Understanding Risks in Milk Supply Chain: An Agent-Based Conceptual Model

Andre R. Daud and Utomo S. Putro

Abstract Milk production is inherently complex and risky business. Risks and complexities are involved in every production stage and process performed by each actors involved along the milk supply chain. It implies that the success of improving the performance of supply chain will in some degree depend on those actors' ability to cope with risks and its emerging complexities. This paper proposes a concept for analyzing the risks existing in the milk supply chain. To conceptualize, the use of agent-based methodology is offered in order to capture the risk complexities in the particular chain. A basic agent-based model that can describe the actors' behavior toward risk and the likely consequences for the entire chain completes the concept.

Keywords Agriculture • Behaviors • Complexity • Dairy production

1 Introduction

Risk in agricultural production has been extensively studied since the beginning of modern agricultural sector. In this phase, risk was being the main concern upon the society, as well as scholar and government, because it may often associate with adversity and loss by the agricultural firm and also with its survival as a business. As rural family farms initially dominate the agricultural sector, most risk studies emphasize on the survivability of their business which being the main source for income and welfare of rural community. Concisely, risk is prevalent in the agricultural operations.

One definition of risk is as uncertainty that "matter" for producers and may involve the probability of losing money or welfare [1, 2]. Previous studies have revealed many sources of agricultural risk, and there are evidences showing risk-aversion as most typically agricultural producers' attitude toward risk. Risk averse

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farmers will prefer to abandon some potential outcome to avoid any possible future risks that may make them suffered from losing some amount of income. In this situation, the outcome of agricultural production would be less optimal under the presence of risks. Thus, producers seek to avoid risk through various managerial and institutional mechanisms.

However, despite from the advancement of studies, our understanding on risk and risk management strategies in agricultural production is still limited. Most of agricultural risks and its associated management are still positioned only in the standpoint of individual entity (for example, in the individual farmers' context). This may not become relevant any further because agricultural production recently has transformed itself to a supply chain in which involves a set of collective entities that performed wide range of activities and processes, from farm-household producers in rural areas into large-modern food processors, retailers and markets in urban area [3, 4]. This condition implies the nature of strong interdependency among business actors, and in turn, complexities in managing risks emerge.

Given the characteristic, more comprehensive approach is considered necessary in risk studies for agricultural supply chain. Recently, agent-based model (ABM) methodology is preferred by scholars in many studies which focus on individuals or agents that are described as unique and autonomous entities that usually interact with each other and their local environment. Railsback and Grimm [5] suggest that ABM can provide a method to address problems that concern emergence complexity. The emergence is system dynamic that arises from how the system's individual components interact with and respond to each other and their environment. The possibility for ABM to address such a problem comes from the model's ability to work across level, i.e., working vice versa between individual and its system. Thus, ABM methodology seems quite feasible to be applied to supply chain risk studies, particularly in agricultural production.

This paper presents a conceptual framework for analyzing risk specifically in milk supply chain in the context of developing countries. Instead of classical approach, which mostly emphasizes on explaining the individual's attitude toward risks, ABM is proposed to be the main method for capturing the effect of risk on the supply chain actors collectively, as will be presented later. After this introduction section, an overview on the complexity in milk production is briefly presented. Thereafter, the framework that combines the concept of supply chain, risks, and modeling is proposed. In the end of this paper, a summary section will give the brief overview of the benefit of ABM approach to be applied in the case of milk supply chain.

2 Complexity in Milk Supply Chain

In agricultural research, the use of ABM approach to understand individuals and the whole system of agriculture is relatively new. Although agricultural field has its own approach to understand the system, i.e., biophysical approach, it is still limited

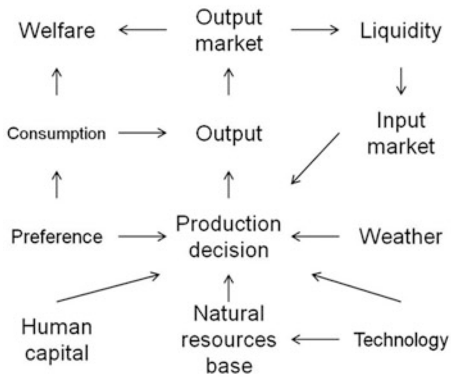

Fig. 1 Agricultural production system complexity (Adapted from Bebe et al. [6])

and constrained by existence of the complexity in the agricultural system. Indeed, agricultural production is one of the systems that are very complex. It is because of the agricultural production which has multidimensional aspect such as the entire biophysical socioeconomic system in the real world. To provide its complex system, we illustrate a generic form of agricultural production system in this figure (Fig. 1).

Agricultural production system, presents all of agents, interactions, and its environment. As we can observe, the agricultural production system comprises many agents who have many interactions within their agricultural environment. In traditional milk production system, millions of smallholder farmers – as the most important agent in the system – with their heterogeneous characteristics and attributes, have their own autonomy to decide how much dairy cow they should keep, to whom they should sell their milk products, on what price and on what market, thus avoiding risks, to satisfy their given family household objectives, under environment uncertainty. Similar situation applies for other agents in this milk production system, thus magnifying the complexity of the system.

As nowadays milk production is in the form of a supply chain, it has been regarded as “complicated systems involving both strategic and operational issues along with complex social and functional behaviors [7, 8]”. Indeed, Choi et al. [9], Pathak et al. [10], and Surana et al. [11] argued the supply chain is “to be regarded as complex adaptive systems (CAS) because individual components or agents within a supply chain can and do intervene at any point in a meaningful way to change the behavior of the whole”. Under these circumstances, an agent may represent an individual, a group, or an entire organization with each having relationship and varying degrees of connectivity with other agents. These allow information and resources to flow between agents.

A widely accepted description of complex adaptive systems is “a system that emerges over time into a coherent form, and adapts and organizes itself without any singular entity deliberately managing or controlling it” [9]. Pathak [10] presented several common features for complex adaptive systems, which are classified into two characteristics, micro and macro. Microlevel describes the basic structure of the system, i.e., the structure which is internally built by the presence of many agents,

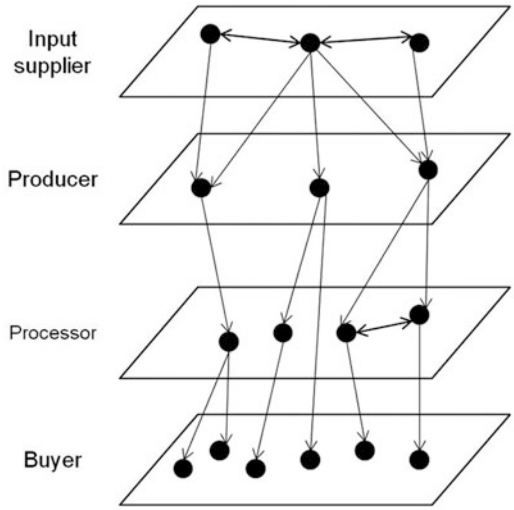

Fig. 2 Network supply chain/net chain (Adapted from Lazarrini [12])

while the macro-level describes how a whole system behaves. Following Lazarrini [12], the micro- and macro-level characteristics of complex adaptive systems in particular milk supply chain can be shown in the following illustration.

On the microlevel, the presence of a variety of actors is the main characteristic of CAS. As can be seen in Fig. 2, there are usually many actors in the supply chain – farmers, processor, manufacturers – who have diverse characteristics and different preferences in the terms of production technology, product features, and interactions, both vertically and horizontally. This implies that there are many different needs and objectives possessed and decision making performed by each actor. In the milk supply chain, this condition increases complexity of particular supply chain system. The presence of local interactions and interdependencies among system components is also the main source of complexity of a system which resulted from various actors. Surana et al. [11] showed that in a supply chain, there could be physical interaction and social as well. With the presence of many actors, these interactions can be numerous and heterogeneous, thus generating an interconnection complexity.

Nestedness and adaptiveness are other microlevel characteristics of CAS [11]. Nestedness refers to the behavior that is formed hierarchically. For example in milk supply chain, the behavior of dairy farmers and their interactions determine the behavior of each farmer group to which they belong. In turn, the behavior of dairy farmer groups and their each interaction internally and externally with another actors in the chain will define the behavior of a milk supply chain system as a whole. Closely, adaptiveness refers to the ability to change behaviors according to their system environment [15] as the behavior of actors can be influenced by its interactions with the environment [11]. For instances, the actual practices of keeping dairy cattle in suburban area will differ significantly with them practicing dairy in rural area.

For the characteristic in macro-level, there are emergent behavior, self-organization, path dependency, and coevolution as features in a complex system. Emergence refers to the behavior in a system that emerges from the behavior of individual components (both social and physical) and their interactions [15]. In the context of milk supply chain, especially in Indonesia, declining trend of milk production is evidenced. It follows the very low scale of dairy operation preferred by farmers. Actually, their behavior often arises without influences from external or central control in the system but from the results of many autonomous interactions between agents in the system.

The CAS also features coevolution and path dependency. Coevolution refers to changes in the structure of a particular system as results from learning and adaptation process experienced by agents in their interaction with the environment. In turn, the structural changes trigger the coevolution of the system and its environment. Following this dynamic, the actions and decisions made in previous state of the system will determine the current and future states. This is defined as path dependency of the system. Choi et al. [9] also showed that the options in the current state are the reflection of microlevel decision making made by actors in the past.

To assess the CAS, Macal and North [15] have suggested a typical of agent-based model (ABM) which comprises three basic elements: (1) a set of agents with their attributes and behaviors; (2) a set of relationship and methods of interaction between agents; and (3) the environment. Briefly in ABM, agents may be any entity that pursues a certain goal, act independently of each other and pursue their own objective. But in the presence of different characteristics and interactions, agents will use adaptive behavior where they adjust their behavior to the current status of themselves, of other agents and of their environment. Furthermore, in other words, ABM focuses on modeling behavior of agents and, at the same time, observing and understanding the behavior of the system made up by the agent.

3 The Conceptual Model for Milk Supply Chain Risk

3.1 The Concept of Supply Chain Risk

To define the concept of supply chain risk management, Jüttner [16] and Juttner et al. [13] presented a theoretical framework as shown in Fig. 3. In this framework, it distinguished four basic constructs for supply chain risk management: (i) supply chain risk sources (or disruptive events), (ii) supply chain structure, (iii) risk-mitigating strategies (management), and (iv) risk consequences (outcome). In fact, the level of impact and the consequences of each supply chain are the result of supply chain structure, the magnitude and profile of disruptive event (or risk source), and also the coping and mitigation strategies that are in place.

Based on this theoretical framework, the conceptual model for supply chain risk should be developed in following steps: (i) supply chain modeling, to define

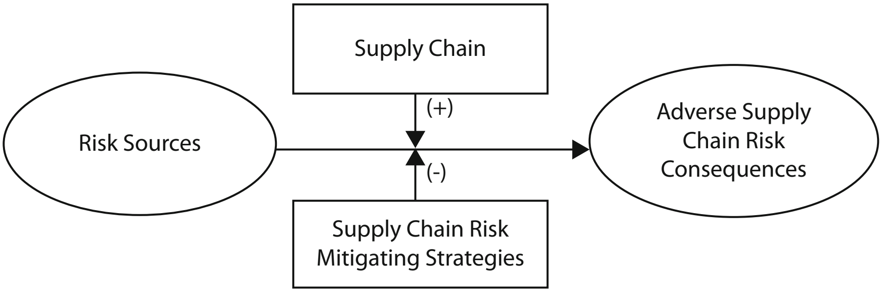

Fig. 3 Supply chain risk analysis framework (Adapted from Juttner et al. [13])

the structure and behavior of a supply chain; (ii) risk modeling, to describe the characteristics of risk or disruptive events; and (iii) risk management modeling, to predict how management practices can be modeled. Among three components above, the supply chain model conceptualization is central, and other two modeling components are constructed based on the former model.

3.2 The Effect of Risks for Agents in Milk Supply Chain

The model of risk management in a particular supply chain system will largely depend on agents' behavior. North and Macal [15] illustrated that an agent is basically an individual who has a set of attributes and behavioral characteristics.

In the authors' term, the attributes define what an agent is, and the behavioral characteristics define what an agent does. Thus, an agent can be described by its state and behavioral rules. In fact, the existence of attributes and characteristics will allow agents to take in information, process the inputs, and then affect changes in a particular system and also changes in outside environment. The illustration of this dynamic process can be depicted in Fig. 4.

In this context, risks can be analogous to the inflow of information (in any form) from the outside "world" to the inside of agent. Basically, agents will always monitor the dynamics of external situation and also the current state the agents have. Based on the available information, from outside world or inside (attribute), agents decide what to do and subsequently take one action. The information the agents have, and the taken action, actually are kept in the agent's memory to be deployed under the subsequent updated state. The action that the agents' take, in turn, will become triggers for the system reaching into a new state of system.

However, so far, it is not yet clear how the agents will perceive and process the risks with the above similar arrangement. As previously discussed, Juttner [16] has provided an analytical framework which presents the relationship between the sources of risk and the consequences of any given risk, with the structure of supply chain and it mitigating strategies as determining factor. Yet, how the risks will pass

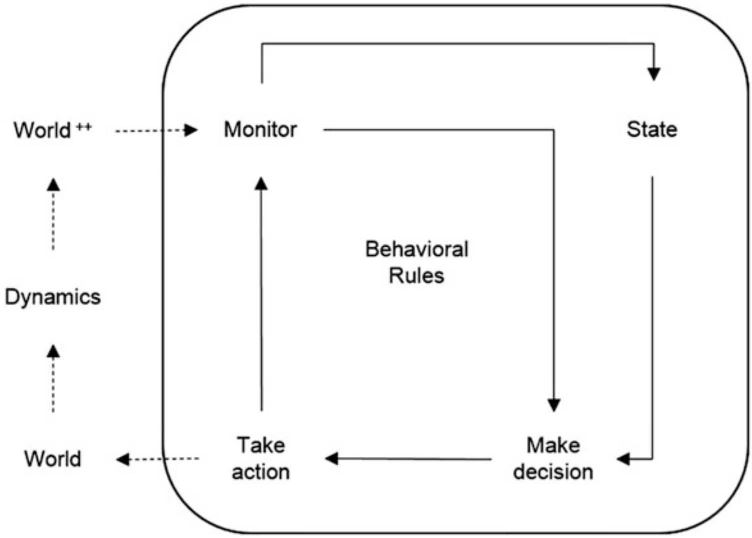

Fig. 4 Generic structure of agent (Modified from Behdani et al. [14]

the effect to every actor in the chain is still indistinct. In the term of agent-based model, these risks affect the state and the behavior of the agents, which in turn, will affect the whole chain system. As the system change, new system's outcome emerges, as in CAS.

For this purpose, additional attribute/properties that are related to risk terminology should be introduced, which are the expected loss and the vulnerability. [17]) defined the expected losses as "a function of the probability of a risky event actually occurring and the exposure to that risky event". A risky event is an event which actually occurs that may influence the outcome. Then, expected losses describe the potential severity of negative impacts from a given event. These losses can be in the form of tangible and intangible, and also in the term of interval, short and long term losses.

In the terminology of agent, the expected losses represent the subject that an agent considers before it makes a decision making to take an action. Just like an information, the agent monitors the probability of any given event that is perceived as risky. Also, the agent will process the information along with the current state and the memory of the agents. In the agents' expected loss, the related main concept is severity.

Severity is a subjective concept which refers to the state of being severe. In fact, an agent, or an actor in the real world, has very limited information about the likelihood of any negative outcomes in the future event; thus, it is very subjective. However, for this purpose, a list of possible outcomes for the expected loss can be derived. One of these outcomes should represent the current state of an agent in the modeling process. Figure 5 illustrates the outcome of expected loss.

		Potential of negative impact / severity	
		Low	High
Probability of risky event	Low	Low probability, low impact	Low probability, high impact
	High	High probability, low impact	High probability, high impact

Fig. 5 Possible outcome of expected loss attribute (Adapted from Jaffe et al. [17])

		Capacity to manage risk	
		Low	High
Expected loss	Low	Low vulnerability	Very low vulnera-bility
	High	High vulnerability	Low vulnerability

Fig. 6 Possible outcome of vulnerable attribute (Adapted from Jaffe et al. [17])

Four possible states for expected losses can be identified, varying from high impact and probability to low impact and probability. Especially in agricultural production, farm assets and their allocation will be determined by the exposure of farms to risk. Jaffe et al. [17] showed that assets allocation which involved in mixed farming (crop and livestock), or diversification of farm and non-farm activities influence exposure to risk, in turn, influenced by risks. Then, both asset allocations and exposure to risk determine the degree of severity in particular risky event.

In conjunction with the concept of expected losses, vulnerability is another concept that should be able to represent the agents' behavior. In this context, OECD [18] defined vulnerability as a function of expected loss and management capacity. For showing direct relationship between the two concepts, Fig. 6 lists the characteristics of vulnerability.

As the concept of expected loss, vulnerability can be a part of an agent's state, which in turn will determine the next action that an agent takes (see Fig. 7). However, the component of management capacity within vulnerability indeed has broader dimension. As accompanied by [17]), they stated that the vulnerability of individual chain participants and the overall supply chain depends on the nature of the risks and on the effectiveness of the risk management instruments in use. Therefore, risk combined with the risk management responses leads to performance outcomes. In this situation, risk management refers to the instruments which could be social or physical instruments that an agent owns or operates. Thus, while expected losses can be a representation of agents' state and behavior individually, vulnerability will be a more collective representation.

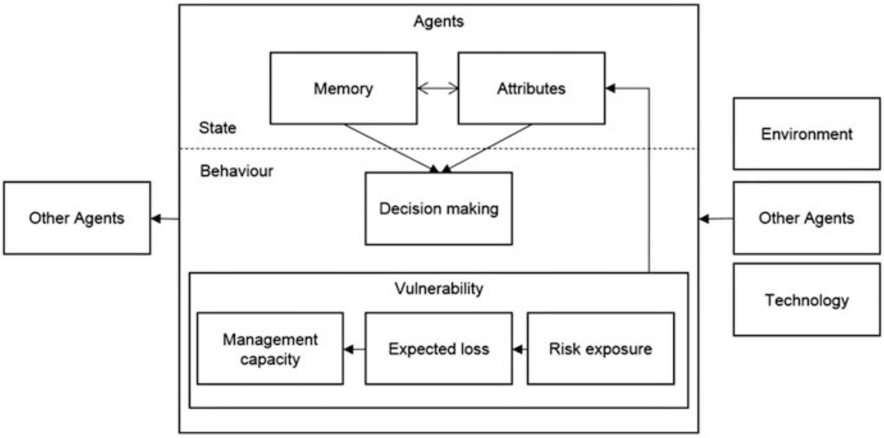

Fig. 7 Structure of agent in the model (Modified from Behdani [14])

3.3 The Basic Model for Milk Supply Chain Risk

The concept of expected loss and vulnerability will now be integrated into the basic model of supply chain to develop a model of supply chain risk management. This integration can be done by modifying the attributes and properties of available agent in order to induce the specific behavior related to the risk and risk management in the system. And in turn, how the agents' behavior will affect the performance of the system is a major importance in this research. The structure of the agent with specific risk-related attributes is presented in Fig. 8. It should be noted that, in this proposed model, farmers and farmers' suppliers will be the agents that deal with risks mostly. This can be justified by actually recognizing farmers as the main producer in the milk supply chain and can be viewed as a push production process (make to stock). However, the other agents, cooperative and manufacturer, will also deal with risks but very specific to organization risks.

Figure 8 presents an experimental design that is proposed in this paper. It also presents the high level of abstraction of decision-making structure that can be modeled. The abstract shows the stage of decision that each agent makes in regard to the flow of products. As can be seen in the figure, the main producers (farmers) will produce raw milk under risks or the perception of risky events. In our previous study, we found several risks (risky events) often faced by farmers [19]. Fodder shortages in dry season and the lack of replacement cattle are the most significant risks perceived by farmers. The poor condition of milk handling and bulking practiced by farmer's cooperative is also perceived as risk that discourages individual milk production.

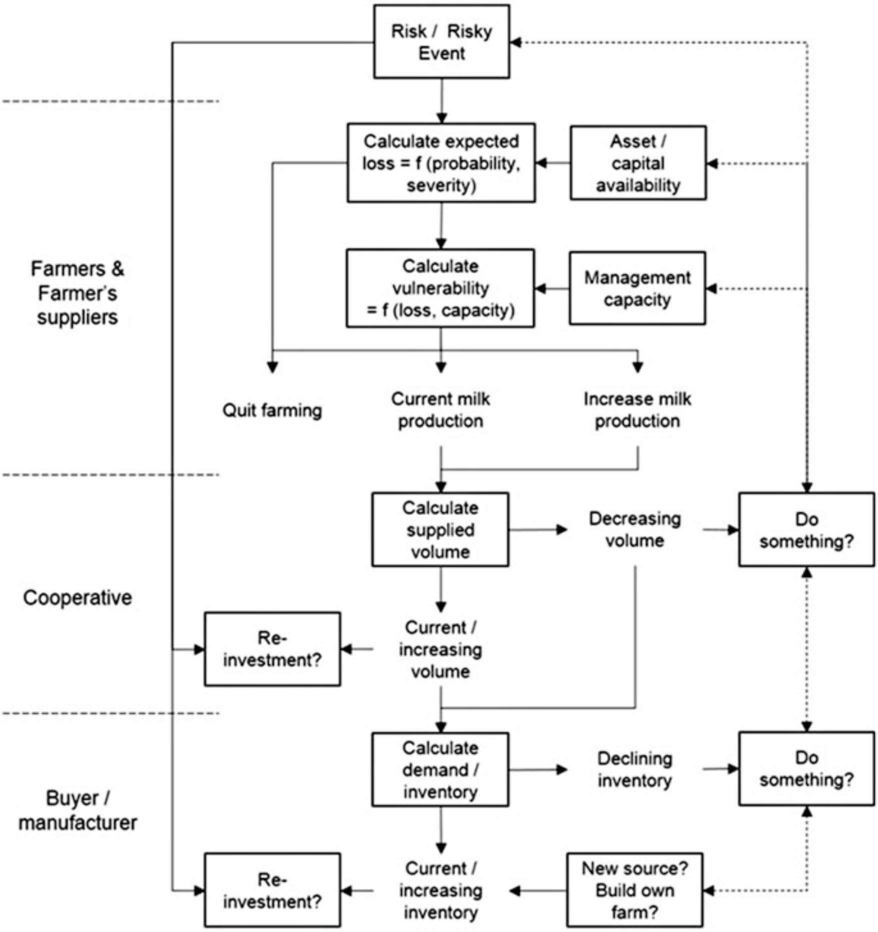

Fig. 8 Agent-based model for milk supply chain risk

In these circumstances, it is believed that there are three possible outcomes for producers, which are (i) staying on the current level of milk production, (ii) somehow increasing the level of production, (iii) or even exiting the dairy business. These outcomes are resulted from the decision-making process that is based on the state of vulnerability consideration. As aforementioned, vulnerability for the main producer is a function of probability of loss, severity, and also risk management capacity. In this case, it should be assumed that if the vulnerability state is relatively low, then the producer will continue to produce raw milk while tending to exit the production if the state is considerably high.

Let's assume that, for any reasons, there are always a small number of producer who quit dairy business over time. For sure, this will lead to gradually decreasing volume of raw milk supplied from the farmers to the cooperatives, which play as milk distributor. This means that the volume that has to be delivered by distributor to the buyer also decreases. As distributor performs a fully logistical function, the volume of products that is forwarded from upstream to the downstream should be the main concern for this enterprise. The consequences from lessening volume of goods will also be experienced financially. To perform day-to-day logistics, it is for sure that a significant level of investment has been realized by the distributor based on the actual and potential volume of products. Thus, if the decreasing level of products supplied from the producers can be assumed to be true, the basic fixed cost to perform such logistical function will be likely increased and weaken the competitiveness of the enterprise. In this setting, this is the main risk which has to be confronted by the cooperative.

The situation is also true for the buyer, which in this case is the manufacturer. This enterprise is the one that confronts the demand for final good from the market. To fulfill its market demand, this enterprise will largely depend on the level of inventory, which is the raw milk received from the distributor. Especially in food industries setting, the raw material (agroproducts) is the most significant component in the production line, both the quantity and quality. As this enterprise sources almost all of its raw material from particular distributor, the decreasing level of raw supply from the distributor will likely also generate undesirable consequences. For handling the customer's orders, the manufacturer will make sure that inventory level is adequate. In this case, gradually decreasing level of inventory will become a significant risk.

As in abovementioned, the proposed model intends to capture and explain how the risks in milk supply chain manifest itself and are transferred throughout the supply chain. Also, this model is expected to present the clear relationship between risks or risky events and the production behavior of each agent in the model. Therefore, the variables that describe the goal of the model are mainly the quantity and the quality of raw milk produced by farmers as main producers and the cost of raw milk collection and distribution incurred by the cooperative and of processing raw milk into dairy products by the manufacturer. Essentially, since changes of flow of raw milk will have a great possibility for disrupting the whole production process and lessen the financial performance of every actor in a particular supply chain, then these variables are expected to provide main indicators for the dynamics of the whole supply chain.

However, the focus of the model is also to find the emergence in the production system given the presence of risk. The "do something" box in Fig. 8 actually represents if there are any efforts from the downstream actors (in this case are the distributor and manufacturer, respectively) to collectively deal with the risks that expose upstream actors. If the previous hypothetic condition is assumed true, it can be seen that decreasing level of production in the upstream actors caused by risks will become systemic risk, or supply chain risk, because it manifested throughout the chain. In this case, the manufacturer has to do something to secure its raw materials supplied from the distributor, and in turn, the distributor does the similar on the main producer to guarantee the capability of its logistical function. Similarly, the main producers have to keep the state of vulnerability low in order to continue the production. For example, to overcome fodder scarcity faced by farmers, the downstream actors could involve in the provision of commercial fodder and other input as well. Therefore, risky events associated with the uncertainty of input availability can probably be reduced in the upstream level. Thus, it is one of the main concerns of this research to present these phenomena through the proposed model.

4 Summary

A basic agent-based model for assessing supply chain risk has been introduced in this paper, specifically in milk production. The agent-based approach used in conceptualizing the model is proposed given that its flexibility to accommodate the real phenomenon is very complex. In the real world, milk supply chain has many stages of production performed by various actors with the different levels of technology and in the different time, thus consisting of complex decision-making structure. The model can conceptually demonstrate that risks faced by upstream actors will likely be transferred to downstream actors throughout the chain through the level of production as the outcome of given risk management practiced by each actor. It is possible that the production outcome of one actor in one stage becomes the source of risk for later actors in the later stages. This condition implies that risk management in a particular supply chain should be practiced in a systemic manner involving all actors in the milk supply chain.

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