSC risks. Qualitative methods are mainly used for identifying or categorising risks, and constructing SCRM ideas (Cavinato 2004), whereas quantitative methods are used for risk assessment (Sodhi 2005). Table 2 summarises some of the most widely used research methods in the AFSC risk research.

Table 2 Typical research methods for AFSC risks

Author(s) (year)	Topic focus	Research methods	Theoretical/ empirical	Qualitative/ quantitative
Ritchie and Brindley (2007)	Risk mitigation	Case study	Empirical	Qualitative
Wagner and Bode (2008)	Risk identification and analysis	Ordinary least square regression model	Empirical	Quantitative
Laeequddin et al. (2009)	Risk assessment	Multiple regression model	Theoretical	Quantitative
Pujawan and Geraldin (2009)	Risk assessment and mitigation	Failure mode and effect analysis	Theoretical	Quantitative
Dani and Deep (2010)	Risk mitigation	Case study	Theoretical	Qualitative
Dowty and Wallace (2010)	Contingency planning	Case study	Empirical	Qualitative
Christopher et al. (2011)	Risk analysis and mitigation	Case study	Empirical	Qualitative
Guan et al. (2011)	Risk identification	Analytic hierarchy process	Theoretical	Quantitative
Zhang et al. (2011)	Contingency planning	Simulation	Theoretical	Quantitative
Diabat et al. (2012)	Risk assessment	Interpretive structural modelling and case study	Empirical	Qualitative
Baghalian, Rezapour, and Farahani (2013)	Risk analysis	Integer nonlinear programming	Theoretical	Quantitative
Leat and Revoredo-Giha (2013)	Risk identification and contingency planning	Case study	Empirical	Qualitative
Ren et al. (2015)	Risk assessment	Shapley value method	Theoretical	Quantitative
Septiani et al. (2016)	Risk identification, assessment and mitigation	Literature review	Theoretical	Qualitative
Behzadi et al. (2018)	Risk mitigation	Literature review	Theoretical	Qualitative
Esteso et al. (2018)	Risk mitigation	Literature review	Theoretical	Qualitative
Moazzam et al. (2018)	Risk assessment	Case study	Empirical	Qualitative
Zhou et al. (2019)	Risk mitigation	Case study	Empirical	Qualitative

Based on the literature review, this study identified a number of research gaps, which open avenues for further research:

1. Although AFSC plays an important role in the world economy as a key source of food supply, there has been a significant lack in empirical studies on identifying AFSC risks in AFSC. Recent literature review articles on SCRM such as Ho et al. (2015) showed that only 10 papers out of 90 considered the risks in AFSC, indicating a clear demand for research on empirical AFSC risk analysis.
2. The existing work has mainly focused on the risk analysis, assessment, and mitigation. However, there is a lack of studies defining the correlations among different AFSC risks (Ho et al. 2015; Behzadi et al. 2018). More research is required to explore the interrelations among various AFSC risks since the hidden effects of one risk related to other risks may cause substantial damages to AFSCs (Chopra and Sodhi 2004).
3. The existing literature mostly uses a single method, adopting either a qualitative or a quantitative approach. For example, most of the aforementioned studies (Ritchie and Brindley 2007; Dani and Deep 2010; Christopher, Mena, and Yurt 2011; Moazzam et al. 2018; Zhou et al. 2019) applied qualitative methods for risk mitigation and assessment. They focused on either examining the implications of risk factors or summarising risk mitigation methods. Only one study (Diabat et al. 2012; Micheli, Mogre, and Perego 2014) adopted a case study approach and ISM to investigate the impact of one risk on another from an agri-food company perspective rather than the whole AFSC perspective. Combining these two qualitative methods has some limitations to identify the causes in theory building because the causality between different risks cannot be explained. Furthermore, from 2003 to 2013, the number of

studies using quantitative methods was almost four times the number of those applying qualitative methods in the SCRM field (Ho et al. 2015). Thus, there is a need to explore the integration of multiple qualitative approaches to tackle the complexity of AFSC risks.

The novelty of this study resides on the empirical investigation of AFSC risks in four countries over one year, which enriches the empirical literature on these risks. Additionally, we adopt a rigorous methodology and use multiple data analysis techniques. Further, we investigate the interrelationships among AFSC risks. The findings of this study help to fill the aforementioned research gaps.

To fill the research gaps in the existing literature, we analyse the risks by defining the interrelationships among risk factors and revealing the impact level of each risk using a multi-method approach with empirical data collected from experienced AFSC practitioners across Argentina, France, Italy and Spain.

3. Research methodology

Interpretivism is adopted in this study to gain a deep understanding of the phenomenon and its complexity in its unique context (Creswell. 2014) by accepting multiple viewpoints of different individuals from different groups (Saunders, Lewis, and Thornhill 2015). Thus, interpretivism is more suitable than other research philosophies for investigating complex issues and management realities. As an AFSC is a complex web of interconnected entities working collaboratively to make food available for consumers (Dani. 2015), a comprehensive and deep understanding of AFSC risks can be reached only by probing AFSC practitioners' thoughts, values, prejudices, perceptions, views, feelings and perspectives (Wellington and Szczerbinski 2007; Morehouse. 2011). Therefore, interpretivism is suggested to be adopted in this study. Researchers believe that there is a tight connection between interpretivism and inductive reasoning (Silverman. 2000; Willis. 2007). Quantitative approaches are largely based on deductive reasoning, while qualitative approaches are based on inductive reasoning. Qualitative research has been approved as an effective strategy to study participants' meanings and the relationship between them by using a variety of data collection techniques and analytical procedures (Saunders, Lewis, and Thornhill 2015), whereas quantitative research has been approved useful for testing objective theories by examining the relationship among variables (Creswell. 2014). Furthermore, qualitative research allows the researchers to investigate the participants' inner experience, and to figure out how meanings are shaped through and in culture (Corbin and Strauss 2014). Thus, a qualitative approach, rather than a quantitative one, is adopted in this study to obtain the AFSC experts' opinions on the AFSC risks, understand how these risks influence each other, and identify the key risks, since such opinions are difficult to capture using quantitative methods. Figure 1 illustrates the research methodology framework for this study.

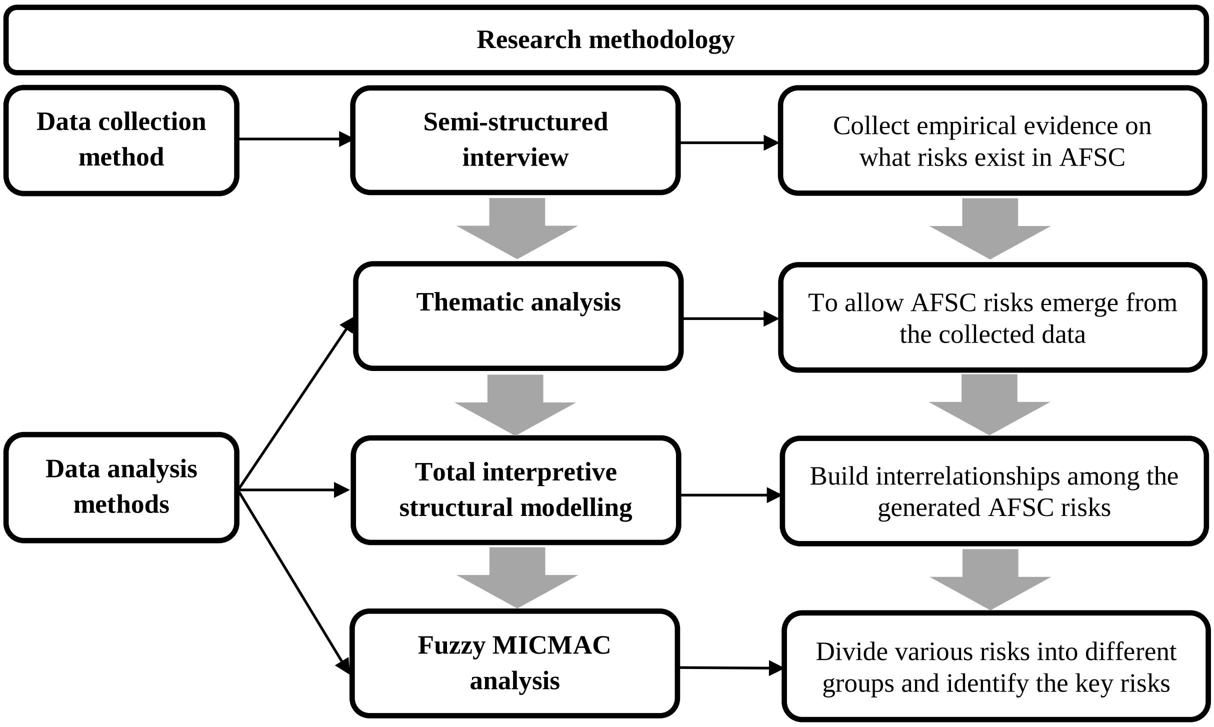

Figure 1 Research methods adopted

3.1 Data collection method

The semi-structured interview is the most widely used interviewing format for collecting empirical data, especially for answering questions that are either complex or open-ended (Dicicco-Bloom and Crabtree 2006). A critical advantage of semi-structured interviews is their ability to acquire unknown information/knowledge (O'Keeffe et al. 2016). When interviewees are provided with sufficient opportunities to speak freely, novel information/knowledge can emerge (Saunders, Lewis, and Thornhill 2015). Compared with other interviewing format such as structured interview and unstructured interview, semi-structured interview well-suited for the exploration of the perceptions and opinions of respondents regarding complex and sometimes sensitive issues and enable probing for more information and clarification of answers (Barriball and While 1994). Thus, the semi-structured interview is selected in this study to obtain AFSC managers' opinions regarding AFSC risks. To obtain valid and complete data during the interviews and get an understanding of the subject domain being explored, a review of the existing literature on AFSC risk identification, classification, assessment, and mitigation was conducted before the empirical data collection. Then, an interview guide was developed. After identifying potential respondents, pilot interviews were conducted before empirical data collection. Additional risk management documents such as risk memos, solution designs, enterprise brochures, and functional documents were collected as replenishment of data sources to achieve triangulation.

3.2 Data analysis methods

The empirical data collected through semi-structured interviews were analysed using a combination of three methods, namely, thematic analysis, TISM, and fuzzy MICMAC analysis. A multiple data analysis methods was adopted in this study as it helps to unpack different possible meanings from a single dataset (Clarke et al. 2015), as well as to balance the strengths and limitations of individual methods against each other (Frost et al. 2011). Thematic analysis is a qualitative data analysis technique used "for identifying, analysing, and reporting patterns (themes) within data" (Braun and Clarke 2006, 79). It helps researchers to conduct qualitative analysis independently and reliably (Vaismoradi, Turunen, and Bondas 2013). In addition, it has three distinct advantages, namely, it can summarise key features of a large body of data with a minimum description, highlight similarities and differences across data sets, and generate unanticipated insights (Braun and Clarke 2006). Compared with other qualitative data analysis methods such as discourse analysis and conversational analysis, thematic analysis is a clear and uncomplicated method that does not need theoretical details and technical knowledge (Javadi and Zarea 2016). Thus, thematic analysis was selected as the first data analysis technique to reveal risk themes.

Afterwards, TISM was chosen to build interrelationships among the identified AFSC risks since it is an effective approach to establishing interactions among various elements and their degrees of association (Jayalakshmi and Pramod 2015). TISM is a well-developed method and has been extensively used in different contexts for building relationships among different elements (Jain and Raj 2015; Yadav and Sushil 2014). To build relationships between different elements, TISM is a suitable approach as pointed out by Sushil (2012). TISM is a technique that evolved from interpretive structural modelling (ISM). Both ISM and TISM can identify the interrelationships among the considered variables; however, the interpretation for direct links is comparatively weak in ISM and may misrepresent the entire decision-making process (Jena et al. 2017). Other methods such as DEMATEL (Decision making trial and evaluation laboratory), graph theory, ANP (Analytic network process), SEM (Structural equation modelling) can be employed to reveal the interdependence among the factors, but due to their drawbacks, they cannot be applied in this study. For example, DEMATEL is limited in dealing with problems of uncertainties and the bias of associated with human judgement (Si et al. 2018); graph theory is limited in deciding the direction of relationships between factors (Bondy and Murty 1976); ANP has limited applicability due to its complex procedure, whereas SEM needs a large sample size to apply (Mangla et al. 2018). Thus, TISM was selected to transform poorly articulated mental models into well-systematic forms. Consequently, it facilitated answering all of the theory building questions (Yadav and Sushil 2014).

Finally, the fuzzy MICMAC analysis was used to identify the key risks in various categories based on the influence of the risks and validate the TISM model of AFSC risks. The MICMAC analysis was initially developed to investigate binary types of relationships among different elements. To increase the sensitivity of the MICMAC analysis, the fuzzy set theory was introduced as an additional input of interaction possibility among the elements (Bhosale and Kant 2016). The inclusion of fuzzy set theory in TISM-MICMAC can beneficial when a large number of elements are included for analysis (Yadav and Desai 2017). Currently, sixteen AFSC risk factors are included in the present research work. Compared to the conventional MICMAC analysis, the fuzzy MICMAC analysis can analyse the interrelationships among elements precisely. Although there are other methods such as IRP (Interpretive ranking process) and AHP can assist in determining the relative importance of factors, they either fails on the part of consistency in experts' feedback or have limited applicability for pairwise matrix of more than 9×9 (Mangla et al. 2018). Thus, the fuzzy MICMAC was selected as it can critically analyse the scope of each element, considering the strength of the relationships among the elements (Bhosale and Kant 2016).

Considering the advantages offered by thematic analysis, TISM, and fuzzy MICMAC analysis, these approaches were combined together to analyse the AFSC risks in this study.

4. Empirical data collection

This study collects empirical evidence from experts who have been involved in AFSC risk management. The semi-structured interview was used to collect data on AFSC risks. Thus, an interview guide was developed to keep the focus of the discussion on the topic, with the questions being focused on obtaining the participant’s opinions on the AFSC risk sources they have experienced. The interview guide consists of five sections (see Appendix A). It starts asking general information about the interviewee and the company, and then specific questions about the relations with upstream and downstream companies. Additionally, it has two specific sections asking about the risks that the company and the whole AFSC have faced. Finally, questions are asked about how risks are mitigated. Interviewees could express their ideas freely regarding the context being discussed. Furthermore, many probing questions are asked to get interviewees to clarify their answers as necessary.

Purposive sampling and snowball sampling (Saunders, Lewis, and Thornhill 2015) were used in this study to recruit suitable participants. Purposive sampling was performed initially to identify suitable participants who were thought to be knowledgeable about AFSC risks. Criteria for recruiting suitable participants were: (1) The participants should come from the agri-food industry and be directly involved in AFSC risk management; (2) they must have more than 10 years working experience in AFSC risk management to ensure a high level of knowledge and experience; (3) the selected company must be either a medium- (from10 to 249 employees) or large-sized company (more than 249 employees), since these companies have rich experience and deep understanding of managing AFSC risks. Normally, there are no criteria for the sample size because they depend on the complexity of the research questions, the interview topic, the diversity of the sample, and the nature of the analysis (Saunders, Lewis, and Thornhill 2015). Francis et al. (2010) suggested at least 10 interviews should be conducted in the initial sample analysis. As a first step, 14 participants were selected using a purposive sampling technique. The data collection process started with a wholesale distribution company in southern France which is a focal company in the local AFSC and has good connections with local upstream and downstream partners. Afterwards, we used snowball sampling to identify additional participants. Based on the criteria for recruiting participants (see above), some companies were found to be not suitable for this study, which resulted in only two potential participants being identified. After conducting further two interviews, new themes did not emerge, indicating reaching the data saturation point; thus, we stopped conducting further interviews, which made the total sample size 16 participants. Detailed information of each interviewee is shown in Table 3, including the interviewees’ countries and companies, their positions in their companies, and the role and responsibilities of their companies in the AFSC.

Table 3 Detailed information of the interviews

Country	Company	Interviewees' position	Role and responsibility in AFSC
Spain	A	Project manager	**Input supplier**: (1) Advising on research and development of agri-food; (2) Transferring the scientific results obtained, and maintain relations with the agri-food sector.
	B	Director	**Cooperative**: (1) Fully involved in aspects of food safety and quality, guarantee in all cases compliance with the established legal requirements and thus securing food with the level of safety demanded by both the market and consumers.
	C	Co-owner	**Food processor, wholesaler, and distributor**: (1) Suppliers of major national and international supermarkets;
	D	Director	**Retailer**: (1) Require the participation of professionals in agriculture through implementing agricultural policy; (2) Securing the farmers' interest and promoting their profitability.
France	A	Marketing manager	**Input supplier**: (1) Developing new varieties of vegetables, mainly on cauliflower, artichokes, shallots, onions.
	B	Operation director	**Input supplier**: (1) Specialising in agricultural equipment and management of rural areas through collaborating with professional agricultural organisations and thousands of cooperatives.
	C	Director	**Farmers**: (1) Cultivating plants to generate a weaker consumption of inputs and impacts more in favour of biodiversity, health and environment; (2) Cultivating different plants to improve the business cluster competitiveness.
	D	Director	**Cooperatives**: (1) Formulating agriculture policies of their regions.
	E	Director	**Food processor, wholesaler, and distributor**: (1) Supporting shippers and distributors; (2) Monitoring consumer trends; (3) Developing packaging formats and innovative solutions in respond to the network demand.
Italy	A	Project manager	**Cooperatives**: (1) Providing information and training opportunities for farmers and agri-food companies; (2) Dissemination of good agricultural practices;
	B	Operation manager	**Food processor**: (1) Building direct relationships with local farmers and doing a business in the field of vegetable extracts.
Argentina	A	Co-owner	**Input supplier**: (1) Mainly responsible for selling agri-chemical and various types of seeds to farmers.
	B	Director	**Input supplier**: (1) Mainly responsible for transferring agricultural knowledge to farmers.
	C	Owner	**Farmers**: (1) Mainly responsible for producing different kinds of vegetables such as tomatoes, eggplants, cucumbers.
	D	Director	**Cooperative**: (1) Disseminating good agricultural practices and providing quality certificates to farmers; (2) Providing training courses for farmers, especially for smallholders.
	E	Director	**Wholesaler, distributor, and retailer**: (1) A platform for farmers to sell their products in this market, 20% of vegetables and fruits production in Argentina are sold there.

The interviews were conducted between April 2017 and July 2018 in four different countries - France, Spain, Italy and Argentina. The agricultural output of France, Spain, and Italy accounts for 16.7%, 12.1%, and 11.7%, respectively, of the total agricultural output of the 28 European Union countries (European Commission 2018). As for Argentina, the whole agro-industrial transformation sector is estimated to be 32% of GDP (Regunaga and Tejeda Rodriguez 2015). The important role of agriculture in these four countries provides a good opportunity to explore AFSC risks. As these four countries are located in both the southern and northern hemispheres, it was worthy for the authors to visit them to investigate potential risks. In the summer and autumn seasons, AFSC practitioners in the four countries experience more biological and environmental, weather-related, and logistical and infrastructure risks. However, they experience more supply and demand risks in the winter and autumn seasons. The interviews with managers, directors and middle management in the agri-food industry provided a robust opportunity to explore risks in depth, and allowed interviewees to elaborate on specific risks, problems and implementation practices to reduce risks. A copy of the interview guide was sent to the interviewees three days before the interview session, which gave them a clear understanding of the questions they may expect in the interview. Interviews lasted for 60 to 90 minutes on average with the interviewees being encouraged to express themselves on any questions asked to facilitate the revealing of new concepts.

5. Data analysis and findings

This section presents the mechanism by which thematic analysis of the data collected from the semi-structured interviews generates various themes (risks). Then, the TISM method is applied for modelling the interrelationships among the identified AFSC risks. Finally, the fuzzy MICMAC analysis is performed to analyse the dependence and driving power of AFSC risks to identify the key driving risks.

5.1 Themes (risks) generated through thematic analysis

The thematic analysis conducted in this research consists of six steps, as shown in Figure 2: familiarisation with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. Verbatim transcriptions were carefully read and edited to ensure the removal of irrelevant data, and then the initial codes were generated. To achieve reliability, two coders were involved in the process, which resulted in an intercoder reliability of $k = 0.81$ (Cohen 1960). All coded data were validated by the companies that were involved in the semi-structured interviews to ensure the integrity of the results derived from these interviews and risk memos. The next step involved searching for themes through evaluating the relationships between codes, between themes, and between main themes and sub-themes, and then sorting and organising all relevant codes into potential themes until all possible themes, sub-themes, and related codes were generated. Afterward, we checked whether themes were suitable for the extracted codes and the entire dataset, generating a thematic map. After reviewing the themes, an ongoing analysis was performed to ensure that there were clear definitions and names for each theme. Finally, we selected vivid, compelling extract examples to produce an analysis report.

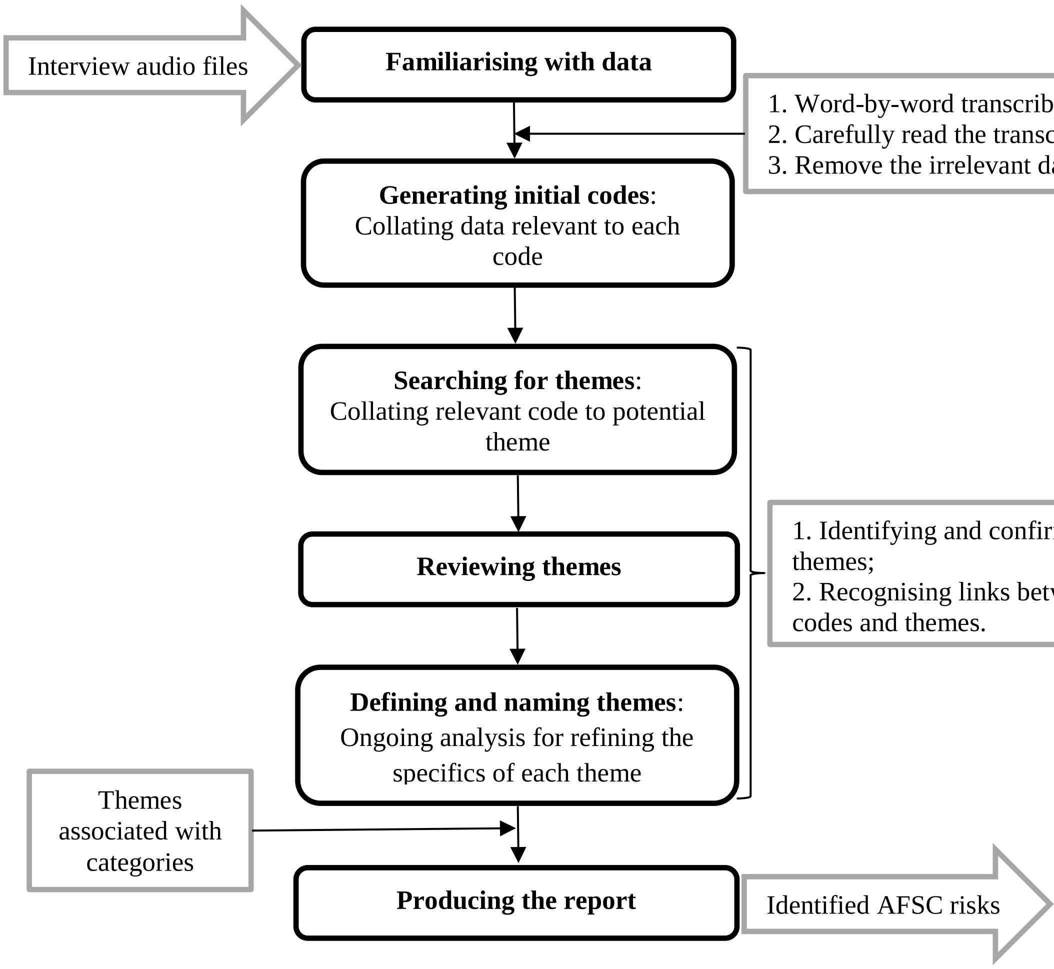

Figure 2 Thematic analysis process

We used first- and second-order codes, as proposed by King and Horrocks (2010), while generating risk themes. (1) Descriptive coding (*first-order codes*): the transcript data from interviews were allocated to suitable descriptive codes. (2) Interpretive coding (*second-order themes*): the descriptive codes that seemed to have some common meanings were grouped together, with an interpretive code being created to capture them. (3) Overarching themes (*aggregate dimensions*): a number of overarching themes that characterised the key concepts in the analysis were identified.

Table 4 presents an overview of the empirical evidence for different risk types, linking first-order codes, second-order risk factors, and the supporting evidence from each interview case. The first-order codes are direct quotes from the interview transcripts (see column one), while the second-order themes are the risk factors that represent the first-order codes (see column two). The third column indicates the presence or absence of evidence obtained from the interview cases. A tick (√) represents the presence of evidence, whereas no ticks represents no evidence (see column three). Finally, the aggregate dimensions reveal the main AFSC risk types (see column four).

Although a number of risk factors were identified in the literature (compared to table 1), the empirical findings still revealed some additional risk factors existing in the current AFSC practices. For example, oral contract or agreement with partners, skill shortage, tax evasion, and the lack of investment in promoting agri-food products in the management and operational risk category, and the rapid technological development in the logistical and infrastructure risks category. It is interesting to note that no policy and regulatory risks were identified through the empirical study, as may be all the interviewees were experienced people who have been working in the AFSC for many years, thus misapplication of the systems or standards was unlikely.

Table 4 Empirical evidence for identifying AFSC risks

First-order codes	**Second-order themes/AFSC risks**	**Support from cases of AFSC risks**																**Aggregate dimensions**
		Spain				**France**					**Italy**		**Argentina**					
		A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**A**	**B**	**C**	**D**	**E**	
"…Sometimes, we may share some information, but we are reluctant to share information with them".	Lack of information sharing among partners	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	Supply risks
"There is no agreement/discussion among farmers about how much they need to produce… Another risk is that there are no clear plans for against diseases and pests".	Poor planning	√	√	√	√	√	√		√	√	√	√	√	√		√	√	
"Another problem is the supply and demand. If you provide a large amount of products, you may not be able to sell the products. This is the problem of the supply and demand".	Supply and demand imbalance	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	Demand risks
"Within the market risk … demand and supply can affect the price. Sometimes, there is too much production, which means the price will decrease".	Market price fluctuations	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
"Some customers do not even have a bank account or maybe cannot apply for a credit from the bank, so they cannot pay on time".	Delay in payment		√	√		√	√	√	√	√	√	√	√	√	√	√	√	Financial risks
"…There is a financial and economic risk that some distributors may not pay to us. So if one of them is not paying us, we will be careful when selling agri-food products to them next time".	Bad debts		√	√	√	√	√	√	√	√	√	√	√	√	√		√	
"The second risk is skill shortage. The number of skilled workers in this area is decreasing as time pass by, to be left with low-skilled workers".	Skill shortage	√	√	√	√		√		√	√	√	√	√		√	√	√	Management and operational risks
"…Not all the farmers pay their labour taxes…because the control system here is not so strict. So this is the problem that you can get a fine - a very huge fine…"	Tax evasion		√	√		√	√				√		√	√	√	√	√	
"…In the past, people who worked in the shops would be knowledgeable and motivated to sell vegetables and fruits. Now, the people who are working there just wants to get some income, and they may not be knowledgeable and very motivated to sell products".	Lack of investment in promoting agri-food products	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	
"…They negotiate with each other on how much each family should pay for renting the land, there is no paper work of the agreement since they do not need to sign an agreement to say that you are going to pay this and you are going to pay that".	Oral contract or agreement with partners		√	√		√					√	√	√	√	√	√	√	
"The most important thing is to know is that there were four political and economic changes from 1989 to 2016 which had an impact on the agriculture value chain".	Political and economic instability	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	Political and macroeconomic risks
"The expenses are mainly the electricity fee because the water is free. We get water from the underground, so it is free. It is quite a lot of electricity fee – 3000 dollars per month in summer…"	High energy costs	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	Logistical and infrastructure risks
"Obviously, the channels, routes and transportations have been improved over the last year… Therefore, there is an opportunity for producers to sell products to further places."	Poor agricultural infrastructure	√	√	√	√		√	√		√	√	√	√	√	√	√	√	
"As the time passes by, there are more innovations. In the past, we needed to do three things with three machines. Now, we only need one machine to do everything".	Rapid technological development	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
"We have all types of risks in here…Biological risk such as pests and diseases' risk…"	Pests and diseases' risk	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	Biological and environmental related risks

“During the last ten years, we had very big thunderstorms. Some big thunderstorms destroyed all the mainly green houses. Today, I think this is the main risk for us”.	Extreme weather conditions	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	Weather-related risks

5.2 Risk hierarchy model built from TISM analysis

The risk factors generated from the thematic analysis were used as inputs to process the TISM analysis to build a risk hierarchy model consisting of nine steps, as illustrated in Figure 3.

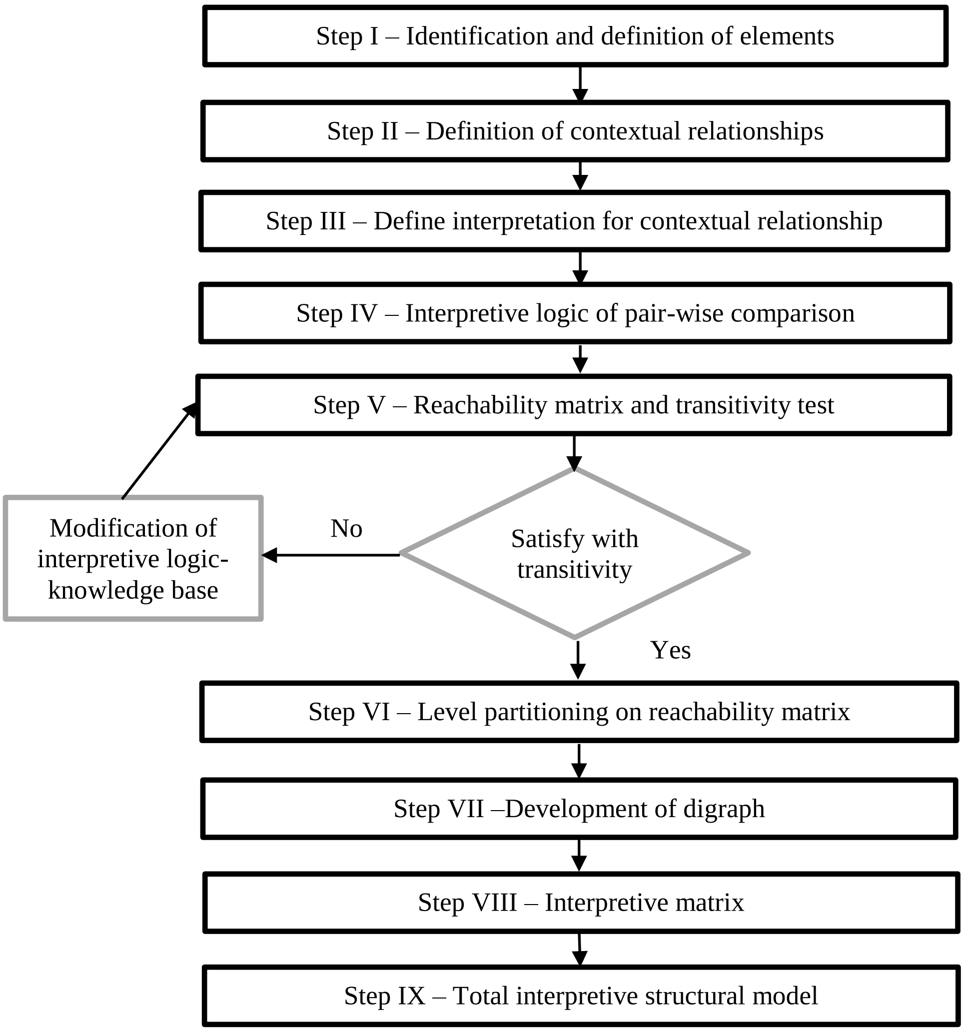

Figure 3 TISM analysis process (Note: Modified from Sushil (2012))

1. Identification and definition of elements: Sixteen AFSC risk factors that were identified through a thematic analysis were used as inputs to process the TISM analysis.
2. Definition of contextual relationships: The contextual relationship between two AFSC risks is defined as "Risk A will influences/causes Risk B."
3. Interpretation of relationships: Eight experts involved in the semi-structured interviews were selected based on their nationality, working experience, job specialisation, and current management level, to obtain their opinions on whether the relationship "Risk A will influences/causes Risk B" actually exists or not (Yes or No). Janes (1988) suggested that it is essential for the participants to have the necessary technical knowledge.

4. Interpretive logic of the pair-wise comparison: An "interpretive logic-knowledge base" was developed for a pair-wise comparison of the 16 identified AFSC risks. There are in total 240 (i.e., 16 *16 - 16 = 240) rows in the knowledge base for implementing this study.

5. Reachability matrix and transitivity test: An initial reachability matrix of AFSC risks was developed from the interpretive logic-knowledge base by entering "1" for the "Yes" and "0" for "No" (see Appendix B). Then, we checked the initial reachability matrix for transitivity rules and further converted it into a final reachability matrix (see Appendix C). The transitivity rules are that: if element "A" relates to element "B" and element "B" relates to element "C," then it is implied that element "A" necessarily relates to element "C."

6. Level partitioning of the reachability matrix: The final reachability matrix obtained from the previous step was partitioned into different levels based on the reachability and antecedent sets for each element through a series of iterations (Singh and Sushil 2013). The level partitioning was performed until the levels of all AFSC risks were determined. The partitioning process of AFSC risks is illustrated in Appendix D. Lastly, the 16 AFSC risks were partitioned into nine levels (I to IX), as shown in Table 5. These determined levels were utilised to develop a digraph and a TISM-based hierarchy model.

Table 5 Final levels of each agri-food supply chain risk

Code	AFSC risks	Level
E3	Skill shortage	I
E4	Market price fluctuations	I
E5	Tax evasion	I
E11	Oral contract or agreement with partners	I
E7	Lack of investment in promoting agri-food products	II
E8	High energy costs	II
E1	Delay in payment	III
E2	Bad debts	III
E16	Rapid technological development	III
E10	Supply and demand imbalance	IV
E6	Pests and diseases' risk	V
E9	Poor planning	VI
E13	Lack of information sharing among partners	VII
E12	Poor agricultural infrastructure	VIII
E14	Extreme weather conditions	IX
E15	Political and economic instability	IX

7. Development of the digraph: For visualisation purposes, the 16 AFSC risks were depicted as a digraph in which direct links were drawn as per the relationships shown in the final reachability matrix, with dotted lines being used to represent significant transitive links in the digraph.

8. Interpretive matrix: Through translating all interactions in the digraph by 1 in the respective cell, a binary interaction matrix was developed. The cells with a "1" entry were interpreted by selecting the appropriate interpretation from the knowledge -base in the form of an interpretive matrix (Jayalakshmi and Pramod. 2015).

9. A total interpretive structural model of AFSC risks: The relevant and interpretive information from the interpretive matrix and digraph were used to develop the TISM hierarchy model of AFSC risks, as shown in Figure 4. The interpretation of each link was written on the line representing the respective links in the TISM hierarchy model.

The TISM analysis of AFSC risks resulted in a TISM model of nine levels. It can be observed that extreme weather conditions (E14), political and economic instability (E15), poor agricultural infrastructure (E12), pest and disease risk (E6), poor planning (E9), lack of information sharing among partners (E13), and supply and demand imbalance (E10) constitute levels four to nine in the TISM hierarchy model. While delay in payment (E1), bad debts (E2), and rapid technological development (E16) are at the third level followed by the lack of investment in promoting agri-food products (E7) and high energy costs (E8) occupy the second level. Finally, market price fluctuations (E4), skill shortage (E3), tax evasion (E5), and oral contract or agreement with partners (E11) constitute the first level in the TISM hierarchy model. The TISM model demonstrates that extreme weather conditions and political and economic instability are the biggest threats to the AFSC, since they cause poor agricultural infrastructure. Poor infrastructure such as the lack of advanced information and communication technologies make the AFSC practitioners reluctant to share information among partners. Thus, the lack of information sharing and its direct result of poor planning are common phenomena in AFSC. Simultaneously, lack of a long-term planning to against pests and diseases makes agri-food products susceptible to them, resulting in less production and more investment in pest and disease research. Therefore, more projects will be conducted to facilitate technological development. It is important to note that pests and diseases cause high energy cost because more water and energy should be used to tackle this problem. Furthermore, poor planning aggravates the supply and demand imbalance. The drop in agri-food products' prices causes a reduction in the AFSC practitioners' income. Therefore, AFSC practitioners always experience delays in payments and even bad debts, thus lacking the money to organise training sessions for employees, avoiding paying labour taxes, and lacking investment in promoting agri-food products.

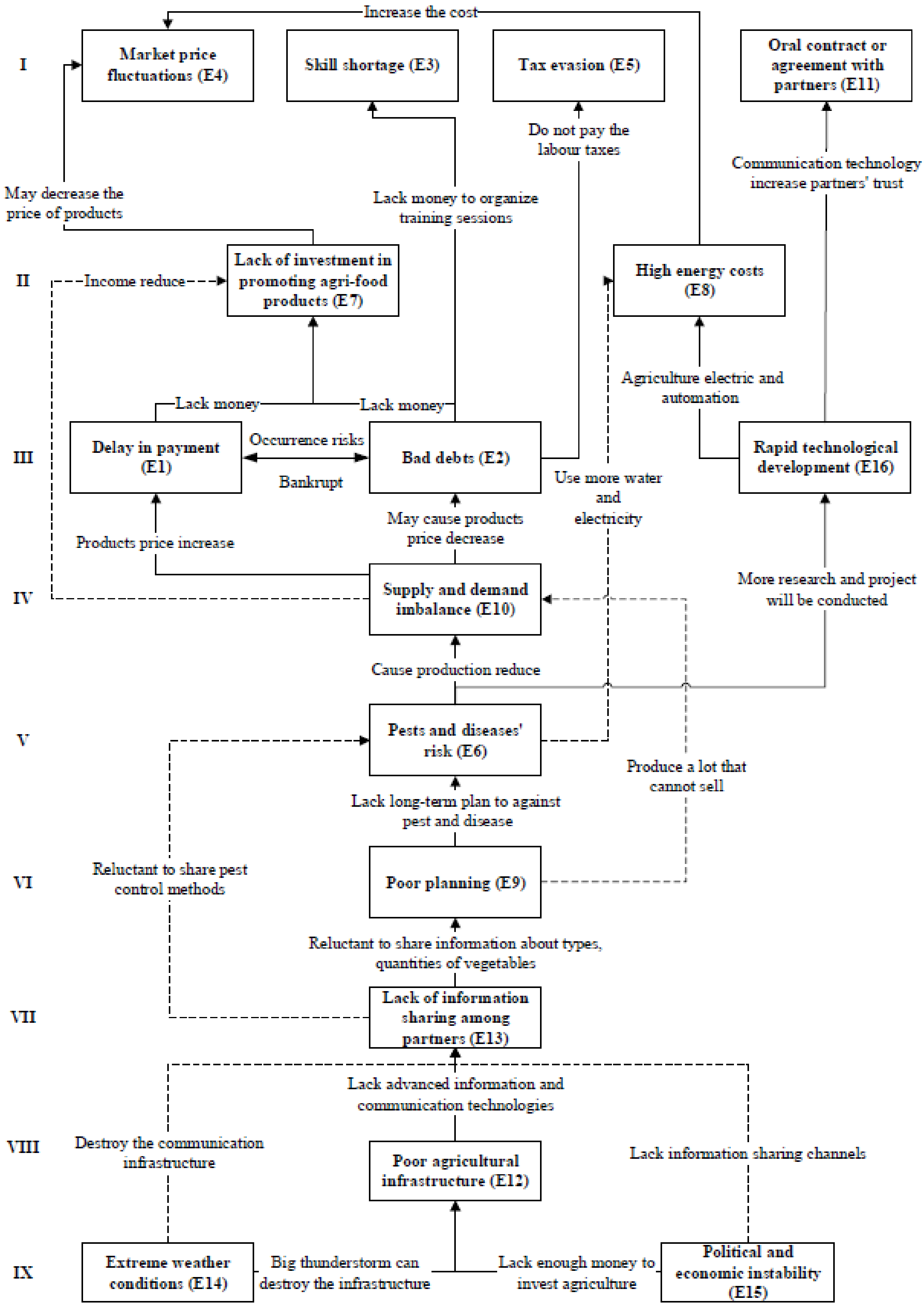

Figure 4 TISM model of AFSC risks

The TISM hierarchy model of AFSC risks, which shows direct and transitive relationships between various identified risks factors, will improve the performance of AFSC by avoiding an increase in the level of some risks when other risks are mitigated.

5.3 Fuzzy MICMAC analysis: classification of AFSC risks

The TISM hierarchy model is developed by computing the relationships between two AFSC risks as “0” or “1”. If there is no relationship between two AFSC risks, then it is denoted by “0”; whereas if there is a relationship, then it is denoted by 1. However, the relationships between these risks cannot always be equal. Some relations may be strong, some may be significantly strong, while other relations may be weak (Yadav and Barve 2016). To overcome the drawbacks of the TISM model, the fuzzy MICMAC analysis was used by assessing the strength of relationships to increase the sensitivity of the analysis rather than the mere evaluation of relationships so far. Regarding strength of the relationship, a higher driving power means a higher driver of the whole system, and a higher dependence power means a higher dependency on the whole system. The fuzzy MICMAC analysis was conducted in three steps.

Step 1: The binary direct relationship matrix

A binary direct reachability matrix was obtained by converting the diagonal entries into zeros and ignoring transitivity in the final reachability matrix of AFSC risks, as shown in Appendix E.

Step 2: Development of the fuzzy direct relationship matrix

The conventional MICMAC analysis considers only binary types of relationships, and therefore to improve its sensitivity, the fuzzy set theory was applied. According to the fuzzy set theory, the possibility of interaction can be defined by a qualitative consideration on a 0-1 scale (i.e., no: 0, very low: 0.1, low: 0.3, medium: 0.5, high: 0.7, very high: 0.9, and complete: 1). Using these values, the opinions of aforementioned experts in the TISM analysis were used to rate the relationship between two AFSC risks. Then, the values were superimposed on the binary direct reachability matrix to obtain a fuzzy direct reachability matrix, thus enhancing the research robustness, as it considers the reachability possibility instead of the simple consideration of reachability used so far. The fuzzy direct reachability matrix is shown in Appendix F.

Step 3: Generation fuzzy MICMAC stabilised matrix

The principle of fuzzy matrix multiplication proposed by Kandasamy, Smarandache, and IIanthenral (2007) was used as a guidance for the multiplication process to obtain stabilisation. Fuzzy matrix multiplication is fundamentally a generalisation of the Boolean matrix multiplication. As per the fuzzy set theory, when two fuzzy matrices are multiplied, the outcome is also a fuzzy matrix. The matrix is multiplied repeatedly until the dependence and driving power are constant. Dependence and driving power were obtained by summing the entries of interactions possibilities in the rows and columns separately. The rule of multiplication is shown as follows:

$$C = A, B = \max k[(\min(a_{ik}, b_{kj})] \quad \text{where } A = [a_{ik}] \text{ and } B = [b_{kj}]$$

Using MATLAB to calculate the matrices following the aforementioned rule, a stabilised matrix was obtained as shown in Table 6. Figure 5 presents the visualisation of the AFSC risk classification along two dimensions: dependence and driving power.

Table 6 The fuzzy MICMAC stabilized matrix

	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**	**E12**	**E13**	**E14**	**E15**	**E16**	**Driving Power**
E1	0	0.3	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0.3	0.9
E2	0.3	0	0.3	0.3	0.3	0	0	0	0	0	0.3	0	0	0	0	0.3	1.8
E3	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0.3
E4	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0.3
E5	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0.3
E6	0.3	0.3	0.3	0.5	0.3	0	0.3	0	0	0	0	0	0	0	0	0	2
E7	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0.3
E8	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0.3
E9	0.3	0.3	0.5	0.3	0.3	0	0.3	0	0	0	0	0	0	0	0	0	2
E10	0.3	0.3	0.3	0.3	0.3	0	0.3	0	0	0	0	0	0	0	0	0	1.8
E11	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0.3
E12	0.1	0.1	0.3	0.3	0.3	0	0.3	0.3	0	0	0.3	0	0	0	0	0.3	2.3
E13	0.3	0.3	0.3	0.3	0.3	0	0.3	0	0	0	0.3	0	0	0	0	0	2.1
E14	0.3	0.1	0.3	0.3	0.3	0	0.3	0.5	0	0.3	0.5	0	0	0	0	0.3	3.2
E15	0.1	0.3	0.3	0.3	0.3	0	0.3	0.5	0	0.3	0.5	0	0	0	0	0.3	3.2
E16	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0.7
Dependence power	2	2	2.6	3.4	2.4	0	2.1	2.2	0	0.6	2.8	0	0	0	0	1.5	

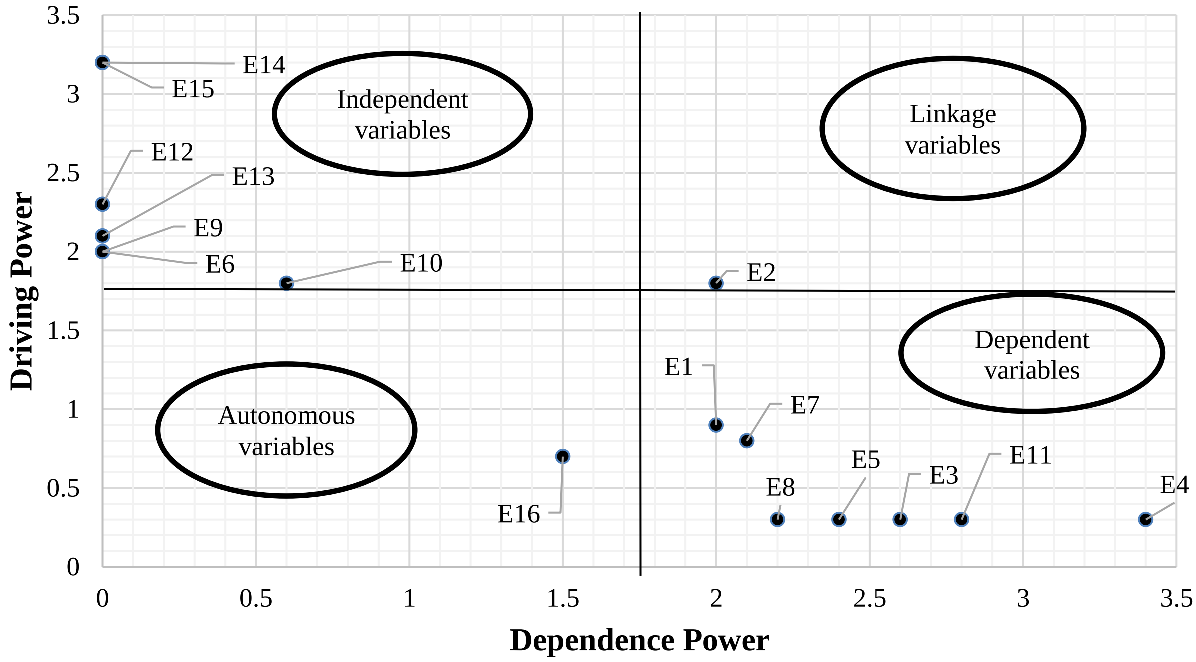

Figure 5 Classification of AFSC risks

As shown in Figure 5, the 16 AFSC risk factors identified from the thematic analysis are classified into four groups:

- Linkage variables group: Factors in this group have both high driving and dependence power. A high driving power has a significant effect on the system, whereas high dependence power is highly dependent on the system. There is only one risk factor in this group, which is bad debt (E2). Any change in this system will have an effect on this risk factor and give a feedback on itself. Though the lower level risks in the TISM hierarchy may induce or affect this risk, it also has a significant driving power to influence some other risks.

- Independent variables group: The risk factors are characterised with high driving and low dependence power, which include pests and diseases' risk (E6), poor planning (E9), supply and demand imbalance (E10), poor agricultural infrastructure (E12), lack of information sharing among partners (E13), extreme weather conditions (E14), political and economic instability (E15). These risks act as inputs and key variables of the system and lie at the bottom of the TISM hierarchy model, which can induce a series of other AFSC risks and have a severe impact on AFSC.
- Dependent variables group: The dependent variables are delay in payment (E1), skill shortage (E3), market price fluctuations (E4), tax evasion (E5), lack of investment in promoting agri-food products (E7), high energy costs (E8), and oral contract or agreement with partners (E11), which have high dependence and low driving power. These risks are highly dependent on the inputs of the system, which indicate that these risk factors require all the other risk factors to minimise the effect on AFSC.
- Autonomous variables group: Factors in this group have less driving and dependence power. There is only one risk factor in this group, which is the rapid technological development (E16). This risk factor is always disconnected from the system, with which it has only a few links in the TISM hierarchy model. Noticeably, it does not have much influence on the system.

6. Discussion

We used semi-structured interviews to collect data on AFSC risks from four countries over one year. Among the 16 AFSC risk factors identified through thematic analysis and shown in Table 4, a minority of the determinants such as oral contract or agreement with partners, skill shortage, tax evasion, lack of investment in promoting agri-food products, and rapid technological development are new AFSC risk factors; however, there are several determinants that support the literature. Prakash et al. (2017) revealed that rapid technological development should be tackled as the second priority following by forecast error, but the findings of this study show that rapid technological development does not have so much influence on the AFSC. This is may be because most AFSC practitioners such as farmers, are reluctant to use the latest technologies to share information, change the flavour, and improve the quality of agri-food products. Mostly, they are relying on their experience to cultivate, prevent pests and diseases, and harvest, rather than technology. Howland et al. (2015) identified a lack of skilled workers who can share data and use information and communication technology (ICT), and this study confirms the result in the context of AFSC. Sharing information is critical for AFSC because it helps to reduce uncertainty in supply and demand, decrease inventory levels, increase food quality and safety, and reduce food wastage due to expiration (Ferguson and Ketzenberg. 2006; Kaipia, Dukovska-Popovska, and Loikkanen 2013). Our empirical findings indicate that it is extremely difficult to hire skilled workers working in rural areas, despite providing proper salaries, permanent contracts, and proper training. We suggest that governments should provide preferential policies for people who want to work in farms like the ones implemented by the European Union to encourage people from Eastern Europe to work in France. Kleindl (2000) stated that the lack of investment is a common situation faced by small- and medium-sized companies, which is reinforced in this study. Additionally, experienced AFSC practitioners suggest that small farmers should cooperate to establish associations to tackle financial limitations, such as the Auction Market in southern France, the Association of Bolivian Farmers in the Argentina, and the Association of Valencia farmers in Spain.

With the help of TISM and fuzzy MICMAC analyses (see Figure 4 and Figure 5), we found that the biggest threat to the AFSC is political and weather-related risks, since the resulting dependencies might lead to logistical and infrastructure risk, and further induce or affect other risks such as demand, financial, and management and operational risks. The study carried out by Peck (2005) illustrated that risks emanating from the political, economic, social, technological, and natural environment with the highest driving power can affect the whole AFSC. For example, independent variables in this study such as extreme weather conditions and political and economic instability, which have the highest driving power and forms the lowest level in the TISM hierarchy model, are considered as the key risks. The research conducted by Alesina et al. (1996) highlighted that political instability would cause low economic growth even recession, and further induce a series of problems such as lack of investment in agricultural infrastructure. Thus, a focus on mitigating extreme weather conditions and political and economic instability will help to control other AFSC risks. Therefore, these risks should be tackled as a high priority. A comparison of present results with previous studies like the work done by Diabat, Govindan, and Painicker (2012) on modelling the risks of food supply chain supports the results of this study to some degree by placing political and weather-related risks at the bottom of TISM hierarchy. But, while the risks of the present study are in the independent variables group, they are classified under the linkage variables group in the earlier work. This contrast shows that the current AFSC of Argentina, France, Spain, and Italy are experiencing more threats from the political and weather-related risks. For example, four political and economic changes from 1989 to 2016 in Argentina, which had a significant impact on the local AFSC. Market price fluctuations, skill shortage, tax evasion, and oral contract or agreement with partners are the dependent risks and have relatively high dependence power, thus forming the top level in the TISM hierarchy model. These risks are greatly affected by many other risks. However, market price fluctuations is placed in the linkage variables groups in previous studies (Diabat, Godindan, and Painicker 2012). This difference is because market price fluctuations identified in the present study is affected by many other risks and their relative significance and interdependencies also vary from that of other studies.

7. Contributions

This study investigates the AFSC risks from theoretical and empirical perspectives. A combination of multiple qualitative research methods was applied in this research, providing guidance for researchers on examining driver-dependent relationships among AFSC risks using semi-structured interviews, thematic analysis, TISM, and fuzzy MICMAC analysis. The key findings of this study contribute to the existing body of knowledge while answering the three aforementioned research questions: (1) it provides empirical evidence of the main risks that can cause vulnerabilities to the AFSC. Although many studies (e.g., Wagner and Bode. 2006; Tang and Tomlin. 2008; Esteso, Alemany, and Ortiz 2018) have analysed the risk factors in the supply chain context from an empirical perspective, this study identified five new risk factors, namely, oral contract or agreement with partners, skill shortage, lack of investment in promoting agri-food products, tax evasion and rapid technological development. We extend existing studies that primarily focus on supply chain risk identification. Though we cannot eliminate political and economic instability and extreme weather conditions, an active supply chain risk identification is very necessary (Quang and Hara 2018). A superior risk identification supports the subsequent risk assessment and this in turn leads to better risk mitigation (Aqlan and Lam 2015). (2) It develops a TISM hierarchy model of AFSC risks, which can help to understand interrelationships among different types of AFSC risks. The interdependencies and interrelationships among various risk types in literature are inadequate (Ho et al. 2015), which confirms the emerging necessity of this research. Previous studies (Pfohl, Gallus, and Thomas 2011; Diabat, Godindan, and Painicker 2012; Bier, Lange, and Glock 2019) only used ISM to identify interrelationships between different risk factors in the supply chain context, with no study using the TISM method to develop an AFSC model that considers the interrelationships among different AFSC risk factors. To the best of the authors' knowledge, this is the first study to define the interrelationships among different AFSC risks using TISM. Furthermore, the proposed TISM hierarchy model identified 16 risk factors at nine different layers and highlights their specific roles. (3) Finally, it identifies the key risks in AFSC using the fuzzy MICMAC analysis. By categorizing various risks into different categories based on the experts' opinion in a structured and systematic way, key risk types that drive the system are identified. This answers the call for strengthening the research in the supply chain risk classification as research on this topic is still in its infancy (Sodhi, Son, and Tang 2012; Rangel, Oliveria, and Leita 2015).

This study contributes to the managerial practices significantly. First, it identifies various types of risks from the AFSC perspective, which provides a general overview of AFSC risks to the practitioners and increase their risk awareness. A survey conducted by Economist (2009) indicated that more than one-third of respondents hold the view that there is a lack of understanding of supply chain risk at the broad level and almost half of the respondents believe their company underestimates the potential impact of supply chain risk. The result of this empirical study will help AFSC managers to build the awareness of possible risks that could happen in the AFSC and enable managers to take necessary actions in advance to prevent the risk happen or mitigate the risk effects. Second, it investigates interrelationships among different types of AFSC risks. Investigating the joint impact of various risks can lead to better management of AFSC than tackling each risk factor in isolation (Ho et al. 2015). A more comprehensive understanding of the AFSC risks and their interrelationships, through a logical structure, will enable AFSC managers to prioritise and allocate the resources in an effective way. Thus, AFSC managers can focus on the key risks (extreme weather conditions and political and economic instability) of causing vulnerabilities to the AFSC. This will reduce the time and effort required to mitigate the effects of risks if the key risk is targeted initially. To mitigate the effect of extreme weather conditions, the large agri-food companies are suggested to get a weather damage and business insurance, whereas the small- and medium-sized companies are suggested to apply disaster relief emergency fund if the agricultural infrastructure is destroyed by extreme weathers. A possible method to alleviate the effect of political and economic instability is to strengthen the partnership with the suppliers and relationship with local government and non-profit organisations. Third, it classifies different risks into different categories such as linkage, independent, dependent, and autonomous variables. This classification also helps AFSC managers differentiate different risks and their mutual relationships and formulate strategies to mitigate the effects of independent risks while developing contingency plans for linkage risks, and to monitor the dependent risks. However, alleviating the effects of dependent risks will not help mitigate any of the other risks because dependent risks are at the top of the TISM hierarchy model. Furthermore, it can be used to explain, communicate, and transfer risk knowledge between different departments of the company, as well as between various partners within the AFSC, thus enabling an effective management that deals with the various risk types from both the company and overall supply chain perspectives.

8. Conclusion and future research directions

In present, having a deep understanding and knowledge of interrelationships among different AFSC risks is significant for researchers and practitioners. To attain this objective and manage AFSC risks appropriately, 16 in-depth semi-structured interviews with experienced AFSC practitioners were conducted in four different countries. Then, 16 AFSC risk factors were identified through thematic analysis. After that, we applied TISM to uncover the potential interrelationships among the identified risk factors. Finally, we used the fuzzy MICMAC analysis to identify the key risks in various categories. The results indicate that political and weather-related risks have the highest driving power and lie at the lowest level of the TISM hierarchy; thus, they should be given top priority.

However, this study does has some limitations. First, there are no prevention strategies to be proposed in this study to mitigate the risks. Second, the empirical study was conducted in a limited number of countries (i.e., Spain, France, Italy, and Argentina). Therefore, when the results are applied to other contexts, country-specific factors such as cultural impacts on supply chain risks should be taken into consideration. Third, only qualitative research methods have been applied in this study. Fourth, the driving direction (positively/negatively influence) between different AFSC risks has not been investigated using TISM. These limitations open avenues for further research as follows:

(1) Resilience capabilities/strategies should be developed to help all AFSC companies to mitigate the risks. This is because all the companies in the AFSC will need some strategies to recover from risks.

(2) The study results should be applied to other countries to check their general validity. Additionally, an international survey would provide further insights concerning the AFSC risks in other countries or could identify cultural differences concerning AFSC risks.

(3) Exploring a hybrid (combination of qualitative and quantitative) technique could improve AFSC risks analysis in further research. Hussein (2015) showed that the use of both qualitative and quantitative methods in studying the same phenomenon has positive effects on improving the wider, accuracy, and deep understanding of the study. Thus, structural equation modelling (SEM) can be applied in future research.

(4) The driving direction (positively/negatively influence) should be incorporated into TISM in the step of defining the contextual relationships and interpretation of relationships. If there is a relationship between two elements, then its driving direction also needs to be specified. Further, experts' explanations that element A will positively/negatively influences element B should be clarified. The systematic guidance for considering the polarity of relationships in TISM has been provided by Sushil (2018).

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Appendix A. Interview guide

Introductory questions
(I) Interviewee information
a. What is your current designation?
b. Can you give me a brief overview of your job within the company operations?
c. How many years are you working in this company?
d. How many years of your working experience in the same job role in total?
(II) Company information
e. Can you give me a brief overview of the company structure, parent company, and its operations?
f. What is the industry sector in which the organisation operates in?
g. How many employees are working for the company?

A. Relationship
(I) Relations with upstream suppliers
1. How many upstream suppliers do your company have?
2. Can you describe the functionality of the main upstream suppliers?
3. Do your company build long-term relationship with the main upstream suppliers?
4. How would you describe the relationship of your company with upstream suppliers?
(II) Relations with downstream consumers
5. How many downstream consumers do your company have?
6. Can you describe the functionality of the main downstream consumers?
7. Do your company build long-term relationship with the main downstream consumers?
8. How would you describe the relationship of your company with downstream consumers?
B. Risks the company faced
9. How would you describe the sources of risks that affect your company?
10. How would you describe what is the biggest risk that you met in your company?
C. Risks the whole AFSC faced
11. How would you describe the sources of risks that affect the whole AFSC?
- ❖ Supply risks
- ❖ Demand risks
- ❖ Biological and environmental related risk
- ❖ Political related risk
- ❖ Weather related risk
- ❖ Logistical and infrastructure related risk
- ❖ Policy and regulatory risk
- ❖ Financial related risk
- ❖ Management and operational risk

12. How would you describe what is the biggest risk for the AFSC?
D. Risk mitigation strategies
13. How would you describe are there having any contingency plans or personnel responsible for dealing with risks?
14. How would you describe the managerial capabilities and strategies employed to mitigate risks?
15. How would you describe what is the risk management plan that the company follows? (Avoidance, Mitigation, Transfer, Acceptance)
16. How would you describe how do you seek to minimize the risks and spread these amongst your supply chain stakeholders?

Appendix B. Initial reachability matrix of AFSC risks

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16
E1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
E2	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0
E3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
E6	1	1	0	1	0	1	1	0	0	1	0	0	0	0	0	1
E7	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
E8	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
E9	0	0	0	1	0	1	1	0	1	1	0	0	0	0	0	0
E10	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
E11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
E12	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0
E13	0	0	0	1	0	0	0	0	1	1	0	0	1	0	0	1
E14	0	0	0	1	0	1	1	1	0	1	0	1	0	1	0	0
E15	0	0	0	1	1	0	1	0	0	1	0	1	0	0	1	0
E16	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	1

Appendix C. Final reachability matrix of AFSC risks

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16
E1	1	1	1*	1*	1*	0	1	0	0	0	0	0	0	0	0	0
E2	1	1	1	1*	1	0	1	0	0	0	0	0	0	0	0	0
E3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
E6	1	1	1*	1	1*	1	1	1*	0	1	1*	0	0	0	0	1
E7	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
E8	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
E9	1*	1*	1*	1	1*	1	1	1*	1	1	1*	0	0	0	0	1*
E10	1	1	1*	1	1*	0	1*	0	0	1	0	0	0	0	0	0
E11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
E12	1*	1*	1*	1*	1*	0	1*	0	0	1	0	1	1	0	0	0
E13	1*	1*	1*	1	1*	1*	1*	1*	1	1	1*	0	1	0	0	0
E14	1*	1*	1*	1	1*	1	1	1	0	1	1*	1	1*	1	0	1*
E15	1*	1*	1*	1	1	1*	1	1*	1*	1	1*	1	1*	0	1	1*
E16	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	1

Note: 1* entries refer to depict transitivity relationship

Appendix D. Partitioning the reachability matrix into different levels

Variable	Reachability Set (RS)	Antecedent Set (AS)	RS∩AS	Level
Iteration 1				
E1	1,2,3,4,5,7	1,2,6,9,10,12,13,14,15	1,2	
E2	1,2,3,4,5,7	1,2,6,9,10,12,13,14,15	1,2	
E3	3	1,2,3,6,9,10,12,13,14,15,16	3	**I**
E4	4	1,2,4,6,7,8,9,10,12,13,14,15,16	4	**I**
E5	5	1,2,5,6,9,10,12,13,14,15	5	**I**
E6	1,2,3,4,5,6,7,8,10,11,16	6,9,13,14,15,16	6,16	
E7	4,7	1,2,6,7,9,10,12,13,14,15	7	
E8	4,8	6,8,9,13,14,15,16	8	
E9	1,2,3,4,5,6,7,8,9,10,11,16	9,13,15	9	
E10	1,2,3,4,5,7,10	6,9,10,12,13,14,15	10	
E11	11	6,9,11,13,14,15,16	11	**I**
E12	1,2,3,4,5,7,10,12,13	12,14,15	12	
E13	1,2,3,4,5,6,7,8,9,10,11,13,16	12,13,14,15	13	
E14	1,2,3,4,5,6,7,8,10,11,12,13,14,16	14	14	
E15	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16	15	15	
E16	3,4,8,11,16	6,9,13,14,15,16	16	
Iteration 2				
E1	1,2,7	1,2,6,9,10,12,13,14,15	1,2	
E2	1,2,7	1,2,6,9,10,12,13,14,15	1,2	
E6	1,2,6,7,8,10,16	6,9,13,14,15,16	6,16	
E7	7	1,2,6,7,9,10,12,13,14,15	7	**II**
E8	8	6,8,9,13,14,15,16	8	**II**
E9	1,2,6,7,8,9,10,16	9,13,15	9	
E10	1,2,7,10	6,9,10,12,13,14,15	10	
E12	1,2,7,10,12,13	12,14,15	12	
E13	1,2,6,7,8,9,10,13,16	12,13,14,15	13	
E14	1,2,6,7,8,10,12,13,14,16	14	14	
E15	1,2,6,7,8,9,10,12,13,15,16	15	15	
E16	8,16	6,9,13,14,15,16	16	
Iteration 3				
E1	1,2	1,2,6,9,10,12,13,14,15	1,2	**III**
E2	1,2	1,2,6,9,10,12,13,14,15	1,2	**III**
E6	1,2,6,10,16	6,9,13,14,15,16	6,16	
E9	1,2,6,9,10,16	9,13,15	9	
E10	1,2,10	6,9,10,12,13,14,15	10	
E12	1,2,10,12,13	12,14,15	12	
E13	1,2,6,9,10,13,16	12,13,14,15	13	
E14	1,2,6,10,12,13,14,16	14	14	
E15	1,2,6,9,10,12,13,15,16	15	15	
E16	16	6,9,13,14,15,16	16	**III**
Iteration 4				
E6	6,10	6,9,13,14,15	6	
E9	6,9,10	9,13,15	9	
E10	10	6,9,10,12,13,14,15	10	**IV**
E12	10,12,13	12,14,15	12	
E13	6,9,10,13	12,13,14,15	13	
E14	6,10,12,13,14	14	14	
E15	6,9,10,12,13,15	15	15	
Iteration 5				
E6	6	6,9,13,14,15	6	**V**
E9	6,9	9,13,15	9	
E12	12,13	12,14,15	12	
E13	6,9,13	12,13,14,15	13	
E14	6,12,13,14	14	14	
E15	6,9,12,13,15	15	15	
Iteration 6				
E9	9	9,13,15	9	**VI**
E12	12,13	12,14,15	12	
E13	9,13	12,13,14,15	13	
E14	12,13,14	14	14	
E15	9,12,13,15	15	15	
Iteration 7				
E12	12,13	12,14,15	12	
E13	13	12,13,14,15	13	**VII**
E14	12,13,14	14	14	
E15	12,13,15	15	15	
Iteration 8				
E12	12	12,14,15	12	**VIII**
E14	12,14	14	14	
E15	12,15	15	15	
Iteration 9				

E14	14	14	14	**IX**
E15	15	15	15	**IX**

Appendix E. Binary direct reachability matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16
E1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
E2	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0
E3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E6	1	1	0	1	0	0	1	0	0	1	0	0	0	0	0	1
E7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E9	0	0	0	1	0	1	1	0	0	1	0	0	0	0	0	0
E10	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E12	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
E13	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1
E14	0	0	0	1	0	1	1	1	0	1	0	1	0	0	0	0
E15	0	0	0	1	1	0	1	0	0	1	0	1	0	0	0	0
E16	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0

Appendix F. Fuzzy direct reachability matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16
E1	0	0.3	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0
E2	0.9	0	0.7	0	0.7	0	0.7	0	0	0	0	0	0	0	0	0
E3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E6	0.5	0.3	0	0.7	0	0	0.5	0	0	0.3	0	0	0	0	0	0.7
E7	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0
E8	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0
E9	0	0	0	0.9	0	0.7	0.9	0	0	0.7	0	0	0	0	0	0
E10	0.7	0.5	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0
E11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E12	0	0	0	0	0	0	0	0	0	0.3	0	0	0.3	0	0	0
E13	0	0	0	0.3	0	0	0	0	0.3	0.7	0	0	0	0	0	0.3
E14	0	0	0	0.7	0	0.3	0.3	0.7	0	0.7	0.7	0.9	0	0	0	0
E15	0	0	0	0.7	0.9	0	0.5	0	0	0.3	0	0.5	0	0	0	0
E16	0	0	0.7	0.3	0	0	0	0.7	0	0	0.5	0	0	0	0	0