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Abstract

This working paper describes a process to develop an agent-based simulation of dairy supply chain in Indonesia. The discussion begins by describing the situation in the case study area. Then we explain the assumptions used in to develop agent-based simulation in this study. The simulation experiments show that the agent-based simulation can produce outputs that resemble the patterns in the real-world data. This paper ends by discussing the conclusions and plan for further research.

Keywords: Agent-based simulation, dairy supply chain

1. Introduction to the dairy supply chain in Indonesia

Figure 1 shows the typical dairy supply chain in Indonesia that is composed of many tiers comprising farmers (producers), cooperatives (collector and handler), milk processing industries (manufactures), retailers and consumers.

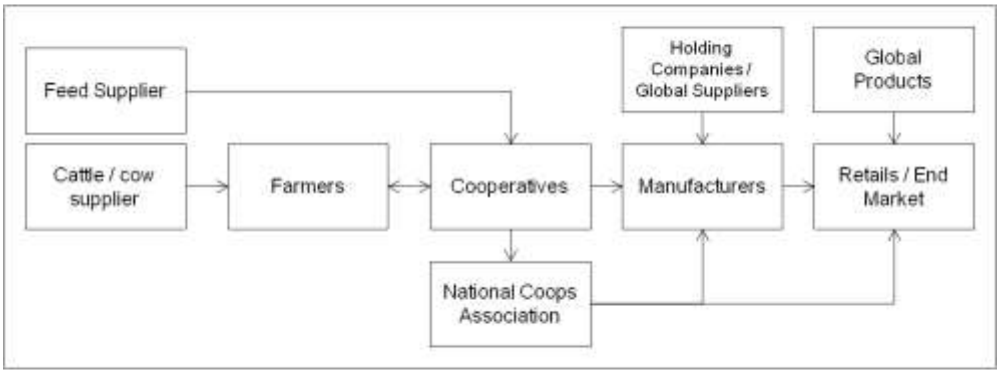

Figure 1 Generic structure of dairy supply chain in Indonesia (Daud et al., 2015)

In common with earlier studies (for example Glock (2012)), the number of farmers is large while the number of milk processing industries. Most farmers are smallholders with low production levels. Due to population pressures, the farmer's land is relatively small and, usually, it is only sufficient to build a pen for their cattle. The pens are usually located next to the farmers' houses in the middle of residential areas for security reasons. The forage grows along the road and river banks. It is difficult for the farmers to herd their cattle through the residential area. Therefore, the forage must be gathered from outside of their village and transported back using carts or motorcycles. In this sense, forage is a common resource for all these farmers. When the forage availability is low, the competition between farmers to obtain forage becomes more intense.

(A) (B)

Figure 2 (A) A cattle pen in the middle of a residential area. (B) A farmer is transporting forage using a cart.

In this supply chain, the milk produced by the farmers is collected and transported to the milk processors by farmers' cooperatives. The role of a farmers' cooperative is important because it is cheaper for the milk processing industries to buy milk in large quantities and, also, the milk that is highly perishable must be transported efficiently and refrigerated at all times (Glover et al., 2014, Manish and Sanjay, 2013), this is prohibitively expensive for the smallholder farmers. However, the farmer cannot fully control the cooperative's decisions because the cooperative also has external investors, shareholders and employs professional managers and workers. Hence the cooperative works like an independent company with smallholder farmers act as its suppliers that have little influence on the cooperative's decisions.

2. The process to model the dairy supply chain in West Java using Agent-Based Simulation

Utomo et al. (2018) suggested that the majority of ABS applications in the agri-food supply chain focus on one tier namely the producer. Moreover, previous studies were commonly carried out in high-income countries and involve big farmers. The agent-based simulation in this paper features a dyadic interaction between smallholder farmers and the cooperative in

Pangalengan, West Java. Pangalengan is a 27,294.77 ha agricultural and plantation region. Smallholder dairy businesses have emerged in this region since the 1940s. Nowadays, the dairy supply chain in this region is one of the biggest in Indonesia hence it is considered to be representative of other dairy supply chains in the country.

We began developing an ABS dairy supply chain in Pangalengan by gathering the relevant body of knowledge from previous studies, as suggested by Gilbert (2004). We found two sets of models relevant to the dairy supply chain in the previous literature. The first set of models assumes that farmers have a land endowment. They maximise their income by allocating their land to produce multiple crops. If they decide to produce milk, then they allocate some of their land to grow the forage. Examples of these models are Happe et al. (2009), Happe et al. (2011), Marohn et al. (2013), and Quang et al. (2014). The second set of models comprise grazing models in which the farmers herd their livestock to a common source of forage (i.e., the rangeland). Examples of these models are Boone et al. (2011), Rasch et al. (2016), Martin et al. (2016), Rasch et al. (2017). In the case study area, the farmers also mainly rely on their surrounding environment as a common source of forage. Hence we considered the second set of models to be more suitable as the foundation of our modelling. The main difference is that the farmers in our case need to transport forage for their cattle, while the cattle do not move at all. Forage transportation introduces more production constraints into our modelling such as labour, working hours and transport capacity.

This model aims to replicate outputs such as milk production, cow population and number of farmer household trends in Pangalengan. We selected these parameters because they are considered to be important by policymakers as such they collect these statistics annually. To produce these outputs, the model uses several inputs such as the initial number of farmer households, number of family labour, cattle ownership, and cow's productivity. Using these inputs, the ABS simulates how agents make decisions such as when to buy or sell their cows, and how to determine milk buying price based on its quality. Figure 3 describes the inputs and outputs of this model.

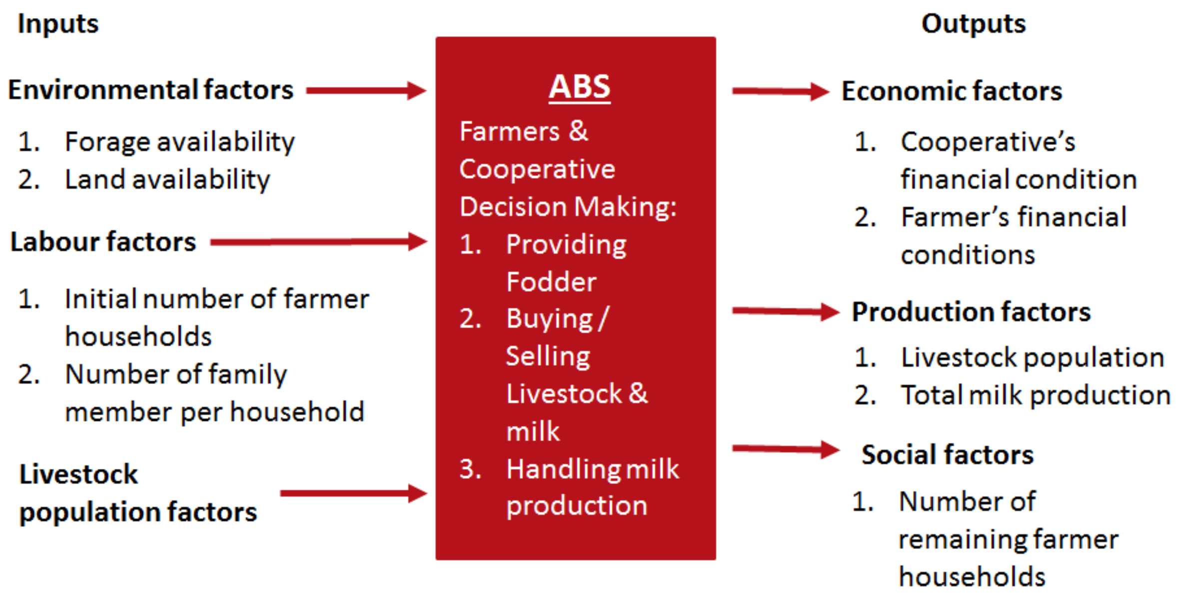

Figure 3 Input and output parameters in the simulation

Following the suggestion from Macal and North (2010), we then specified the agents, their attributes, relationships and behaviours based on this body of knowledge. We used NetLogo (Wilensky, 1999) programming platform to implement the conceptual model. After the simulation implementation, we carried out verification and sensitivity analysis to eliminate errors in our ABS. We presented and discussed our ABS in front of with an expert panel in Indonesia to face validate it. This panel comprised of university researchers and policymakers from the Animal Husbandry Department, and an experienced farmer. The face-validation aimed at ensuring that our ABS has some correspondence with the reality and that its behaviour can be accepted rationally (Schmid, 2005) by the expert. As suggested by Sonderegger-Wakolbinger and Stummer (2015), in this face-validation process, the experts could recommend revisions on the assumptions, the agent's behaviour and the parameter values used in our ABS. We then used the experts' suggestions to adjust and to improve our ABS described below.

3. Model description

The ABS of dairy supply chain in Pangalengan involves three types of agents namely, a number of separate farmer households, a cooperative and patches. The farmer households' role is to produce milk and supply the cooperative. The cooperative sets the milk price based on the milk quality and then sells the milk to the milk processing industry. The farmers interact with the patches whose main function is to provide forage for their cows. The conditions in the case study area are representative for the typical supply chain in Indonesia although the arrangement of the agents in the system may vary. The simulation operates on daily time step, although some processes occur on a monthly and annual schedule.

3.1. The patch agent

One patch represents one kilometre square area (in total there are 306 patches in the model). In the simulation, there are three types of patch (i.e., used patch, unused patch and forage patch). Used patches represent the land area that has been occupied by building, houses, roads, etc. Unused patches represent empty land areas that are not suitable to grow forage but can be used to build new cattle pens. Forage patches represent land areas that are currently overgrown with forage.

Every day the forage patches produce forage. The amount of forage production on these patches (kg per km^2 per day) is defined as a function of the amount forage grow and forage taken, as described in equation 1.

$$\frac{dF}{dt} = Min\big((F_{max} - F_t - Fc_t), (F_t - Fc_t) * (1 + G)\big) \quad (1)$$

F_{max} represents the maximum amount of forage (kg) in one kilometre square area. There are various forage grass species in the case study area, and observation about the actual composition is not available. However, (Bahar, 2014) estimated the forage productivity of various grass composition that can grow in one kilometre square area in Indonesia is between 270 and 734 (tonnes per km^2). Hence, in each run, the maximum amount of forage that can grow on a patch is randomized within this range. F_t is the initial forage level and Fc_t is the amount of forage taken by the farmers on the given day. *G* represents the forage growth rate, which average value is 1.1% (per day) (Bahar, 2014) and it is taken as a constant. Other factors such as precipitation (Gross et al., 2006), are neglected in the current model version.

3.2. The farmer household agent

A farmer household agent consists of several family members who work together to rear cattle. Each farmer household has several attributes. We modelled some of the farmer's attributes as variables (e.g., money, number of cattle, pen area and type of transportation mode). Other farmer attributes are modelled as lists (e.g., family members' age, cattle gender, cattle age, the percentage of fodder fulfilment, services per conception and maximum milk production). Each element in the services per conception and maximum milk production list represent the fertility and the maximum milk that can be produced by each cow respectively. The elements in these lists only have a non-zero value for the cows.

We assume that the farmers accumulate their assets over time, this is in line with the previous studies such as (Gross et al., 2006, Boone et al., 2011). Farmers' assets in this simulation consist of money and cattle. Farmers' income comes from milk and cattle selling, and they use their money to pay monthly living expenses. Based on the discussions with the experts, very few farmers have sources of income other than producing and selling milk. This is because rearing dairy cattle is very time-consuming. Therefore, our model assumes that the farmers do not produce crops or have off-farm jobs. To increase their assets, we assume that farmers have strategies to collect forage, sell milk, sell cattle, buy cattle and expand pen area, this assumption is also in line with previous studies such as Gross et al. (2006) and Boone et al. (2011).

3.2.1. Forage collection procedure

Every day farmers collect forage to feed their cattle. They scan forage patches around their house. The maximum distance they can travel is constrained by the number of working hours and the speed of the transportation mode at their disposal. Each farmer household typically has 8 hours per day to collect forage, after and before they send milk to the cooperative (the cooperative collect milk from farmers at 7 am and 3 pm). In the case study area, the farmers collect forage by walking, motorcycle or truck. In line with Martin et al. (2016), farmers are assumed to prioritise the location with the highest forage level when choosing the location to collect forage. If there is more than one location with the highest forage level, then agents prioritise forage collection from the closest location to their house.

Having decided the location to collect forage, the agents move to the designated patch. Their travel time is taken away from their remaining working hours. The amount of forage they can collect from the given patch is constrained by the patch's forage level, the number of family labour, their remaining working hours and their transport capacity. Actual measurements regarding these variables are not available. Hence we asked the expert to suggest reasonable approximations based on their experience. The expert suggested that each family labour can harvest 40 kg of forage per hour. Further, the expert approximated that they can carry 40 kg of forage per person per trip if they transport the forage on their back or using a cart, 60 kg of forage per trip if they use motorcycle and 600 kg of forage per trip if they use a truck.

3.2.2. Cattle feeding procedure

Farmer agents use the forage to feed their cattle. One cattle require 40 kg of fodder per day which is consists of forage and additional fodder. The expert suggested that to stay healthy, a cattle requires 30 kg of forage a day. For the cows, the forage fulfilment also affects the quantity of the milk they produce. However, the expert suggested that the farmers usually substitute forage with additional fodder whenever they cannot collect sufficient amount of forage for their cattle. This is also in common with a previous study that assumed the level of additional fodder used is affected by the forage availability Gross et al. (2006).

3.2.3. Milk production procedure

Farmers' cows which have been pregnant can produce milk. The first pregnancy usually occurs after the cow's age reaches two years old. The quantity of milk produced is determined by several factors (i.e., age, genetics and forage), which is described in equation 2.

$$Qm_i = \begin{cases} MaxProd_i * NumPreg_i * \overline{Forage}_i & , PregPeriod < 7\ month \\ 0 & , PregPeriod > 7\ month \end{cases} \quad (2)$$

Qm_i denotes the quantity of milk produced by cow i in a day. The $PregPeriod$ variable represents how long the given cow has been pregnant. The farmers usually stop milking a cow which has been pregnant for 7 months and restart the milking process after it gives birth. Hence the milk production during this period is zero. $MaxProd_i$ denotes the maximum milk production which represents the genetic attribute of the given cow. $NumPreg_i$ denotes how many times the given cow has ever been pregnant and it represents the age factor. The expert suggest that a cow achieves its maximum milk production after the second pregnancy ($NumPreg_i(2)$= 100%), the milk production then decreases in the subsequent pregnancies. Actual measurements to establish this function are not available. However, the expert suggested that it is reasonable to assume that the milk production is decreasing linearly. We also assume that the milk production is proportional to the $\overline{Forage}_i$ which represents the average forage fulfilment (between 0 and 1) of cow i. The average forage fulfilment of 1 means that the given cattle always obtain sufficient forage throughout its lifetime.

In addition to the quantity, we also consider the milk quality in our simulation. This variable determines the milk price per litre received from the cooperative. The expert suggested that the milk quality is determined by the average proportion of forage from the total fodder. Accordingly, the highest milk quality is achieved when the average proportion of forage is 75%. Hence, whenever the farmer agents substitute forage with additional fodder, the milk quality decreases and this leads them receiving a lower milk price. We model the relationship between forage proportion and milk quality as a linear function in which the milk quality value is 100% when the forage proportion is 75% or higher.

3.2.4. Cattle selling and buying procedures

Decisions regarding how many cattle should be retained are the most important decision made by the farmer agents because it would affect the amount of forage required, cattle weight, mortality and the amount of additional fodder used (Gross et al., 2006). In this ABS three separate procedures rule how the farmers buy or sell their cattle. In the first procedure, the decision to sell or buy cattle is triggered by the forage availability (Gross et al., 2006, Lie and Rich, 2016, Lie et al., 2017). In the second procedure, this decision is triggered by the cattle's age (Rasch et al., 2016, Rasch et al., 2017). Finally, the last procedure is triggered by farmers' financial condition (Boone et al., 2011).

In line with the previous study (Gross et al., 2006, Lie and Rich, 2016, Lie et al., 2017), in the first procedure, we assume that the forage availability is a trigger for the farmers to sell or buy cattle. When the forage is less available (e.g., during a drought), they sell some of their cattle and, conversely, buy new cattle (cows in particular) when the forage becomes more available. We assume that the farmers sell or buy their cattle to an external agent outside the system and not to other farmers (Boone et al., 2011, Lie and Rich, 2016, Lie et al., 2017, Rasch et al., 2016, Rasch et al., 2017).

Our ABS assumes that the farmers can make a short-term forecast of forage availability when deciding whether to sell or buy cattle. They do this by calculating the average forage they obtain each day. If the average forage collected is less than the amount of forage required to feed all of their cattle the farmers will start to sell their cattle. According to the experts, since the bulls do not generate routine income, the farmers will prioritise to sell them first. Only when they do not have any more bulls will they start to consider selling their cows. When selling the cows, farmer agents compare the potential income they can obtain by feeding less forage but retaining all of their cows (equation 3), and the potential income they can obtain by selling some of their cows in order to feed the remaining cows with sufficient forage (equation 4).

$$income^{retain} = \#Cow\left(\left(\overline{Qm} * \overline{MP} * \frac{\overline{Fc}/_{\#cow}}{30}\right) - \left(\left(10 + 30 - \frac{\overline{Fc}}{\#Cow}\right) * AfP\right)\right) \quad (3)$$

$$income^{sell} = \frac{\overline{Fc}}{30}\left((\overline{Qm} * \overline{MP}) - (10 * AfP)\right) \quad (4)$$

In equation 3 and equation 4 equations #cow denotes the number of cows currently owned by a farmer. $\overline{Fc}$ represents the average forage obtained by the farmer and $\overline{Fc}/_{30}$ represents the maximum number of cow the farmer can retain for the given forage availability. $\overline{Qm}$, $\overline{MP}$ and AfP represent the average milk production per cow, the average milk price per litre and the additional fodder price respectively. In equation 3, the farmer has more cows to produce milk but suffers a production penalty owing to the lack of forage and must pay more for extra additional fodder. In equation 4, the farmer has fewer cows but each cow can produce more milk and the agent does not need to buy extra additional fodder. If $income^{sell} > income^{retain}$ then the farmer will decide to sell the cows and vice versa.

Our ABS assumes that when selling cattle the farmers will prioritise to sale the oldest cattle first, this is in line with the previous modelling studies (e.g., Boone et al. (2011)). The farmers use this priority because an older animal usually has more live weight and more valuable (Quang et al., 2014). For the cows, in addition to having more live weight, the milk productivity of an older cow has decreased.

On the contrary, if the farmers can collect more forage than is needed, then they start to consider to buy more cows. The number of new cows a farmer is willing to buy is proportional to the additional cows that can be fed using the excess forage (see equation 5).

$$Add\_Cow = \begin{cases} Roundeddown\left(\overline{Fc}/_{30} - \#cow\right) & \text{, if } \left(\overline{Fc}/_{30} - \#cow\right) > 0 \\ 0 & \text{, if } \left(\overline{Fc}/_{30} - \#cow\right) \leq 0 \end{cases} \quad (5)$$

The constraints in the buying decisions are the pen capacity and the farmer's money. If the farmer owns sufficient pen capacity to contain all of his/her cows (including the new cows), then the farmer only needs to have enough money to buy the cows. However, if the farmer does not have sufficient pen capacity, then he/she must have enough money to buy the cows and to increase the pen capacity. The farmer's ability to increase pen capacity is also limited by the land availability on the patch where he/she is living. The fertility and productivity of newly bought cows are assumed to be random.

In the second procedure, a farmer decides to sell his/her cattle by considering the cattle's age. The bulls are commonly sold at two years old. According to experts, farmers believe that the bulls have reached their optimum live weight at this age. Meanwhile, the cows are commonly culled when they reach the age of 10 years. It is believed that at ten years old a cow's milk productivity has become too low. In future research, we will collect data regarding the actual age at which the bulls are sold, and the cows are culled.

In the third procedure, a farmer decides to sell his/her cattle by considering his/her financial condition. Each month, the farmer agent forecasts the amount of money it will have at the end of the month by taking into account the income it earned in the previous month and the living expenses it must pay. The living expense value is calculated by multiplying the number of the farmer's family members and the standard cost of living in the area. If the forecasted amount of money is less than the living expense value, then the farmer agent starts to consider selling its cattle. As in the first procedure, the farmers are assumed to sell the bulls first. In this procedure, we also assume that the farmers select the cattle to sell based on the age. The selling process is repeated until the farmer's money deficit is covered.

In all of those three procedures, the price received by the farmer agent when selling their cattle is assumed to be proportional to the age of cattle being sold (see equation 6 and 7). In these equations, Bull price and Cow price denote the money that will be received by the farmer agent. Age_i denotes the age of the animal being sold in moths. Max Bull Age and Max Cow Age represent how long an animal is usually retained by farmers (i.e., 24 months for a bull and 120 months for a cow). Finally, Max Bull Price and Max Cow Price represent the price of bull and cow that is sold at optimum live weight i.e., 16 and 13 million rupiahs (Indonesian currency) respectively.

$$\text{Bull\_price} = \frac{Age_i}{Max\_Bull\_Age} * Max\_Bull\_Price \tag{6}$$

$$\text{Cow\_price} = \frac{Age_i}{Max\_Cow\_Age} * Max\_Cow\_Price \tag{7}$$

When a farmer decides to buy a new cow, the price that must be paid is assumed to be constant, i.e., 9 million rupiahs.

3.2.5. Cow reproduction

In the previous studies the cow reproduction is commonly modelled with a fixed schedule (e.g., annually) or growth rate (e.g., increase the population by 10% every year) (e.g., Gross et al. (2006), Rasch et al. (2016), Martin et al. (2016), Rasch et al. (2017)). Our ABS considers cow fertility factor that is heterogeneous. In cow reproduction procedure, the farmers artificially inseminate those cows who are two years old or older and not pregnant at the beginning of each simulation month. The successfulness of the artificial insemination process depends on the cow's fertility, which is represented by the services per conception variable. If the artificial insemination fails, then this process would be repeated in the subsequent month.

If the artificial insemination process is successful, then the pregnancy process lasts for nine months. The cow then gives birth to either a male or female calf each with 50% probability. If the cow gives birth to a female calf, then the newborn calf inherits the milk productivity and fertility of its parent.

3.2.6. Farmer households retirement and succession

There are two main factors affecting farmer retirement and succession namely, age and financial condition. At the end of each simulation year, all farmer household members who are older than 72 years old (the productive age in the case study area) are removed from the farmer household family member list and the number of family labour decreases. A farmer household agent can also acquire a new family member with a probability of 1.2% (the average population growth in Indonesia). A farmer household agent is deleted from the simulation if it does not have any family member left or if it runs out of money and cattle.

Probabilistically, a new farmer household can be generated in the simulation. Its attributes are defined based on the input parameters, as in the initiation procedure of farmer household agents. However, as we mentioned earlier, owing to population growth, the farmland that was once located in the rural area is currently surrounded by residential areas. The existence of a farmer household who continue dairy farming is tolerated by the non-farmers because they are native to the area while the non-farmers are mainly newcomers. The cooperative's database also shows that all of its members are farmer families from generation to generation. However, conflict with non-farmers could spark easily if a newcomer tries to start dairy farming. This conflict is usually triggered by pollution caused by manure production and potential water contamination. When a farmer household decides to quit dairy farming their land will usually be sold and converted into residential area settlement or another business. Our simulation aims to replicate the reality in the case study area so the probability of a new farmer household agent entering the system is set to be equal to zero.

3.3. The cooperative agent

The cooperative agent collects and grades milk from all farmer household agents. We assume that the cooperative determine the milk buying price as a linear function of milk quality, ranging from 3350 to 5200 (IDR per litre). Based on the discussion with the experts, the cooperative sell the milk to the milk processing industry at a fixed price. The actual buying price from the milk processing industry is unknown, but the experts estimated that it is approximately 5500 (IDR per litre). The experts agreed that the cooperative's daily operational costs could be assumed to be fixed regardless of the total volume of milk they handle. Hence, it is more profitable if they can operate at full capacity.

4. Simulation experiments

This section discusses simulation experiments aim to analyse the output of the model. To validate the ABS the real cattle population, cow population, milk production and the number of farmer households data obtained from the farmer cooperative (KPBS, 2016) are used. The number of agents involved in these experiments was 5700 farmer households; this is in line with the number of farmers in the case study area in January 2010.

The ABS was run for five simulation years (from January 2010 to December 2014) and replicated 30 times. The simulation data in Figures 4 to 7 represent the average of 30 simulation replications.

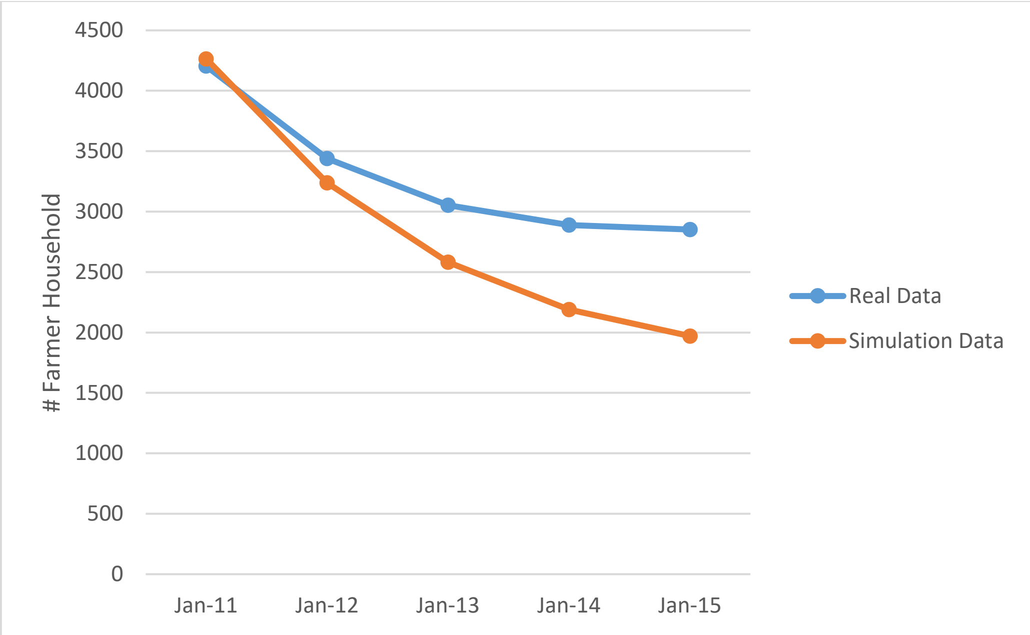

Figure 4 the number of surviving farmer household

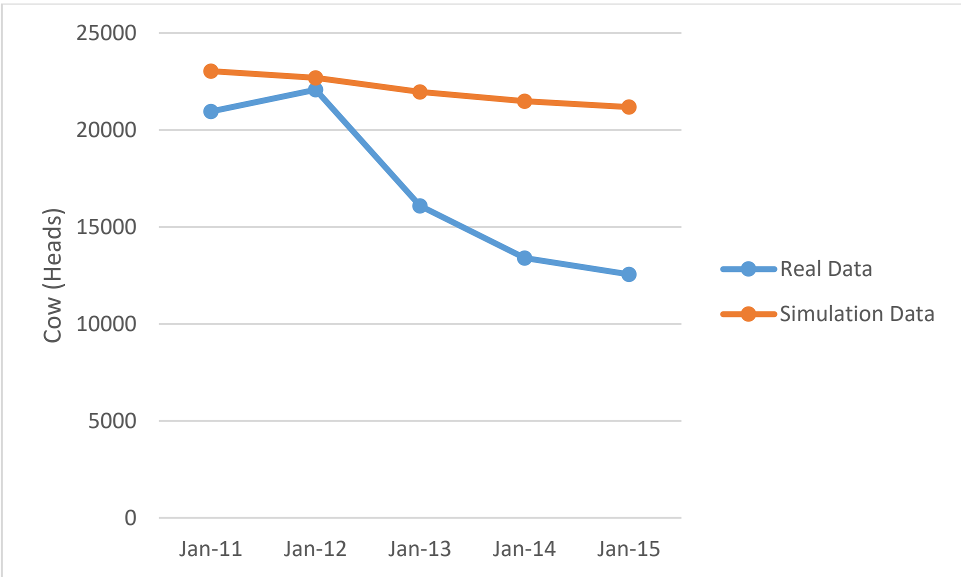

Figure 5 the cow population

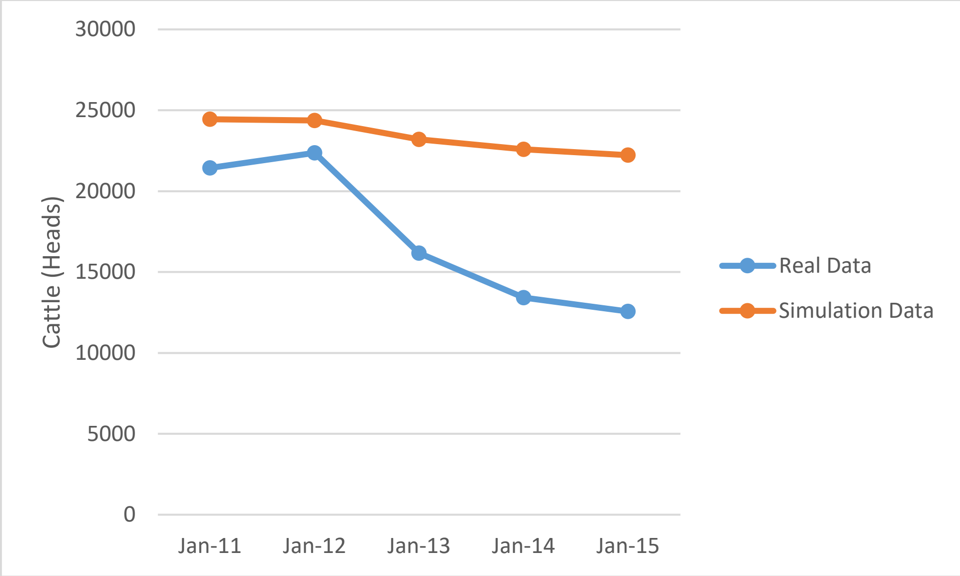

Figure 6 the cattle population

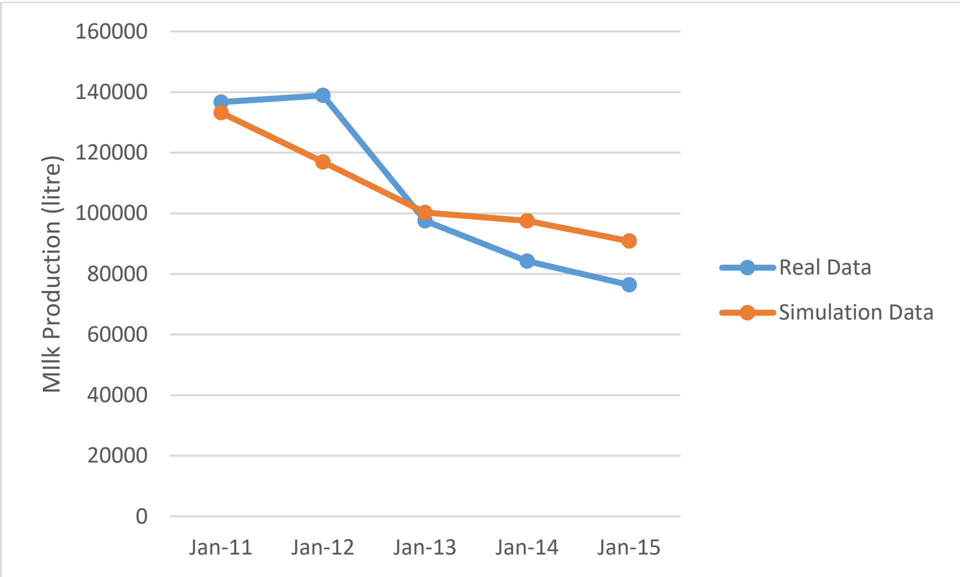

Figure 7 the daily milk production

These experiments show that the number of farmer household, cow population, cattle population and the daily milk production tend to decrease overtime. Figures 4 to 7 show that these patterns correspond to real data obtained from the farmer's cooperative. Thus the ABS presented in this working paper has sufficient validity.

5. Conclusion

This working paper has described a case study of dairy supply chain in West Java Indonesia. We have discussed the process to model this dairy supply chain using ABS. Our ABS has some uniqueness compared to previous ABS applications because it features dyadic interactions between the farmers and the cooperative. Moreover, it considers the heterogeneity of cow's fertility and milk productivity. The simulation experiments show that the output of our ABS has high correspondence with the real-world data. In the future study, we plan to collect primary data to calibrate this ABS empirically.

6. References

BAHAR, S. 2014. Produktivitas hijauan pakan untuk produksi sapi potong di Sulawesi Selatan. *JITV,* 19.

BOONE, R., GALVIN, K., BURNSILVER, S., THORNTON, P., OJIMA, D. & JAWSON, J. 2011. Using coupled simulation models to link pastoral decision making and ecosystem services. *Ecology and Society,* 16.

DAUD, A., PUTRO, U. & BASRI, M. 2015. Risks in milk supply chain; a preliminary analysis on smallholder dairy production. *Livestock Research for Rural Development,* 27**,** 137.

GILBERT, N. 2004. Agent-based social simulation: dealing with complexity. *The Complex Systems Network of Excellence,* 9**,** 1-14.

GLOCK, C. H. 2012. Coordination of a production network with a single buyer and multiple vendors. *International Journal of Production Economics,* 135**,** 771-780.

GLOVER, J. L., CHAMPION, D., DANIELS, K. J. & DAINTY, A. J. D. 2014. An Institutional Theory perspective on sustainable practices across the dairy supply chain. *International Journal of Production Economics,* 152**,** 102-111.

GROSS, J. E., MCALLISTER, R. R. J., ABEL, N., SMITH, D. M. S. & MARU, Y. 2006. Australian rangelands as complex adaptive systems: a conceptual model and preliminary results. *Environmental Modelling & Software,* 21**,** 1264-1272.

HAPPE, K., HUTCHINGS, N. J., DALGAARD, T. & KELLERMAN, K. 2011. Modelling the interactions between regional farming structure, nitrogen losses and environmental regulation. *Agricultural Systems,* 104**,** 281-291.

HAPPE, K., SCHNICKE, H., SAHRBACHER, C. & KELLERMANN, K. 2009. Will They Stay or Will They Go? Simulating the Dynamics of Single-Holder Farms in a Dualistic Farm Structure in Slovakia. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie,* 57**,** 497-511.

KPBS 2016. Data Populasi dan Penghasilan Anggota KPBS. *Unpublished Dataset.*

LIE, H. & RICH, K. M. 2016. Modeling Dynamic Processes in Smallholder Dairy Value Chains in Nicaragua: A System Dynamics Approach. *International Journal on Food System Dynamics,* 7**,** 328-340.

LIE, H., RICH, K. M. & BURKART, S. 2017. Participatory system dynamics modelling for dairy value chain development in Nicaragua. *Development in Practice,* 27**,** 785-800.

MACAL, C. & NORTH, M. 2010. Tutorial on agent-based modelling and simulation. *Journal of Simulation,* 4**,** 151-162.

MANISH, S. & SANJAY, J. 2013. Agri-fresh produce supply chain management: a state-of-the-art literature review. *International Journal of Operations & Production Management,* 33**,** 114-158.

MAROHN, C., SCHREINEMACHERS, P., QUANG, D. V., BERGER, T., SIRIPALANGKANONT, P., NGUYEN, T. T. & CADISCH, G. 2013. A software coupling approach to assess low-cost soil conservation strategies for highland agriculture in Vietnam. *Environmental Modelling & Software,* 45**,** 116-128.

MARTIN, R., LINSTÄDTER, A., FRANK, K. & MÜLLER, B. 2016. Livelihood security in face of drought – Assessing the vulnerability of pastoral households. *Environmental Modelling & Software,* 75**,** 414-423.
QUANG, D. V., SCHREINEMACHERS, P. & BERGER, T. 2014. Ex-ante assessment of soil conservation methods in the uplands of Vietnam: An agent-based modeling approach. *Agricultural Systems,* 123**,** 108-119.
RASCH, S., HECKELEI, T., OOMEN, R. & NAUMANN, C. 2016. Cooperation and collapse in a communal livestock production SES model – A case from South Africa. *Environmental Modelling & Software,* 75**,** 402-413.
RASCH, S., HECKELEI, T., STORM, H., OOMEN, R. & NAUMANN, C. 2017. Multi-scale resilience of a communal rangeland system in South Africa. *Ecological Economics,* 131**,** 129-138.
SCHMID, A. 2005. What is the Truth of Simulation? *Journal of Artificial Societies and Social Simulation,* 8.
SONDEREGGER-WAKOLBINGER, L. M. & STUMMER, C. 2015. An agent-based simulation of customer multi-channel choice behavior. *Central European Journal of Operations Research,* 23**,** 459.
UTOMO, D. S., ONGGO, B. S. & ELDRIDGE, S. 2018. Applications of agent-based modelling and simulation in the agri-food supply chains. *European Journal of Operational Research,* 269**,** 794-805.
WILENSKY, U. 1999. NetLogo: Center for Connected Learning Comp.-Based Modeling. *Evanston, IL: Northwestern Univ,* 158.