ISSN 2234-3075(Print)
ISSN 2288-7806(Online)
Http://dx.doi.org/10.14771/AIM.9.1.1

Exploring Quality Issues of Dairy Supply Chain and Proposing IOT -enabled Tracking Systems in Developing Country

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Abstract Recent scandals of milk additives in several developing countries provoked controversy about quality issue of dairy products, grapping academic attention to the dairy supply chain. In this paper, we first focus on moral hazard problem of self-interested entities about the quality across the dairy supply chain, due to unobservable and unverifiable quality management efforts of all entities – including dairy producers, stations, and a final producer – and high inspection cost for the quality. Based on the identified moral hazard problem, we understand why the adoption of IoT-based tracking systems about quality produced from each entity is a must, different from RFID-based tracking systems.

Keywords dairy supply chain, moral hazard, incentive, quality management, IoT-based tracking systems

Article history
Received 31 October 2016
Received in revised form 2 November 2016
Accepted 8 November 2016

1 Introduction

Demand of dairy products in developing countries has been increased for the last few years, and its margin has been considerably increased through proactive promotion for the credit side of milk, and with the increase of income. (Delgado 2003, Food and Agriculture Organization of the UN 2014).
Nevertheless, the quality of dairy products in most of developing countries is far from unsated level. Especially, the scandals in relation to dairy products occurred in developing countries have lead to a crisis of dairy industry itself, and this has drawn an attention from the government and academic circles (Sarnsamak 2010, Souza et al. 2011). In China, for example, as melamine is contained in milk and other products for infants, together with other food additives, 300 thousand people were victimized officially, and 6 of them were deceased because of renal calculus. (Branigan 2008, McDonald 2008, Macartney 2008)
Despite this problem, the quality management of dairy supply chain has been recognized as uncontrollable due to a few reasons. First, in most of the countries including China and India, the farms which produce and process raw milk are scattered around the country. It is because they need a wide land and good environment to raise dairy cattle. In case of China, Inner Mongolia takes 16.05% of the total milk production.
Second, as diverse types of enterprises, including producers, stations and final producers, are participating in the process of dairy production, while taking part of the whole supply chain, they may affect the quality directly or indirectly. Therefore, if the quality issue of final raw milk products are aroused, it will be very hard to find the reason, or who is responsible for it.
However, as the cost of testing raw milk collected by the gatherers from producers is very high, they just have to rely on a simple test. For the raw milk producers, as the final product is not released under their names, they just fulfill the minimum requirements of simple quality test (Gale and Hu 2009, Siddhaye 2010). Speaking of the shock caused by melamine in China, it was revealed that the raw milk producers added melamine to reduce the production cost, and they made unfair profits by abusing this simple quality test (Omore et al. 2005, Khan 2008). Therefore, through this study, I will discuss about the incentive problem of the entities in the raw milk supply chain of developing countries, and try to find out a solution

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based on the existing researches. Furthermore, as most of the problems are related to the quality management of the supplied raw milk, I will try to find out the effect of IoT-based history tracking systems from the economic point of view. Lastly, I would like to propose a designing method of IoT-based history tracking systems.

2 Structure and Incentive of Dairy Supply Chain

All the enterprises in the raw milk supply chain do not have much interest in the quality of final products. In this paper, I will first look into the economic incentive of each entity based on the simplest type of raw milk supply chain. First, the minimum number of entities is shown in the picture below.

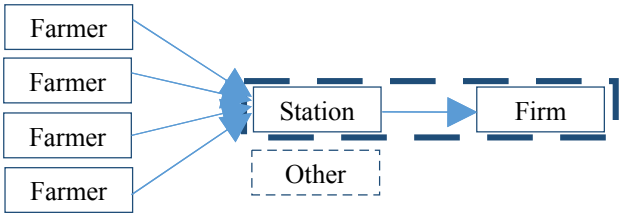

Figure 1 Structure of raw milk supply chain

In developing countries, most of the raw milk producers have too many responsibilities. First, they have to take care of all the procedures including the purchase of milk cows, their health care and milk collection, and they also have to manage the environment of inside and outside of the cattle breeding farm. In addition, in most of the farms as mentioned before, as they put the cattle out to pasture to provide a healthy environment, it is necessary to maintain the freshness of raw milk in the process of delivering it to the gatherers, after collecting it.

In other words, they have to manage the supply and demand according to the environment change, and control the freshness in the process of delivery, after collection. Therefore, even apart from the problem of adding toxic materials such as melamine, they have a considerable incentive to use non-toxic food additives for maintaining its freshness.

Gatherers check the quality of milk coming from diverse producers, and deliver it to the final producers, after mixing them. In most of the developing countries, gatherers have to manage at least 100 to 200 producers, and process the milk collected from them every day, as it has to be transported to a long distance instantly due to its characteristics. In addition, diverse tests for specific milks are executed, as well (Jones 2012).

Generally, gatherers may check if the milk is in good condition or not through measuring the weight of it, and a simple visual inspection. For example, the level of body fat in milk can be measured by Gerber test which is considered to be relatively cheaper one. However, Resazurin test, which is developed to check the level of quality and the existence of food additives, is known as relatively expensive one (Food and Agriculture Organization of the UN 2009).

Therefore, the problem of testing the quality of raw milk inevitably leads to that of testing cost, and practically, gatherers are doing the minimal tests in accordance with that problem.

Lastly, we also have to consider the producers and sellers of the final products. (In some of the countries, most of the gatherers are final sellers. However, I consider them separately in this paper. Although I regard theses entities as one enterprise, there is no difference in theory.) The final sellers can produce diverse milk products by using the raw milk collected from the gatherers.

The problem is that the quality of the final products may be greatly influenced by that of raw milk, and it also influences the price, as well as the reputation of enterprises. Therefore, if a problem is caused by food additives (We call it 'external failure'.), we have to decide how its responsibilities can be distributed to the entities in the supply chain.

As mentioned before, we cannot observe[1)] who is responsible for the problems among those producers or gatherers, and it cannot be effective even if it is forced by making an agreement. Therefore, there occurs a problem of information asymmetry about the result of each final producer's effort for quality.

To sum up, the producers try to fulfill the minimum quality requirements demanded by gatherers, and if gatherers increase the number of requirements, the quality of raw milk can be improved, however, they have to accept the cost for testing the raw milk supplied by hundreds of producers, everyday.

3 Incentive Design of Dairy Supply Chain

With regard to incentive design, we may consider two types of situations. First, it is the case that quality problem is caused only by the producers, and practically, almost

1) I quote the economic terminology 'verifiability.' That is, even if there is a problem, and a lawsuit and dispute arose, it is not possible to find out exactly who supplied the raw milk in bad quality, and how much of it, eventually.

every problem of food additives has been caused by them. (Refer to Omore et al. 2005, Kenya)
In this case, as the quality problem of raw milk is caused by the producers, the gatherers can find out the problem of low quality only when they test it, and if there is an external failure, it is not possible to find out who is responsible for the problem. Therefore, I define it as 'Single moral hazard.'
In this case as well, the supply chain may have difficulties because of high test cost and free-riding of the producers. On the other hand, if gatherers may influence the quality due to the problems created by storage, processing or refrigeration facility, we call this 'double moral hazard.' Generally, as the former problem is more serious in developing countries (Mu et al. 2014, Mu et al. 2016), I am going to deal with the double moral hazard first to make this paper more interesting.

3.1 Benchmarking: First-Best Outcome

Same as in the case of prisoner's dilemma, even if having a phenomenon of information asymmetry, participants in the supply chain can earn the first-best outcome[2] when they are managing the quality not for their own benefits, but for the success of supply chain.
In this case, it does not create an inspection cost in the supply chain, and minimizes the amount of cost for external failure. I think that IoT-based tracking system will make the participants can share all the information about stock farming and its environment, eliminate the information asymmetry of supply chain by opening the final producers' information and profits, and eventually, solve the problem of moral hazard. I will discuss about the detailed flow of data and information that should be collected, later.

3.2. Double Moral Hazard Problem

First, if an external failure is created, let's think about the case where the enterprise (or the government) imposes a penalty to both producers and gatherers. Intuitively speaking, producers and gatherers may seem to produce and process quality milk as they are worried about being fined. However, it is just a case where the responsible entity, whether it is one of those producers or gatherers, can be identified through a correct ex-post evaluation. In the present raw milk supply chain, it is not possible to clarify who is responsible as a large amount of raw milk is coming from a number of producers every day, in a mixed state, and if the gatherers' effort influences the quality, the responsibility cannot be identified.
As the second possible solution, we may consider a group penalty. However, Lee et al. (2013) showed that responsibility sharing does not lead to the first-best outcome if moral hazard is committed by both parties. For example, let's consider the case where producers pay 50% of the cost for D (Damage) caused by an external failure, and gatherers pay the other 50%.
Gatherers and producers will make a decision by considering the desired probability of an external failure which will cause a financial loss, and comparing the costs for managing the quality, as well. In most cases, as the quality management cost is relatively high, producers may improve the quality in a certain level, however, it can never reach the level of satisfaction (i.e. the first-best outcome). Therefore, in most of the raw milk supply chains, if group penalty is imposed to the participants of them, it will give them a clue to escape, thus it will increase the total cost of the supply chain, and it will not help to improve the quality.
Interestingly, Balachandran and Radhakrishnan (2005) showed that if gatherers raise the quality level of raw material collected from the producers by strengthening the test standard, and accept all the charges caused by an external failure while processing and delivering the product to the final sellers, we can get the first-best outcome in the supply chain. In other words, although the test cost is high enough, we can make the gatherers do the best to manage the quality while encouraging the producers to raise the quality as much as possible, if strengthening the quality standard. In this case, however, who pays for the test will be an issue.
For this problem, it seems possible to be solved through the governmental intervention, or driving a mutual competition between the final sellers or gatherers. However, Mu et al. (2016) showed that providing a government subsidy or supporting for the test cost would rather exert a bad influence. Therefore, in case that both parties have a problem of moral hazard, it will be positive to the dairy supply chain ecosystem when the producers can reduce the quality test cost, and the gatherers share a responsibility in case of an external failure.

2) First-best outcome an economic term which is about the behaviors of each participant under the perfect information where the information about all the activities of the people participating in a game is shared, and in this case, the problem of moral hazard will not be created.

3.3. Single Moral Hazard Problem

If all the quality-related problems are coming from the raw milk producers, the issue can be simplifed. However, if there are a number of producers, and raw milk is mixed by the gatherers and delivered to the final producers, each producer tents to take a free riding[3] while thinking that the others will take care of the quality problem. How about giving compensation to the producers who produce quality products? In terms of economics, a number of different types of compensation have been suggested. However, compensation to the producers who produce high-quality products could rather lower the quality level, and decrease the gatherers' profits (Mu et al. 2014).

As there are a growing number of producers who produce high quality milk, the gatherers tend to have a burden for having tests, and in this case, the producers try to lower the quality level and have a free ride, rather than making profits from compensation. It showed that imposing fine to the producers who produce low-quality products will be helpful.

On the other hand, we may have a different result if there are several gatherers who compete against one another. According to Mu et al. (2016), when gatherers are competing against one another, group compensation, which provides rewards to the gatherers with a high test standard and the producers who supply products to those gatherers, is helpful for managing the supply chain.

In other words, as the producers can make more profits through a competition than having a reward for quality tests, they are willing to accept it. In addition, as producers in the supply chain can make profits by producing high-quality milk, it is necessary for them to invest more. However, even in this case, although the level of quality can be increased, it can never reach the first-best outcome.

I have been going through diverse research papers which were written about the economic problems of each entity in the milk supply chain, and its solutions. I could find the best efforts and results from the entities of the supply chain if it is an unrealistic and special case (i.e. in case that the quality of raw milk is solely depends on the producers, and there is only one producer). Therefore, it appeared that compensation for high quality and diverse punishments for an external failure bring a result which is a lot different from our intuition. Therefore, it seems that we need a system which can trace each entity's endeavor.

In the next chapter, I will find out what kind of positive economic benefits each entity can have, if we adopt an IoT-based tracking system.

4 Economic Issues of Iot-based Tracking Systems Adoption

There is an economic argument about the subject who will adopt a tracking system. Pouliot and Summer (2008) typically shows that traceability improves the stability of food. However, Resende-Filho and Hurley (2012) also showed that if the government forces them to adopt a tracking system through imposing fines, it does not increase the stability of food, but increases the cost only. On the other hand, Hwang (2009) analyzed the cases of each entity's voluntary adoption of RFID, one of the core technologies of IoT-based tracking system. Interestingly, if an upstream firm adopts RFID first, downstream firms in the supply chain tend to wait until it is finally adopted, as they can reuse this system[4]. Therefore, the firms tend to adopt RFID system later than it is supposed to be. Thus it is important to have a cooperative adoption of technology where all the entities in the supply chain participate in.

5 Justifcation for Iot-based Tracking Systems Adoption

As the interest in safe food is increased, history-tracking system and RFID-based tracking service have been proposed, and its feasibility test has been executed. For the sake of argument, let's find out the information collected through RFID-based tracking system (or, history-tracking system).

We have to obtain the information about dairy cattle, its feeding environment and milking, from the raw milk producers. First thing is about the dairy cattle. We need the information about the milk cows' growth period, varieties and purchasing route. With regard to the feeding environment, the information about manure disposal method, disinfection cycle of the farm, size and distribution of the breeding farm, distribution of dairy cattle and environmental pollution should be included.

3) The problem of free-riding, which is well-known in economics, can be applied to the milk supply chain where gatherers take a mixed testing for the collected milk from producers, which is generally executed to lower the test cost, and the producers producing low-quality milk take advantage of that of the ones who produce high-quality products. Testing all the milk collected from hundreds of producers costs a considerable amount, thus mixed testing is common in most of the developing countries.

4) Hwang named this as 'One-sided free riding.'

Lastly, we need the information about the milking cycle. Speaking of the collection places, we need to propose a standard for clear inspection, compensation and punishment for them. Index of evaluation and the information of applied tests should be recorded. Detailed information such as perception index, physical and chemical indexes, microbiological indicators and pollution index should be included as well. Perception index includes the information about correct colors and smells, and the physical and chemical indexes include the contents of fat, protein and other non-fat materials. Microbiological indicators include the number of germs and information about colon bacillus. Pollution index includes mercury content and inorganic arsenic.

In the transport information, the information about the quality of raw milk in the process of transportation should be recorded. Information about the added artificial materials, their mixing ratio, equipments and environment should be recorded as well. Besides, the information about how the final producers used the specific raw milk may be included.

If RFID is attached based on the collected information above, a limited tracking is possible based on the stored information when having an external failure. In case of the raw milk, however, as it is in liquid state, it is difficult to find out the contributor of a specific problem, which is different from solid foods, and we cannot solve the problem of moral hazard existing in the supply chain by tracing a simple history. In other word, the benefits of adopting RFID are not big enough, practically.

IoT (Internet of Things) is a technology that connects various 'Things' to internet with its built-in communication functions. All the things connected to IoT should have a common IP, and they may have a built-in sensor to receive data from the external environment (Holler et al. 2014).

It is the same as RFID-based tracking system in terms of tracking the quality information based on the data extracted from internet. However, the more important thing is that the extracted information can be applied for extracting advanced information about the traced quality, together with that of being extracted from other objects, and this can also be applied to dairy products. Through IoT, the information about the milk cows and their breeding environment at the time of milking is recorded by each producer, together with the amount of supply, all the information about the transport environment, the quality of other producers' products, and the gatherers. Therefore, if having an external failure, the final producers or gatherers can trace the cause of external failure by tracking back the information about the producers' supply quantity and milking environment. In other words, we can realize an almost perfect information system in the raw milk supply chain.

There still is a problem of expenses for the dissemination of IoT system. A follow-up research on the economic feasibility of the perfect information system and the cost for optimal quality is not introduced yet. It seems desperate to have a research on this part.

6 Conclusion

As the scandals related to dairy products breaks out in developing countries, the government and final production companies' interest in the quality of dairy products is getting higher than ever before.

Based on this idea, various incentive policies related to compensation and punishment have been suggested, and it has created the need for adopting RFID-based history tracking system. Therefore, in this paper, I have tried to find out the problems of these incentive system and RFID-based history tracking system, and brought up a question why we need IoT-based history tracking system.

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