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Faculty of Natural Resources and Agricultural Sciences

Blockchain in agri-food chain

– Shaping an integrated food ecosystem

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- shaping an integrated food ecosystem

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Abstract

Agriculture is on the brink of entering a data-driven economy that will impact growth and business relations. The information- and communication revolution in the agri-food chain aspires to collect data at a low cost. Applying information- and communication technologies to the agri-food chain is believed to help optimise resources and therefore contribute to a smaller environmental footprint. At present, however, there are barriers and many issues that need to be resolved; For example, it is not an easy task to aggregate and interpret large amounts of detailed data to be used in decision support tools for farmers and primary producers. There are also transparency issues due to numerous intermediaries and a need for strengthening the link between different chain actors and levels in the agri-food chain. The agricultural has never before undergone such a digital transformation.

In Great Britain and the Netherlands, Blockchain has been included in the agri-food chain. In Sweden, however, the agri-food chain does not yet apply this new digital structure. Even though digitalisation is used, Blockchain involves larger quantities of information and requires capacity of handling information in transparent and efficient ways. This study investigates the advantages and disadvantages with Blockchain and will hopefully lead to an answer whether Blockchain might influence the transaction costs and the collaboration in the agri-food chain in a positive way.

This study was conducted via secondary sources about Blockchain complemented with four interviews. Because no practical experiments about Blockchain have yet been carried out in the Swedish agri-food chain, the study was limited to the respondents' knowledge of Blockchain acquired from theoretical case studies and working experience. The result from the respondents and from the secondary sources give both positive and negative answers regarding whether Blockchain has potential to decrease transaction costs in the agri-food chain. The transaction costs that have been studied regard information/search costs, bargaining costs and enforcement costs.

The study investigates Blockchain's potential to reduce transaction costs in the Swedish agri-food chain. Transaction costs are additional costs not included in the value of the unit under transaction. The Swedish agri-food chain is characterised by several transaction costs caused by issues such as food frauds, insufficient trust among agri-food chain actors, transparency and traceability issues.

The study concludes that with a Blockchain applied in the agri-food chain, several transaction costs can be reduced. Information costs can be reduced, as more information becomes accessible and traceable. Blockchain also has potential to reduce monitoring costs through cryptographic Smart Contracts and performance-based payment. However, Blockchain is not likely to encourage information sharing unless information sharing is monitored by statutory requirements. Also, the Blockchain network runs on high operation costs of electricity and Internet to verify the Blockchain network's constant update on information.

1 Introduction

The use of digital technologies in the agri-food chain is believed to disrupt the structure of the current agri-food chain (worldgovernmentsummit.org). The World Government Summit (2018) uses the term *Agriculture 4.0* to describe the use of recent communications- and information technologies (ICTs) applied in the agri-food sector. The purpose of the new technologies is to integrate information flows across all levels of collaboration in the agri-food chain, as today's agri-food chain is increasingly knowledge-intensive. Fourth industrial revolution technologies refer to technologies where information and communication technology (ICT) converge (Sung, 2018). In the agri-food chain, the Fourth Industrial Revolution differs from previous industrial revolution in many ways due to smart communication and information sharing. This enables the ability of *Smart Farming*. *Smart farming* involves a more efficient production with sensors and information technologies, where precise and more detailed information can be shared. Above all, it is likely to link producer and consumer in real time (*ibid*.). The Swedish agri-food chain is part of global trade agreements that enhance transparency and information sharing. These technologies are believed to disrupt the existing market structure of intermediaries between producer and consumer (Sung, 2018).

A prerequisite for using information on different levels of the agri-food chain is sharing a common information platform. An important component that is believed to revolutionise the agri-food chain is *Blockchain*. The distributed ledger technology, *Blockchain* offers new ways to transfer value in the agri-food chain. Blockchain is a decentralised electronically shared information system that registers, stores and shares information in a shared network (Abadi & Brunnermeier, 2018). Blockchain initially emerged in 2008 to provide the payment transfer service *Bitcoin* with encryption of data. Using cryptographic mathematical formulas, Blockchain provided Bitcoin with the necessary safety mechanism and made Bitcoin the first platform not to be controlled by one central party or intermediary. The Blockchain technique was the mechanism that enabled data to be shared and stored between its members in a secure decentralized network. Before Blockchain was invented, information could not be shared online without the verification from a trusted third-party. This implied that all transactions had to be made via an intermediary (e.g. bank, Hotmail). The intermediary would usually charge a fee for its service of providing a safe platform/network/system for transferring. Also, information from the transactions was stored and accumulated by the intermediary. The intermediary caused a centralized structure, in which transacting parties were dependent on transfer through the intermediary. This central structure limited data sharing to only one transaction at a time per transacting party. After the breakthrough of Bitcoin, people discovered the potential of Blockchain to be used in other areas than payment transfer service. In the agri-food sector, Blockchain is believed to revolutionize the agri-food chain (FAO, 6, 2018).

1.1 Problem

In 2017, Sweden was poorly ranked as fourteenth of Europe’s most innovative food countries in the yearly European Bloomberg innovation index (Regeringen, 2018; Tillväxtverket, 2018). Poor collaboration between different levels across the agri-food chain was one of the key explanations to the ranking (*ibid*.). Research in the Swedish agri-food sector is concentrated to only a few large chain actors, whereas numerous small actors face challenges in coordinating and communicating research needs (OECD, 1, 2018). Therefore, agricultural research fails to reflect the needs of the whole food sector (*ibid*.). In a survey made by AGFO (2018), appeared that poor collaboration prevents innovation in Swedish agri-food sector.

As a response to the poor ranking results in the European Bloomberg Innovation Index, the Swedish government launched a package of measures to strengthen innovation and competitiveness in the Swedish agri-food chain, with focus on collaboration between different levels in the agri-food chain (Regeringen, 2018). Increased collaboration between different levels in the agri-food chain is believed to stimulate innovation through knowledge exchange and research, as well as advancing decision-making for agricultural authorities. On initiative of the Swedish government, a collaboration platform between different levels in the agri-food sector, called Sweden Food Arena, was launched in 2018. Sweden Food Arena aims to stimulate innovation according to three focus areas, one of the focus areas being “Digitalization and Automatization”. OECD (2, 2013; 3, 2019) carried out a study on information exchange through digitalisation. Several countries were compared. The result shows that implementing digital technologies improves efficiency and can also decrease transaction costs. Transaction costs imply the cost of moving food products along the agri-food chain (Niforos, 2017). The cost of moving food products along the agri-food chain is high and accounts in general for about two thirds of the final price of the products (*ibid*.). Transaction costs prevent beneficial transactions from happening. Transaction costs arise due to inefficient processes; high proportion of manual work or paper work, limited traceability and unavailable information sharing among agri-food chain actors. Transaction costs also arise due to risky situations, which implies that transacting value causes an additional cost. For example, a third-party or a large chain actor accumulates information and has an informational advantage over the small chain actor. Unequal information access is the main reason for the occurrence of transaction costs in agri-food chain (FAO, 3, 2005). Information asymmetry in combination with distance between agri-food chain actors result in possible hiding of information to e.g. consumers about food products. It is also hard to control how and when quality and safety measurements have been done properly. The way the agri-food chain is structured prohibits chain actors from sharing information with each other. IVA (2016) suggests that the Swedish agri-food chain is characterised by a widespread problem of trust among agri-food chain actors, meaning that agri-food chain actors on different levels do not trust each other enough to collaborate and share information with each other. Lack of equal information access reduces transparency, which affects collaboration negatively. This can give rise to trust issues. Large chain actors prevent small chain actors from accessing information (*ibid*.).

Emerging technologies in agriculture (e.g. for precision agriculture) provide more diverse and detailed data that can generate new value and help fulfil political agendas (OECD, 1, 2018). OECD (*ibid*.) argues that digital information platforms have potential to function as political instruments as well as offer new services (advisory and educational) for Swedish agri-food chain actors. Digital technologies for data sharing may decrease the cost for allocating and analysing data as well as administrative costs. Encryption of data offers new possibilities for sharing data and decrease transaction costs in the agri-food chain (*ibid*.). Jordbruksverket (2018) highlights that sharing data and information can help decrease transaction costs in the Swedish agri-food chain.

1.2 Aim and research questions

The aim of this study is to investigate the potential of data sharing through Blockchain to reduce transaction costs in the Swedish agri-food chain.

Based on this aim, the following research questions have been formulated:

Is it likely that Blockchain will reduce transaction costs for chain actors in the Swedish agri-food chain? Which are the opportunities and constraints?

1.3 Contribution

Limited research has been carried out on how to handle data that may be critical for business and confidential, when connecting with chain actors in a data-driven economy. This study aims at addressing how Blockchain can reduce transaction costs in the agri-food chain. Most research conducted on Blockchain in the agri-food chain concerns sustainability issues in the agri-food chain. Little research has been carried out on how Blockchain can address transaction costs. This research aims at filling this gap.

1.4 Delimitations

The study confines itself to the Swedish agri-food chain in general without any further branch specialisation. At this point of time while this study is being made, Blockchain is still in its practical implementation phase. Blockchain has not yet been implemented in the Swedish agri-food chain, however, several theoretical case designs have been made on how the outcome of applying Blockchain would be. There is no empirical evidence or practical examples from Sweden on the outcome of Blockchain in the agri-food chain except for theoretical case designs on the Swedish agri-food chain. There are also several case designs and pilot studies that have been carried out in other European countries.

1.5 Structure of the thesis

The first chapter introduces a background to the subject of Blockchain. Then a description of the problem is presented, leading to the research questions of the study. The second chapter explains the chosen method of research. The third chapter presents the chosen theories. The fourth chapter provides an introduction to Blockchain, in which the sub chapters 4.1 and 4.3 should be read to attain an understanding of Blockchain. The fifth chapter is a combined empirics and analysis chapter. The last chapter presents the conclusions and ideas for further research. Throughout the thesis, additional facts can be found in the grey boxes for those who want more information.

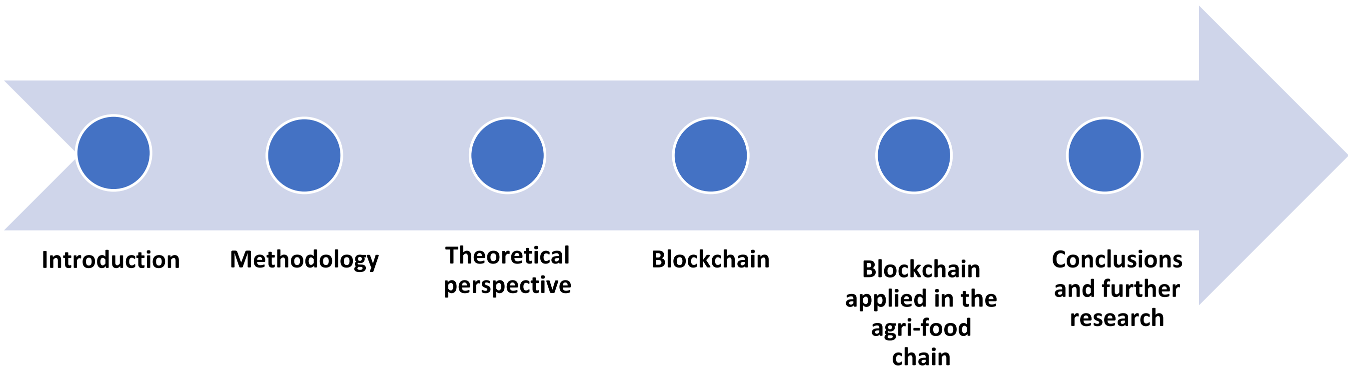


Figure 1. *Structure of the thesis. Summarized by the author.*

2 Methodology

The following chapter describes the research methods used to conduct the study. First, the research design is presented. Second, the companies that have been interviewed for this study are presented.

2.1 Research Design

The aim of this study is to investigate the potential of data sharing through Blockchain to reduce transaction costs in the Swedish agri-food chain. The study was conducted through a literature review and by interviewing Swedish consultancy companies with knowledge and theoretical experience on Blockchain. The reason for choosing experts with *theoretical* experience from Sweden, instead of choosing experts from outside of Sweden with *practical* experience on Blockchain, is to gain an understanding of Blockchain applied in a Swedish context. Blockchain is new in the context of the Swedish agri-food sector; there are no practical pilot projects or field studies that have been carried out in the Swedish agri-food sector yet. Because there is not much information on Blockchain in the Swedish agri-food sector, a qualitative research approach was chosen. A qualitative research approach is useful when one aims to gain a deeper understanding of a phenomena (Woundenberg, 1991). Qualitative research methods may use hypotheses, speculation and judgement, as compared to quantitative research that focuses more on numerical data, speculations and measurements (Bell, 1997, from Puglisi). The qualitative research approach focuses on the contextual understanding, which implies that the matter in question must be looked at in its specific context (Bryman & Bell, 2011). A new technology usually meets resistance in the beginning, and this resistance is often due to cultural reasons (e.g. unwillingness to try new technology, fear of change etc.) (Nazarko, 2017). The attitude to new technology may differ depending on the culture of the country (*ibid*.). Because Blockchain has not yet been practically applied in the Swedish agri-food sector, the study aims at grasping the possible outcomes of Blockchain but also expectations and attitudes of applying Blockchain in the Swedish agri-food sector.

Qualitative studies can be classified as either explorative or normative (Puglisi, 2001). Explorative research looks at the future from the present whereas normative research investigates what needs to happen in order to reach a specific goal. Explorative forecasting is useful when looking at different outcomes and directions of a phenomena from the present, whereas normative research defines desirable futures and the possible ways to get there. This study is an explorative study because it aims at investigating the possible outcomes of Blockchain in the agri-food chain from the present when Blockchain is not yet applied in the agri-food chain (*ibid*.).

A literature review was carried out to map existing research on the topic (Tranfield, Denyer & Smart, 2003; Saunders *et al*., 2009). A literature review can help systematise current knowledge on the topic. A systematic literature review has been carried out and involves three steps: 1) specifying research questions and planning the research 2) examining and reviewing the literature 3) reporting on the literature review. Following these steps first gives the researcher an overall view of one or several phenomena, and then exploring a possible theoretical framework to explain the phenomena (Bryman & Bell, 2011). Specifying the research question and planning the research implies finding a correlation between different variables that become the focus of the research (*ibid*.). Variables are context-specific and describe effects, mechanisms and results of phenomenon or activities. To find variables, the literature review started by finding information on the latest news and current knowledge on Blockchain in the agri-food chain. First, a general Google search on Blockchain in agri-food chain was carried out. Research words were combined such as "Blockchain + Agri-food Chain", "Blockchain + Information Sharing + Agri-food Chain". Information from large international organisations such as FAO (Food and Agricultural Organisation of the United Nations) and World Economic Forum on Blockchain in the agri-food chain helped find variables and a correlation between variables. Based on the information from the international organisations, *general* research questions were formulated. General research questions meant different variables without a specific geographic context. The variables were specified by comparing research results from international organisations with results from Swedish organisations and companies on academic search engines such as Google Scholar, SLU Primo, Web of Science and Scopus. Results from the literature review showed very little material from Sweden on Blockchain, whereas countries such as UK, the Netherlands, the US and Australia were prominent in research on Blockchain. These countries have carried out practical examples on Blockchain applied in the agri-food chain, whereas Sweden has only carried out theoretical case studies on Blockchain (so far). Results from the international research were used to explain the phenomena of Blockchain as well as the possibilities with Blockchain. To attain a Swedish perspective on Blockchain in the agri-food chain, four Swedish organisations were interviewed on Blockchain. These four organisations were chosen based on their knowledge on Blockchain and experience with Blockchain applied in the Swedish agri-food chain. The results from the interviews complement the international research. The results from the international research points at what *has been done* so far, whereas the interviews from the Swedish organisations are speculative and describe what *could happen*. Using both the material from international research and the material from the interviews with Swedish organisations are important. This is important to understand the implications of applying Blockchain in a Swedish context.

2.2 Individual interviews

Four individual interviews with Swedish organisations and companies (Axfoundation, Landshypotek Bank, Macklean and One Agency) were conducted. The informants were chosen mainly from consultancy companies within the agri-food chain and agriculture that have come into contact with Blockchain. The choice of consultancy companies was because that they have already carried through analyses on blockchain in the Swedish agri-food chain and therefore have knowledge on Blockchain in a Swedish context. The organisations and companies have looked at Blockchain from different perspectives in a Swedish context. Axfoundation has looked at Blockchain applied in the Swedish agri-food chain from a sustainability perspective, whereas One Agency has looked at Blockchain from a technical perspective. Ladshypotek Bank has looked at Blockchain mainly from an economic perspective whereas Macklean has looked at Blockchain from a Big Data sharing perspective. The interviews were conducted through telephone.

2.2.1 Axfoundation

An interview was made with Hanna Skoog, project manager in sustainability, from Axfoundation. I chose Skoog because she has participated in several case studies on Blockchain in the Swedish agri-food chain.

Axfoundation is an independent, non-profit organization working with innovative solutions and transformative change for sustainability. Axfoundation runs projects and initiatives in broad collaborations with business, academia, civil society and others through the organization's four programs: sustainable production and consumption, future of food, circular economy and inclusive society. As part of the program sustainable production and consumption Axfoundation is looking into the potential of blockchain technology to increase transparency, traceability and monitoring in global agri-food chains. The project is right now in the face of running three design studies, meaning theoretically applying the Blockchain technique on three different agri-food chain cases; Swedish ecological pig production, Marine Stewardship Council-labelled pike-perch fish and Moroccan picked strawberries sold in Sweden.

The assessment has been made in collaboration with actors from the Swedish food chain including among others; the procurement organisation of the Swedish municipalities and county councils (SKL Kommentus) as well as the National Secretariat Sustainable Public Procurement, a cooperation between the Swedish County Councils and Regions, Axfood, the food service company Martin & Servera. In assessing the compatibility of Blockchain of the supply chain, one looks at where Blockchain could add value. Critical evaluation points are e.g. parts of the supply chain already digitalized and not digitalized and what type of information is shared between actors in the supply chain. Axfoundation is evaluating Blockchain from a sustainability point of view, meaning, evaluation points have included understand where and under what conditions blockchain can add values such as improve traceability and control of sustainability labels such as MSC, secured working conditions and social standards for workers, and guarantee and secure data on animal welfare practices in Swedish organic pig production. In all three cases in the design phase, the project has looked primarily into the first steps of the supply chains, from primary production, throughout processing to retailer/food service (Skoog, interview, 2018).

Compared to other European countries or the US, Sweden has not yet carried through any practical pilot studies on Blockchain, only theoretical case studies. Sweden usually lags a couple of years behind in testing new technology compared to first running countries such as the US. Skoog (interview, 2018) believes there are several reasons for this. Sweden is small, as compared to for instance the US and hence, does not have the same muscles to carry through costly pilot studies of new technology that is still in the developing stage. It is costly to invest in projects in which effects and risks are unknown. There should be a consensus about what values the new technology may add, according to Skoog. The benefits should also be proportionally distributed among users and not disbenefit some while favouring others (*ibid*.).

2.2.2 One Agency

The second interview was made with Said El Shobaki from the Swedish technology consultancy company One Agency. One Agency started ten years ago (2008) and embraced the idea of having a different and more personal approach to consulting by enhancing personal growth as a central part of a business's success. Consultants at One Agency are given great own responsibility and room to explore new possibilities of innovations and work with projects in their own interest area. Around 120 consultants work at One Agency. Interviewed Said El Shobaki has worked with project management, product development and product ownership and now works with recruitment since February 2018. El Shobaki has come into contact with Blockchain through his work experience at One Agency.

2.2.3 Landshypotek Bank

Landshypotek Bank is one of Sweden's ten largest banks and operates within Swedish agricultural and forestry businesses and investments. Landshypotek Bank was founded in 1836 to financially support the transformations of Swedish agriculture (Landshypotek Bank, 2018). Landshypotek bank is owned by its 40 000 members and offers loans, saving services and finance investments to private customers and businesses operating within agriculture, forestry and rural development. Interviewed Merete Salmeling works as Head of Digital and Innovation at Landshypotek Bank. Salmeling has knowledge on Blockchain through case studies.

2.2.4 Macklean

Macklean is a consultancy company, mainly focusing at the branches of food companies, viewing problems and solutions from an outside perspective. Their service is to help establish platforms, facilitation of workshops and evaluations of business decisions. Efficiency and good leadership are a must in business competition and is looked upon to add value. Filip Lundin from the consultancy company, Macklean, was interviewed. Lundin has carried out case studies on possible effects of Big Data sharing in the Swedish agri-food chain. Even though no studies have been carried out on Blockchain, Lundin was chosen for interview because of his knowledge on Big Data sharing in the agri-food chain. Big Data is the data shared in a Blockchain, knowledge on Big Data is therefore considered relevant for this study.

2.3 Validity and reliability of the study

Validity refers to whether the study measures what it is aimed to measure (Bryan & Bell, 2011). The internal validity implies the match of theory and the empirics of the study (*ibid*.). This requires that the material from articles and reports are appropriate and *representative*. A r*epresentative* material implies a sample that represents the population adequately (*ibid*.). The study was delimited by choosing actors with research experience on Big Data sharing and Blockchain. Articles and reports from international organisations containing both theoretical and practical experience on Blockchain were used. Information on Blockchain without any application in the agri-food chain was acquired mainly from reports from large international consultancy companies such as PWC, Deloitte, CapGemini Consulting, IBM (International Business Management Corporation) and OECD (Organisation for economic co-operation and development). The reports from the large international organisations gave information on Blockchain in general but also offered clues on further research. Key words such as "transaction cost" and "information sharing" were picked from the reports and used for further search on academic search engines (Google Scholar, Web of Science, Scopus, SLU Primo). This resulted in the discovery of the variable "transaction cost" to be used as the main focus in this study. To acquire information on Blockchain applied in the agri-food chain, material from mainly FAO (Food and Agriculture Organisation of the United Nations), WEF (World Economic Forum), World Government Summit and Wageningen University were used. The reports from these international organisations were found on Google. Information on Blockchain applied in the Swedish agri-food chain was acquired from a large Swedish organisation, SKL Commentus (Sveriges Kommuner och Landsting) and the Swedish consultancy company, Macklean, both also found on Google.

Besides the reports from the Internet, four Swedish organisations were interviewed based on their theoretical experience and knowledge on Blockchain applied in a Swedish context. Compared to international actors with practical experience on Blockchain, the Swedish respondents have theoretical experience on Blockchain in the Swedish agri-food chain. The reason for choosing actors with theoretical experience was because no practical research has been carried out in Sweden yet. In other words, no research on the practice of using Blockchain in Sweden was possible. Three of the interviewed organisations are prominent in research on Blockchain applied in the Swedish agri-food chain, whereas the fourth interviewed organisation (One Agency) is a technological consultancy company without any connection to the agri-food chain.

The external validity implies to what extent the result can be applicable to other situations and generalised. A qualitative research recognises that representing a complete and objective reality may be difficult, because the results of the research depends on its specific context (Dependability) and may vary depending on the circumstances. The result is therefore difficult to measure and generalise. The material in this study is adequate for answering the research questions because it contains both theoretical and practical research on Blockchain in the agri-food chain. On the other hand, the international organisations have carried out their research in other countries than Sweden, meaning that their results may therefore not be generalisable to Sweden. Furthermore, the interviewed Swedish organisations in this study have carried out their research in collaboration with other countries. As mentioned earlier, Axfoundation has collaborated with Marine Stewardship Council (MSC) on a Blockchain study that was carried out in Morocco. The research results from Morocco were then generalised to the Swedish agri-food chain in Axfoundation's research study. Because several organisations interviewed in this study base their research on international research results, the result of this study may not be fully generalisable to Sweden. This study has in a similar way used research studies from other countries and applied them in a Swedish context. The study has theoretical contributions on transaction costs that may be generalisable. In a qualitative research, the external validity can be strengthened by making research questions clear and well formulated (Bryman & Bell, 2011), which is sought after in this study.

It would have been desirable to find more Swedish organisations or companies to interview.

However, this was not possible as little research on Blockchain in the Swedish agri-food chain has been carried out in Sweden by the time this study is conducted. Even though the interviews for this study are few, the material from these interviews is considered representative for two reasons; 1) the respondents are prominent in research on Blockchain in the Swedish agri-food chain 2) by the time this study was conducted, there were few other organisations and companies with knowledge on Blockchain in the agri-food chain. Because no practical pilot projects or field studies that have been carried out in the Swedish agri-food sector yet, this study is based on assumptions on the future, rather than facts on the past and what has happened.

Reliability in qualitative research is closely connected to the concept of validity and can be described as measuring the quality of the research. Good quality of a qualitative research implies “understanding a situation that otherwise would be confusing” (Eisner, 1991). While the quality of a quantitative research involves “purpose of explaining”, the quality of qualitative research refers to “generating understanding” (Stenbacka, 2001). The quality of the research was strengthened by feedback from the respondents.

3 Theoretical perspective

This chapter provides the theoretical framework to analyse the empirical result and the material from secondary sources used in this study. Economic theories are applied to describe technical features of Blockchain and how these technical features provide a new way of sharing information for agri-food chain actors. The theory of transaction cost economics is deployed, regarding three types of transaction costs; for searching for information, for bargaining/negotiation contracts and for monitoring/enforcing contracts.

3.1 Transaction Cost Economics

Commons (1934, p. 58) defines *transaction* as the transfer of the property right to a good or service, which does not consider only the physical transfer, but also the transfer in terms of property right and rights of using a resource. The theory of transaction costs deals with the problem of economic organization from a microanalytic perspective (Coase, 1937). Transaction cost economics believes that apart from the cost of buying and selling a product, the transaction itself can be resource intense for contracting parties (e.g. time-consuming searching for information, establishing contract, product inspection), and therefore be considered an additional cost that is sometimes not included in the price of the product (Konkurrensverket, 2011). A transaction cost therefore occurs if the transaction on the market implies greater risk exposure or resource consumption than the gain from the transaction (Cuevas, 2014). Even though exchanging parties invest a lot of time, energy and money in investigating, executing or monitoring transactions to decrease uncertainty, there is always a risk of being deceived or misled by information fraud or by the unexpected actions of the contracting party (Konkurrensverket, 2011). The focus of the theory is on the transactions and the saving attempts in the organization of transactions (Coase, 1937).

Farmers are exposed to several transaction costs due to the risky and unpredictable business environment they operate in (Goetz, 1992; Konkurrensverket, 2011). Because agricultural production is a biological production, agriculture is affected by weather and climate changes. For example, despite Sweden's geographic position and rich water supplies, droughts, perhaps - caused by changing climatic conditions, risk reducing the yield to half (Forskning, 2019). Climate change could have serious consequences for food production and food supply, both in Sweden as well as internationally. Due to such insecurities with climate changes, farmers can only predict possible yield output, which puts farmers in a vulnerable position against their business partners (*ibid*.).

High transaction costs prevent economic development in the agri-food chain (FAO, 5, 2017). One of the major reasons for high transaction costs is because most information is not traceable.

Eggertsson (1990) argues that the following activities may give rise to transaction costs; searching for information (search/information costs), bargaining in contracts (bargaining/negotiation costs) and enforcing contracts (monitoring/enforcement costs). Information costs imply the cost of searching for information about products on the market, like price, availability etc. Bargaining cost imply costs of coming to an acceptable agreement with the other party of the transaction. Policing and enforcement costs are costs that arise due to monitoring of whether the other party sticks to the terms of the contract and taking appropriate action if this turns out not to be the case (Man *et al*., 2017). The mentioned transaction costs are described in the following sub-chapters.

3.1.1 Information and Search Costs

The cost of searching for information (search/information cost) implies the *opportunity cost* of searching for information, in other words what one otherwise would have spent time and money on. Opportunity cost is the benefit one misses out when choosing one alternative over another (businessdictionary.com). Opportunity cost can be defined as "*the net benefits of the next best alternative that are forgone when a specific action is chosen. It can be expressed as the difference between the net benefits of the next best alternative of the chosen alternative*" (Jouan *et al*., 2019). Opportunity cost can also be described as: "*the value of the best alternative choice when pursuing a certain action. In other words, the difference between what you chose to do and what you could have done… If I chose to do this, what will I have to give up not doing?*" (marketbusinessnews.com).
The opportunity cost can be either internal cost (mental effort of searching for information) or external cost (acquiring/attaining information) (Yousuf, 2017).

Asymmetric Information

Asymmetric information implies that exchanging parties on the market have unequal access to complete information. Open information may be available for several exchanging parties simultaneously, however, there may also be private information available only to certain actors (Hobbs, 1996). This creates informational advantage for actors that have access to private information, whereas informational disadvantage occurs for those actors that do not have access to the private information. When certain actors are more informed than others (information asymmetry), a market failure arises because all market actors cannot make fully rational decisions based on full access to information (*ibid*.).

Collecting information usually implies a cost for the information seeking party. In many cases, it may be difficult for the information seeking party to segregate safe and unsafe suppliers (Loader, 1997, p. 25). Interacting with unknown suppliers and buyers always imply uncertainties and possible risks, compared to interacting with known suppliers and buyers. In that case, the cost for acquiring information may be greater than having insufficient information. In the agri-food chain, transaction costs arise for large chain actors when interacting with a large number of small-holder farmers (Hayes, 2000). For example, the opportunity cost of time used to coordinate with several small-holder farmers, the cost of establishing contracts, screening costs linked with the reliability of potential suppliers or buyers and the bureaucratic cost of managing and coordinating integrated production, processing and marketing (Moustier, 1998). If transaction may result in too large risks or costs, the transaction may not take place at all. The buyer or seller may choose to transact with an already known farmer, instead of screening the market for new potential farmers (*ibid*.).

Transparency

Transparency refers to the disclosure of business-related information that traditionally has been concealed from stakeholders on the market (Lambrecht *et al*., 2018).
Information always reveals something that we are interested in. In the context of transparency regarding food, information revolves around the *integrity* of food products, and the processes and resources (Trienekens *et al*., 2011). Integrity of food products implies that the food product contains what is promised according to the specifications on the label. Ingredients, processes and resources of the food product must comply with predefined specifications (*ibid*.). Food integrity means that the consumer gets what is promised about the food and that information on the label is credible and reliable. For example, the origin of the food product corresponds with the information of origin on the label. False or incorrect information about the food product harms the integrity of the food product and the brand. False or incorrect information could be for example; a fast food meal contains beef according to the label but in reality, the product contains horse meat.

Transparency implies attaining a *complete* picture of a product from the information given. Transparency is defined as "*the extent to which all its stakeholders have a shared understanding of, and access to, the product-related information they request, without loss, noise, delay or distortion*" (Hofstede, 2003). To be considered transparent, information should; be shared without delay (as it affects timeliness), not be affected by noise or added non-relevant data to the information (as it affects relevancy), not be transmitted (as it affects completeness) and not be changed or failed to be updated in that it no longer describes the product (as it affects validity). Stakeholders may develop a shared understanding of product-related information (e.g. raw materials, environmental impact) through quality standards or key concepts to help interpret and evaluate the information (*ibid*.). This could include adopting process standards (e.g. ISO 9000).

Konkurrensverket (2018) highlights that even though increased information access via information technologies have given Swedish consumers increased transparency, consumers still have limited opportunities to assess food quality and safety. Wolfert *et al*. (2017) claim that consumers' increasing demand for information is a sign of lack of trust and a need for transparency. FAO (2, 2009) advocates that market transparency is necessary for providing food security globally.

Traceability

Traceability can be defined as "*The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identification*" (Olsen & Borit, 2013).
Drivers for traceability in the agri-food chain can be divided into the following categories: *safety and quality*, *social* and *economic* (Bosona & Gebresenbet, 2013; Aung & Chang, 2014). Safety and quality regards ensuring that food products are safe to eat and fulfil certain quality criteria. A traceability system increases the awareness of food quality by agri-food chain actors capturing data and performing documentation processes. However, a traceability system cannot be considered sufficient to ensure the requirements of food quality and safety without trace. A traceability system always needs to be combined with traceability activities (e.g. documentation, monitoring, evaluation) to ensure quality and safety.

3.1.2 Negotiation and Bargaining Costs

Bargaining cost can be defined as "*cost incurred by communication of preferences between the parties and by analysing whether the proposal of one party fits the preferences of another party*" (Szczerbowski, 2018). Bargaining costs can occur when 1) contracting parties have conflicting objectives and interests 2) there is uncertainty on whether the opposite party wants to transact on the same terms and 3) there is uncertainty on the rights and obligations in the transaction (Jaffee, 1995). Bargaining power can be defined as: "*the power to obtain a concession from another party by threatening to impose a cost, or withdraw a benefit, if the party does not grant the concession*" (Kirkwood, 2005). The definition implies that the *threat* of the stronger party can influence the *behaviour* of the weaker (dependent) party. Establishing formal and written contracts may be advantageous in situations where partners have different objectives. However, the use of formal contracts can be perceived as a way of exercising power by the more powerful actor (Ferguson *et al*., 2005). The more powerful actor may constrain the behaviour of the opposite contracting party by writing detailed contracts. Contractual arrangements and lack of alternatives may result in that the less powerful party may be locked-in into a dependent situation, in which the more powerful party can set unfair terms (Wuyts & Geyskens, 2005). The Swedish bread supplier-retailer relation is monitored by a take-back policy, in which the bread supplier is responsible for removing and paying for all bread that was not sold within the selling time (Eriksson *et al*., 2016). The practice of the take-back policy results in a conflict of interest where supermarkets want full shelves to attract customers but where suppliers take the risk of unsold bread (*ibid*.). Larger supermarkets tend to negotiate the full take-back service compared to smaller supermarkets (Ismatov, 2015).

Retailer's bargaining power can lead to unfair trading policies, such as in the competition for shelf-space in the supermarket to market own private brands (Eriksson *et al*., 2016). Large retailers controlling the scope of distribution usually control marketing channels and the physical placement of food products. Retailers with private brands are considered to have an advantage in innovation of food products, due to the fact of being closer to consumers (*ibid*.). Large agri-food chain actors contracting with small-holder farmer may have access to important market information that small-holder farmers might be missing (FAO, 4, 2005). Large retailers also have power to specify food requirements and food quality standards to food processors and producers. The largest retailer in Sweden, ICA, has imposed environmental demands on its products and suppliers (*ibid*.).

IVA (2016) claims that the bargaining power in the Swedish agri-food chain is concentrated to a few chain actors. Also, the competition is concentrated mainly to the domestic market (*ibid*.). IVA (*ibid*.) asserts that the combination of concentrated bargaining power and competition has led to widespread problems with trust among Swedish agri-food chain actors. Trust is defined as "*a willingness to rely on an exchange partner in whom one has confidence*" (Moorman *et al*., 2002, p. 42). A study comparing the rate of innovation in European agri-food chains points at that Swedish agri-food chain actors compete mainly on the domestic market, whereas successful European agri-food chains such as the Netherlands, Denmark and Ireland compete internationally with a higher rate of export. Innovative food countries in Europe are characterised by a stronger strategic collaboration and information sharing among different levels in the agri-food chain, compared to Sweden. Poor collaboration and information sharing has led to hat Swedish agri-food chain actors fail to adapt a holistic perspective. Agri-food chain actors fail to adapt a holistic perspective that efficiently integrates the different levels of the chain (such as between companies, authorities and political actors).

Writing detailed contracts may signal distrust and may as well encourage opportunistic behaviour (e.g. exploiting situations that are unspecified in the contracts) (*ibid*.). The more powerful actor may strategically choose to contract with someone less powerful and exploit it through agreements in the contract (*ibid*.).

Access to transaction data and the ability to select what transaction to execute may give intermediaries market power due to information advantages (Bessy & Chauvin, 2013; Granovetter, 1973; Burt, 2000). Information transacted through an intermediary can be reused outside of the contractual agreements without contractual parties knowing it. Collecting information can give the intermediary a strategic overview of the market and find new business opportunities. The intermediary can use information to connect entities that were previously separated, called "structural holes". Burt (*ibid*.) sees the power of intermediaries in "*the possibility to control the interactions or the network of separated social actors*".
The intermediary reusing information outside of the contractual agreements give rise to privacy risk as well as censorship risk for the contractual party (Catalini & Gans, 2016). This risk causes additional costs for the contractual party.

Adverse Selection

An exchanging party with informational advantage often exploits the situation to its own advantage (Williamson, 1989). Adverse selection occurs when a party intentionally hides information from the opposite party to its own advantage. The food market is particularly exposed to adverse selection because of its uncertainties. For example, characteristics of food products are hidden, and are observable either only after purchase (experience good) or not observable even after purchase (credence good). The distance between consumer and producer often results in that the consumer has limited opportunities to control product information, and consequently, the seller hides information intentionally. In contrast to traditional food systems that were essentially production-oriented with minimal processing and distribution exchange, modern agri-food chains have altered in complex interlinked global networks with increased informational uncertainties for buyers and sellers (FAO, 3, 2005, p. 5).

The market usually deals with adverse selection and information asymmetry by involving a third-party (intermediary) that ensures that the transaction is carried out accordingly to the agreement of the contractual parties. However, intermediaries cannot ensure that contracting parties hide information. Catalini and Gans (2016) see that transacting through intermediaries is not risk-free. Transacting through intermediaries usually implies privacy risks for contracting parties as information can be reused by the intermediary outside of the original contractual arrangement. This is because intermediaries collect information and therefore gain an informational advantage. Intermediaries' collection of information also implies that intermediaries can choose what information to disclose and what information to prioritise. Another privacy risk with intermediaries comes with that on today´s digital platforms, intermediaries use central information systems that may be prone to information leakage. Starbird (2007) takes up that quality standards can be used as a strategy for making parties with informational advantage reveal more information. If revealing information becomes valuable and can increase profitability, this may signal to suppliers that reveal information will be more advantageous than withholding it.

3.1.3 Monitoring and Enforcement Costs

Monitoring and enforcement costs occur after the transaction has taken place, when exchanging parties invest energy and time in ensuring that the transaction has been carried out according to the terms of agreement (Cuevas, 2014). Inability to control the contracting party's action and behaviour during the transaction result in the parties monitoring after the exchange has taken place, which give rise to monitoring and enforcement costs.

Moral hazard and Principal-Agent theory

Moral hazard implies hidden behaviours and actions whose consequences reveal after the transaction or exchange has taken place. Moral hazard occurs because actions may not be directly observable by the opposite party (Quiggin *et al*., 1993). Food safety measurement represents large transaction costs (Starbird, 2005). Because food is produced in large volumes and passes the supply chain on a daily basis, it is impossible to do a thorough safety control of all food produced. Food safety measurement may be prone to sampling errors, meaning that the characteristics of the sample is different from the characteristics of the lot. Even though random samplings are taken to control sampling errors, it may not be representative for the rest of the lot. This means that there may be food that has passed without being tested. Food safety measurement is partly done internally by the producing company, so buyers, consumers and the rest of the market have limited options to control whether the measurement is sufficient. Because the producer or seller knows more about the safety of the food than the buyer or consumer does, the buyer might exploit its informational advantage and not fulfil its promises of safe food (Starbird, 2005).

Hart and Holmström (2016) describe moral hazard as "*a party may take actions that increase its own profit but that reduce the overall surplus of the relationship*". The moral hazard dilemma is often described through the Principal-Agent relationship. The Principal-Agent theory views that an agent is hired to take certain actions on the principal's behalf. The principal cannot directly view the actions of the agent. In that situation, moral hazard may occur. The agent may take decisions for its own profit but that is in conflict with the principal's objectives (Cong & He, 2017). Hart and Holmström (2016) advocates an alternative way to decrease the risks of moral hazard by allocating decision rights. If for example in a research and development (R&D) case, the researcher (agent) is given a fixed salary from the research company (principal). The fixed salary will decrease the researcher's intentions to go against the research company's objectives because the fixed salary is correlated to developing an innovation according to the researcher company's wishes. If the researcher goes against this, he will not receive the salary. This gives the researcher no bargaining power after he has developed a specific innovation because the premises were known before innovating and the reward is conditioned. This sets clear definitions on what the agent must achieve to get the reward and there is little risk for confusion or misunderstanding, while the principal protects itself from moral hazard.

Cong & He (2017) takes up that contracts in general are hard to be complete because of the many details and contingencies that need to be considered. There may also be unforeseen contingencies that are har to predict in advance. Contracts are agreements (written or oral) that imply promises or obligations about future performance (Macneil, 1978; Zhang & Aramyan, 2009), and are established avoid conflict and inappropriate agent behaviour between contracting parties.

Tirole (1999) advocates that there are four requirements that can make contracts incomplete: 1) unforeseen contingencies 2) writing costs 3) enforcement costs 4) renegotiation
The first requirement regarding unforeseen contingences revolve around that it is impossible to predict the future and eventual unexpected or unforeseen contingencies that are hard to include in the contract before they have happened. No matter how much contracting parties try to protect themselves against eventualities, there may be other eventualities that contracting parties have not thought about to include in the contracting. The second factor making contracts incomplete regards the writing of contracts for contracting parties. Contracting parties must both understand the contractual agreements and clauses that are necessary to enforce the contract. This implies that contracting parties must have a mutual understanding on the prerequisites that the contract revolves around. Furthermore, enforcement costs may make the contract incomplete because of the number of parties that are involved in enforcing the contract. For example, courts and laws may be involved. Because third parties are involved in contracting, instead of just the contracting parties, this takes extra time and effort for contracting parties that otherwise could have been avoided if only the contracting parties were involved.

3.1.4 Summary - Transaction cost economics

Information asymmetry in combination with distance between agri-food chain actors result in chain actors intentionally hiding information to e.g. consumers about food products. It is also hard to control how and when quality and safety measurements have been done properly. The way the agri-food chain is structured constrains chain actors from sharing information with each other.

3.2 Supply chain collaboration

Collaborating supply chain actors share both risks and benefits. Sharing both benefits and risks is called incentive alignment. Incentive alignments implies strengthening both one's own supply chain and also the supply chain in general. Even though supply chain collaboration (SCC) offers many advantages, these advantages may be hard to realise and implement due to several barriers. First of all, businesses usually over-rely on technology to solve their problems. Starting a collaboration can be difficult because one may not know with whom to collaborate. There may also be a lack of trust between partners (Sabath & Fontanella, 2002), as with agri-food chain actors in the Swedish agri-food chain.

One of the most important aspects with supply chain collaboration is trust, openness and information exchange (Barratt, 2004). Partners that trust each other are more willing to exchange information with each other and fulfil collaborative activities. Information exchange is the most important aspect of supply chain collaboration. Using information technologies to facilitate information exchange is common within supply chain collaboration. Supply chain collaboration requires that collaborating parties adjust their technology use behaviour, meaning that parties need to be willing to share their network resources to facilitate the collaboration. Transparency and the quality of information are also important aspects to forge trust. Popp (2002) takes up that intermediaries may become a hinder to transparent information, which may impact negatively on the collaboration. This can lead to lower performance among collaborating actors.

Companies may collaborate with different chain actors both vertically and horizontally. This means that different chain actors can play different roles in different supply chain settings. For example, in one setting a supply chain actor may be a collaborating partner and in another supply chain setting a supply chain actor may be a competitor. Often, supply chain actors are involved in several different supply chains at the same time, that have different processes that develop at different pace (Trienekens *et al*.,2011). This causes the complex structure of today’s supply chains.

Collaboration has shown several advantages to agri-food chain actors such as; provide greater visibility along the chain, access to new skills and encourage innovation and reduce costs and provide greater security (KPMG International, 2013).

4 Blockchain

This chapter gives the reader an overview of the phenomena of Blockchain. First, an overview of the latest research on Blockchain is presented. Then, the technical features of Blockchain are presented. More detailed information on how Blockchain works can be found in the appendix.

4.1 What is Blockchain?

Blockchain is a form of a *distributed ledger*, a decentralised, digital database and platform for sharing information between geographically spread users (blockchaintechnologies.com; towardsdatascience.com). All users access a replicated copy of information and are updated on the same information simultaneously no matter the distance. Compared to a centralised ledger, in which a third-party (e.g. authority, bank) controls the information flow of its users, a decentralised ledger offers the same functionality of a centralised ledger but users are given the authority to monitor their own data without a third-party collecting or controlling information flow (blockport.io). A decentralised platform empowers individuals to control what information to share with others and what information to keep to themselves.

The difference between a Blockchain and other distributed ledgers is that a Blockchain is built as a "peer-to-peer" network in which information needs to be approved by all users before it can be saved in the Blockchain (towardsdatascience.com). This means that one simply cannot spread information to other users without all users approving the information first.

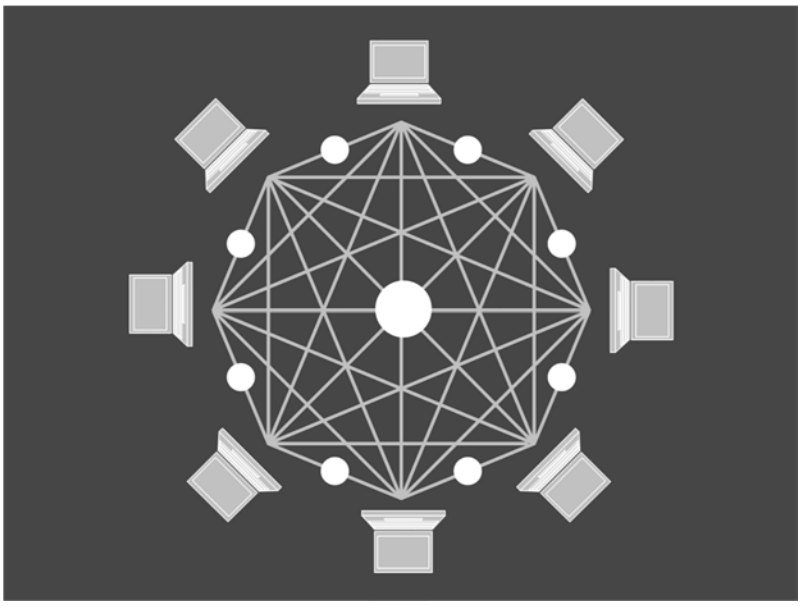


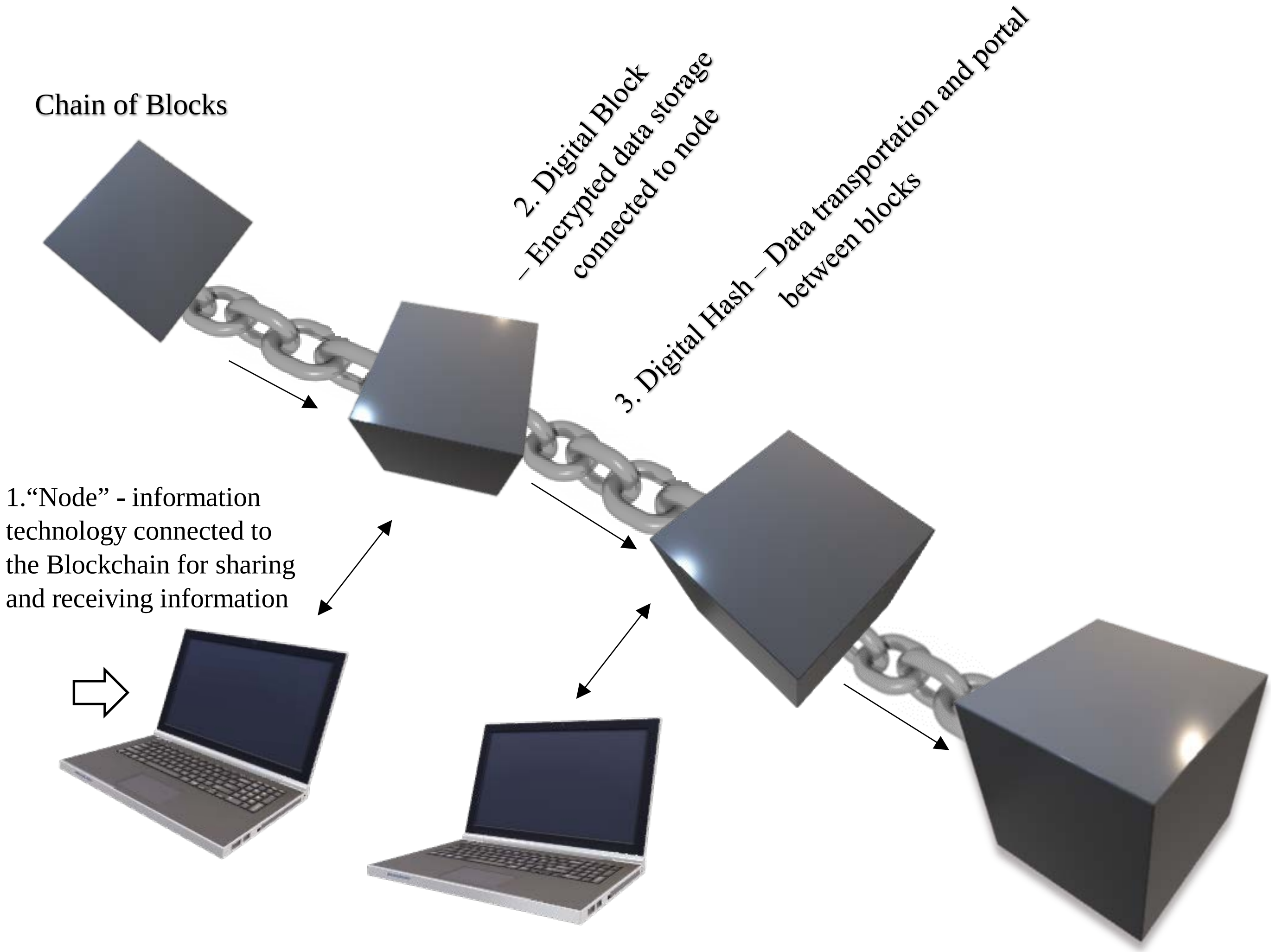
Figure 2. *Distributed ledger as a peer-to-peer network. Picture source: Pixabay.com, may be used according to Google.*

Box 1*. Basic architecture of Blockchain providing traceability and transparency*

Blockchain is digitally built up as a traditional sequential supply chain forming a sequence of digital *blocks* (blockchaintechnologies.com). *Blocks* are small databases that store the data in a Blockchain. Each block comprises of a replicated copy of all data in the Blockchain. All blocks in a Blockchain therefore contain the same data.

The blocks are chained together by digital *hashes*. *Hashes* function as a transportation channel that transports the contents out of the block to the next block. Each hash is uniquely defined by the block's content.

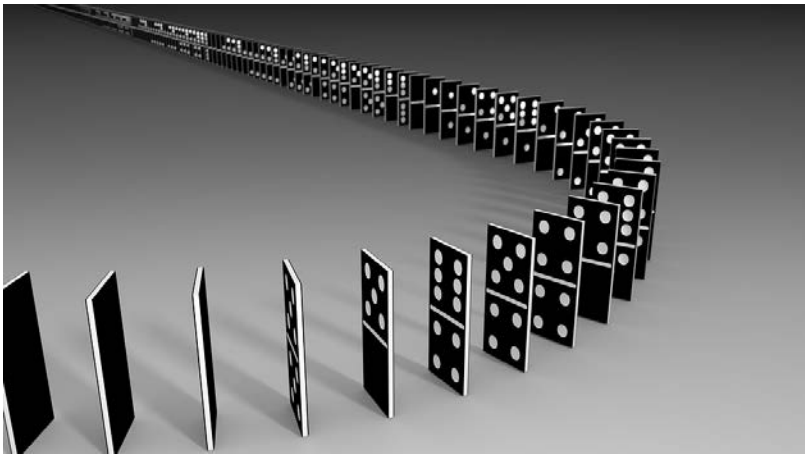
Blocks and hashes are the technical features of Blockchain that enables traceability (Medium, 1, 2018).



Exhibition 3. *Blockchain - micro and macro relation. Illustration by the author.*

4.2 Why Blockchain?

Today's agri-food chains are characterised by unequally distributed information sharing among downstream and upstream agri-food chain actors (FAO, 8). The lack of a shared information system between different levels of the agri-food chain prevents all chain actors from attaining equal information simultaneously. This causes a delay when trying to rapidly adjust to unexpected contingencies. The agri-food chain operates in a reactive way instead of in a proactive way, which means that problems are discovered and tackled *after* the damage already has been done instead of tackling it in advance. Defected food products are often discovered first after they have passed several stages of the agri-food chain (e.g. processing, packaging and transportation). This means that defected food may be transported around the world to be e.g. packed or processed and then transported back before it finally reaches the final stages of the agri-food chain (consumer or retailer) that eventually discover the food defection. Defected food fraud that cannot be used then becomes food waste. In economic terms, food frauds and diseases on food account for large economic costs; according to PWC (2016), the cost of food fraud has been estimated to approximately US$40 billion annually. This can be compared with the cost caused by diseases in food products that account for about US$55 billion every year (*ibid*.).



Exhibition 4*. Blockchain provides a Domino-effect to information sharing in the agri-food chain; information shared by one chain actor is spread and updated rapidly to the rest of the agri-food chain like a domino.*

4.3 What Blockchain does

Blockchain is considered the most disruptive technology after the Internet of Things (IoT) (Investopedia, 2; Medium, 3, 2018). A technology is disruptive if it fundamentally changes the way a business or an entire industry is operated (Rahman et *al*., 2017). A disruptive technology will impose new values on society, stimulate new markets and override old markets. The essence of the disruptive technology is its magnitude of impact and change on society, which is usually measured by its effect on current markets and business models. There are several ways in which Blockchain is considered a disruptive technology compared to the Internet of Things (IoT);

First, Blockchain is likely to change the **nature of information**:

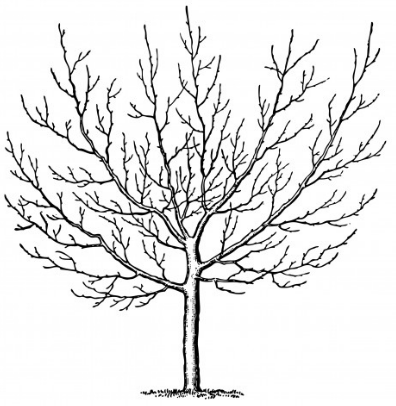
1) Immutability of transactions

Compared to the Internet in which information is editable and deletable, information entered in a Blockchain cannot be deleted or changed (Hackernoon, 1, 2018). Blockchain provides immutability of transactions, implying "*the ability for a Blockchain ledger to remain a permanent, indelible, and unaltered history of transactions*" (*ibid.*). Immutability enhances trust among and integrity among users. While the Internet of Things (IoT) was designed to share copies of editable information, Blockchain is a further step that allows us to replicate *uneditable information from the original source*, ensuring that **shared contents stay unchanged** and **retain the same value** along its movement from primary source to end stakeholders.

2) Traceable, auditable, persistent and reliable data

Apart from allowing information sharing securely without any need for intermediary, users can enter and insert information in the Blockchain for free (Hackernoon, 1, 2018). The information entered in one block or ledger may therefore be replicated to a new Blockchain for free (see exhibition 5). This means that users cannot profit from monitoring the Blockchain. Neither do readers pay to participate and access the information.

Each transaction is recorded and validated with a timestamp, which implies that users can easily verify and trace the previous records through accessing any node in the distributed network (blockchaintechnologies.com). No transaction can be falsified as each transaction is unique and recorded.



Exhibition 5. *A Blockchain can be replicated to a new identical Blockchain for new users. A replicated Blockchain can be compared with the branches of a tree, every branch stems from the original source of information (tree). Every branch contains a replicated copy of undeleteable and irreversible data, thus preventing false or edited information from spreading. Picture source: publicdomainpictures.net, may be used according to Google.*

Box 2. *Smart Contract ensures that information complies with action and performance*

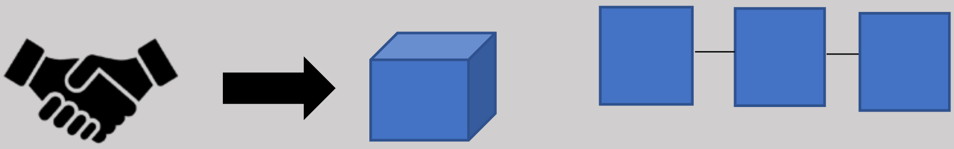
A cryptographic *Smart Contract* can be added to a Blockchain (Forbes, 2019). The *Smart Contract* is a digital contract or protocol with clearly defined rules and a self-executing mechanism that reacts on the actions of contracting parties and automatically executes certain rewards or actions when predefined actions are met. A Smart Contract does not need an intermediary (e.g. lawyer) to ensure that the contract is executed according to the terms of agreement for contracting parties (El Shobaki, interview, 2018). Cryptographic Smart Contracts encrypt information and data that is spread between users. Encrypted information can be safely shared between users without the involvement of a third-party ensuring that information is protected. The absence of intermediary provides the decentralised features of Blockchain and enables information to be shared in a decentralised but safe way (Medium, 4, 2018).

Secondly, Blockchain is likely to change the **structure and organisation** of supply chains and changes the coordination of transaction:

Providing transacting without intermediaries/disintermediated
Blockchain creates a decentralised structure to a supply chain and provides a more flexible supply chain (blockchaintechnologies.com).

Box 3. *The Consensus Mechanism is what distinguishes Blockchain from other distributed ledgers, preventing information fraud. Elaborated by the author.*

The peer-to peer network in a Blockchain is managed by the *Consensus Mechanism*, a digital protocol that synchronises all users in the Blockchain and ensures that all users are agreed upon (Hackernoon, 2, 2018). The Consensus Mechanism is also the mechanism that legitimates transactions and makes sure that transactions are added and stored in a new block. Without the Consensus Mechanism, no information could be saved.



Consensus Mechanism verifies approved data between users — *Data is saved in new Block* — *Block added to chain*

Note! More information on Blockchain can be found in Appendix 1, e.g. on the difference between various types of Blockchains, technical features of Blockchain and how Blockchain co-collaborates with other information technologies.

5 Blockchain applied in the agri-food chain

5.1 Blockchain's impact on transaction costs in the agri-food chain

5.1.1 Blockchain's ability to reduce informational costs in agri-food chain

The (internal) cost of searching for information - asymmetric information, transparency and traceability

The decentralised structure of Blockchain is likely to reduce the internal cost of searching for information (time spent and mental effort of searching for information) for many chain actors, as e.g. governments can make quicker decisions on payments or loans while reducing bureaucracy (Lundin, interview, 2018).

A public Blockchain applied in the agri-food chain implies that information can be shared without delay. A public Blockchain therefore fulfils the criteria of both timeliness and completeness in the transparency concept. The criterion of timeliness and completeness are fulfilled because information entered in the Blockchain network is updated to all chain actors simultaneously and needs to be verified by all chain actors before it can be forever saved in the network (El Shobaki, interview, 2018). Blockchain holds great potential to be applied to the current structure of agri-food chains as it digitally provides the same sequential structure but contrastingly operates in a decentralised way than today's agri-food system (PWC, 2016). Information in Blockchain is also accessible for free, which enables tracking and tracing. However, the criteria of timeliness requires that chain actors are willing to share information to other chain actors and that information actually is being shared. There is a risk that chain actors share only non-relevant data, which will affect attaining a complete picture of the food product.

A central aspect of whether Blockchain can solve the transparency issue in the agri-food chain revolves around whether information sharing should be statutory or not. This might affect the criteria of completeness in the transparency concept. If information sharing is optional it might impair the quality of information and/or reduce information sharing in general. Chain actors may share only selected data (e.g. non-sensitive, favourable data) or share no data at all, which might prevent others from attaining a complete picture of the food product. In this respect, Blockchain may not eliminate information asymmetry, as chain actors intentionally would hide information for their own advantage. El Shobaki (*ibid.*) sees that some sort of statutory requirements may be necessary for Blockchain to reach its full potential. One way to provide information sharing is by statutory requirements of information sharing through established routines, e.g. statutory journaling or log booking of daily activities in the food supply chain (*ibid.*). This can be compared with the statutory administration in today's ecological labelling system that is controlled by a third-party such as authorities and certifying organisations (*ibid.*). The difference, however, would be that Blockchain administration would be verified by all users in the Blockchain network. This would create a more efficient market because several stages of the agri-food chain would control the administration. Inputs, improvement proposals and new perspectives are therefore likely to be contributed from the different supply stages. Legislation or recommendations are therefore likely to be enriched from all stages of the supply chain. Yet, sharing too detailed information may put actors in vulnerable situations of threats from e.g. animal activists (Skoog, interview, 2018). From this point of view, transparency and traceability would instead increase transaction cost due to the increased risks.

Applying Blockchain to the agri-food chain, one can tackle illegal actions and agreements in *real-time* and in advance. FAO (1, 2009) takes up that the ability to track and trace every detail of food products will facilitate ensuring that food products comply with quality standards (regarding freshness), safety standards (health and risk management, disease outbreak among animals or plants) and sustainability standards (organic, Fairtrade). Contaminated food products can be pinpointed more quickly in advance by retailers and prevent spread of risk and contamination among consumers. Even though governments require recording of data of food products today, none of the agri-food chain actors are able to follow the movement of food products along the agri-food chain or capture so diverse and detailed data as Blockchain offers. With Blockchain, it is possible to track the exact source of e.g. an outbreak or disease. A pilot study of Blockchain applied in a mango supply chain showed that it takes only a couple of seconds to identify the exact origin or the mango (FAO, 6, 2018). This can be compared that without a Blockchain, it took six days and 18 hours to track the origin of the same mango (FAO, 6, 2018). In practice, consumers would be able to track information from all stages of the agri-food chain regarding the food product. This would be possible by registering all information of the food product in the Blockchain. Consumers would then scan a QR code to access information on the movement of the food product. For example, information from the primary producer such as feed and medicines, animal health, location, breed, age, sex, cost of production would be traceable and registered on the Blockchain (FAO, 6, 2018, p. 8). Each time the food product would move between different levels and chain actors, information would be registered in the Blockchain and be traceable. Information on time would also be traceable such as e.g. slaughter date, time in transit and expiration date (*ibid.*). FAO (*ibid.*) highlights the importance of tracing detailed information to bring efficiency gains as well as food safety and sustainability of food products.

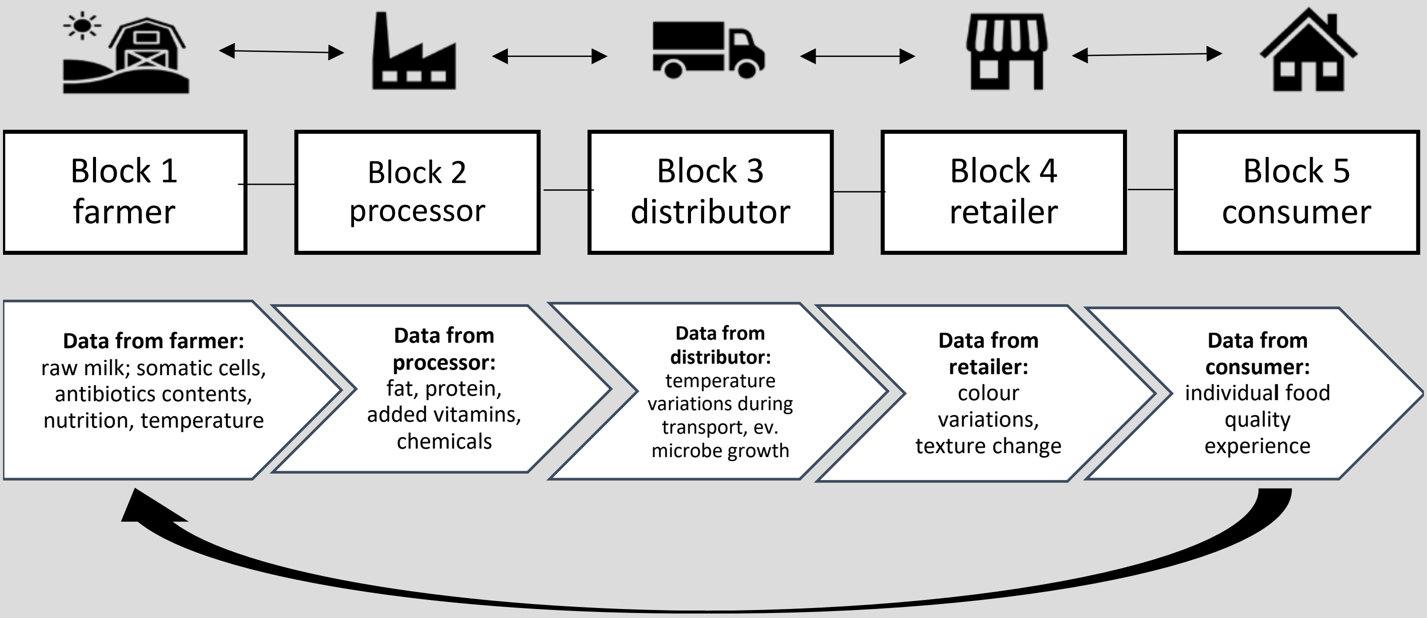
The Food and Agriculture Organisation of the United Nations (FAO, 6, 2018) sees great potential in Blockchain applied in the fisheries sector to detect illegal, unreported or unregulated fishing, which is the major threat to marine ecosystems. FAO (*ibid.*) points at an ongoing Blockchain pilot project carried out by the World Wildlife Fund (WWF) in New Zealand that identifies illegal tuna fishing in the Pacific Islands. Each fish is marked with a unique ID that is registered and saved in the Blockchain network. The ID linked to each fish can then be traced back and controlled via Blockchain. Human rights abuse can also be tracked. The collaboration has been made with other organisations to track the fish from vessel.

Both relevant and non-relevant data is saved in Blockchain, which will reduce the risk of information fraud (Hackernoon, 1, 2018). However, the fact that both relevant and non-relevant data is forever saved in the Blockchain network may make it difficult to sort out data that is relevant. It may take time to process data and sort out which data is relevant and which is not. Having too much non-relevant data also takes up space in the Blockchain (*ibid*.). .

Blockchain is believed to help enhance trust in the agri-food chain for several reasons. The decentralisation of the Blockchain network is likely to create more transparent information because it takes away the need for intermediaries (Popp, 2004). Increased trust among agri-food chain actors is likely to strengthen the relationship and increase information exchange (Barratt, 2004). Agri-food chain actors connected to the Blockchain can verify transactions themselves instead of an intermediary regulating the business relationship. This implies that agri-food chain actors can set the terms of the contracts themselves. The reduced need for an intermediary would shape the current, sequential agri-food chain into a decentralised network. This decentralised network can be compared to an ecosystem, in which chain actors on different levels of the agri-food chain are connected through information exchange.

Box 4. *Illustration of traceability in agri-food chain using Blockchain, elaborated by the author.*

Every agri-food chain actor that is digitally connected to a block of a Blockchain is constantly updated on new information added to the Blockchain network. All blocks contain a copy of all information in the entire Blockchain network, which means that all agri-food chain actors receive exactly the same information and a copy of all information of the entire network. The figure below maps information flow with a Blockchain applied in a milk chain. The figure depicts three layers of action: 1) chain actors performing and generating value, 2) blocks digitally connected to chain actors sharing data and transferring value and 3) data and value transferred, linked to each chain actor and block.



Customising food products to individual food quality experience, based on data saved in Blockchain

Traceability address new value to information:
Information and data become traceable for all agri-food chain actors. This means that data can be traced both backwards and forwards in the chain by all chain actors. In this way, data and information can always be controlled by all chain actors. This function completes today's rigid and sequential chain structure in which communication and information sharing is slow or limited between chain actors. A more agile and flexible agri-food chain is shaped with Blockchain.

Information is strongly linked with actions, implying that information can only be entered in the Blockchain first after actions have been made. This means that data always correlates with actions and performance. This is because information is linked to the food product itself. In this way, no chain actor can cheat by entering information without having acted accordingly to the information. Also, because data cannot be edited and is forever saved and traceable, previous transactions can be traced to discover eventual food frauds over time.

Risks with traceability

Tracking and tracing of information implies that users can be tracked and traced down through their information sharing, as information is connected to the location of the user node (Skoog, interview, 2018). It would in practice mean that farmers' production could be traced down even though they operate anonymously in a public network. Skoog (interview, 2018) showed in a Blockchain case study that traceability of information can expose farmers to threats from animal rights activists that are enabled to trace the farmer via detailed information about the animal production. Depending on the type of food supply chain and production specialisation, traceability of information may put information sharers in a consignment and vulnerable position. Results from Axfoundation's (interview, 2018) Blockchain case study showed that in the case of ecological pig production, potential threats from animal activists on farmers could worsen, if too much detailed information revealed e.g. higher levels of antibiotics usage (e.g. during a disease outbreak among pigs). A similar result was confirmed in a Blockchain pilot study carried out by Marks and Spencer (Skoog, interview, 2018). Marks and Spencer solved this by aggregating production data about antibiotics to anonymize the information of users and reduce traceability of from which farmer the data originated. Aggregation of data would still enable the total use of antibiotics to be measured for reducing the overall levels of antibiotics usage. In the case for MSC-labelled fish, Blockchain could increase the transparency and information about origin. Futhermore, imidiate information about fish caught along the chain showed to improve efficiency of the sales and auction processes. Full transparency obstructs the possibilites to substitute the fish and eliminate the potential of food fraud.

Blockchain holds the potential to increase transparency of working conditions and social standards for pickers, useful for retailers and food service companies in Sweden, as shown in the result of Marroccon strawberries. This implies great value since audits and control mechanisms along food supply chains are complex, costly, time consuming and are limited to self assessments and third party audits on sites. The assessment has been made in collaboration with actors from the Swedish food chain including among others; the procurement organisation of the Swedish municipalities and county councils (SKL Kommentus) as well as the National Secretariat Sustainable Public Procurement, a cooperation between the Swedish County Councils and Regions, Axfood, the food service company Martin & Servera. In assessing the compatibility of Blockchain with the supply chain, one looks at where Blockchain could add value. Critical evaluation points are e.g. parts of the supply chain already digitalized and not digitalized and what type of information is shared between actors in the supply chain. Axfoundation is evaluating Blockchain from a sustainability point of view, meaning, evaluation points have included the understanding of where and under what conditions Blockchain can add values, such as improved traceability and control of sustainability labels such as MSC, secured working conditions and social standards for workers, and to guarantee and secure data on animal welfare practices in Swedish organic pig production. In all three cases in the design phase, the project has looked primarily into the first steps of the supply chains, from primary production, throughout processing to retailer/food service (Skoog, 2018, interview).

The (external) cost of acquiring information in the agri-food chain with a Blockchain

The external cost of searching for information (acquiring information) is likely to be reduced as information becomes easily accessible. On the other hand, Lundin (interview, 2018) sees a risk with that some chain actors will be forced to share information against their will. For example, consultancy companies may collect detailed sensitive data and these companies may serve as "gatekeepers" for information, avoiding to pass it along in the chain.

Because information is forever saved and traceable in the Blockchain network, information shared stays intact in case of a system shutdown. The Blockchain network is therefore not as vulnerable to a cyber-threat as the Internet network (El Shobaki, interview, 2018). The public Blockchain network usually has a large number of interconnected nodes (computers), which will serve as a security for the information backup of the network. Every node will always have a copy of the original source, so information can never be lost or deleted without other participants' consent. One single node, either placed in Sweden or abroad, can back up the whole Blockchain system of all information and technically verify the correct information. Nodes placed abroad would still have all information stored, and be able to keep the network intact if the system crashed. Network participants will be notified about any update on information once the system successfully starts up again. Blockchain senses whether new information corresponds with information in the Blockchain platform. Information therefore always becomes reliable, intact and verified, which is important and accurate in times where contents of information easily can change (*ibid*.). A traditional ledger can be destroyed or hacked by attacking the middleman or central node of the system in which all information is stored (Chedrawi & Howayeck, 2018). Trying to hack a Blockchain, on the other hand, requires an attack on all blocks simultaneously because every block has a copy of its network's informational contents. All users have their own versions to check against, so there can be no fake blocks. Blockchain has potential to discover when information is wrong and prevent fake news from spreading. This is because information needs to be verified and validated by all users. Users can evaluate the credibility of the data. With data shared comes information about the data and on who shared it. The Smart Contract encourages to discover if data is fake or not.

Cost of sharing information

An open Blockchain implies that information is shared for free, meaning that agri-food chain actors do not have to pay a fee to a third-party to access information (El Shobaki, interview, 2018). Sharing information in the agri-food chain will be free of charge for agri-food chain actors. This is because all information stored in the agri-food chain can easily be copied and transferred to a new Blockchain. Because all information stored in the agri-food chain can easily be copied, no information can be excluded from anyone. If no information can be excluded from anyone, it means that no one can make any profit by charging a fee for granting access to certain information.

However, even though information is shared for free, Blockchain is likely to increase the cost of acquiring information due to high operational costs caused by intense consumption of Internet and electricity to keep the Blockchain network running.

A Blockchain applied in the agri-food chain does not necessarily mean that the agri-food chain actors automatically can access information in the Blockchain network and share information with each other (El Shobaki, interview, 2018; Lundin, interview, 2018). Agri-food chain actors need to be updated on co-collaborating information technologies that support Blockchain to collect and store detailed information. Lundin (interview, 2018) highlights that Blockchain is dependent on other information technologies to function, such as communications infrastructure. Communications infrastructure on the countryside and in rural areas may be underdeveloped or may not be updated at a pace that is necessary to keep up with the technical progress of Blockchain. Inability to update on matching technology may prevent rural agri-food chain actors from connecting to the Blockchain network and access information from other agri-food chain actors (Macklean, 2019).

Lundin (interview, 2018) asserts that: "*Only agri-food chain actors that are updated with technology will have the opportunity to gain informational advantage whereas chain actors that lag behind in technology are likely to be excluded from the benefits of Blockchain*". This will cause problems because in the future, access to information is likely to be crucial to increase the value of products and services, Lundin explains. The development of new communications infrastructure is rapid. Some chain actors might be eager to keep up with the latest technologies while others do not. Compatibility of different versions and updates of technologies are likely to become a problem when sharing information with each other (see Figure 7).

Cost of verifying the Blockchain network

Constant update on information consumes a lot of energy and Internet traffic. High operation costs are therefore likely to increase the cost of acquiring information. Even though sharing information is free in a Blockchain network, providing replicated copies to all agri-food chain actors requires that information is being constantly updated to every chain actor. This consumes large amounts of electricity and Internet. Intense consumption of Internet and electricity makes external information costs (costs of acquiring information) high. Even though information sharing is free, the Blockchain network is likely to come with the price of high operational costs due to intense consumption of Internet and electricity. Resource consumption increases operational costs and therefore the cost of networking and acquiring information. For new information to be saved in the Blockchain network, every single participant needs to verify the transaction, implying that the transaction should be checked and accepted by every user before it can be saved in the network. Involving every agri-food chain actor in the Blockchain would imply constant updates of information because the agri-food chain comprises of many chain actors. Every chain actor is in turn connected to a computer (node or device) that is constantly running and updating new information entered in the Blockchain network. A public Blockchain in which anyone is free to enter will easily grow large with many agri-food chain actors connected to the Blockchain network. This is likely to become resource intense regarding electricity and Internet traffic (FAO, 6, 2018; El Shobaki, 2018; IBM, 2017). El Shobaki (interview, 2018) sees that this is already happening to the payment transfer service, Bitcoin. Bitcoin trading has become so popular so that operational costs from Internet consumption as well as electricity has made the operation of the system more expensive than the actual value of the Bitcoin currency itself. High operational costs indicate that the operational system of Blockchain is inefficient and might not be as cost saving in practice as in theory regarding common verifying and free sharing of information. The network system is never turned off since it regularly verifies and updates itself on new information throughout the whole network. Blockchain consumes electricity constantly, even when users are not online in the network at the moment (*ibid*.).

El Shobaki (interview, 2018) questions the amount of user nodes that are required to justify the existence of a Blockchain for a specific purpose. If a Blockchain network is to cover an entire food supply chain with many chain actors, the network will consume a lot of energy from all nodes to function because information is always updated to every chain actor. El Shobaki (*ibid*.) poses the question: how much should it cost to verify the food supply chain digitally to enable transparency and facilitated networking?

The cost of verifying the Blockchain network should be compared with the cost of operating the agri-food chain today. As mentioned earlier, the cost of operating the agri-food chain accounts for about two thirds of the final price of food products in general (Niforos, 2017). These costs arise due to uneven access to information, limited traceability but also paper work and the involvement of intermediaries (FAO, 3, 2018; 4, 2018). All these factors pose risks to chain actors and slows down the processes of transferring value between the different stages of the chain. With a Blockchain applied in the agri-food chain, on the other hand, transferring value and communicating between different levels in the chain would be faster (*ibid*.). Decision making could be faster for all agri-food chain actors and therefore facilitate the transferring of value along the chain. In this respect, Blockchain would save both time and money for several chain actors while also increasing the value of food products (*ibid*.). Even though verifying the Blockchain network is costly, it should be compared with how much the total cost of operating the agri-food chain is today; this includes all risks, costs and time invested in transacting, finding information etc. but also, additionally, the cost of electricity and Internet consumption for each and every chain actor using a central computer system for themselves.

In summary, with a Blockchain applied in the agri-food chain, information access for agri-food chain actors will be conditional and depend on two important factors: 1) access to advanced technology supporting information collection 2) willingness to share information. First of all, only chain actors that are updated with technology can gain informational advantage whereas chain actors that lag behind in technology are likely to be excluded from the benefits of Blockchain. This means that the cost of acquiring information will be high for those chain actors that cannot afford to stay updated on new technology. This is likely to raise the external cost of acquiring information. Second, the outcome of technology depends on who monitors the Blockchain. Blockchain is a collective technology meaning that its function depends on collective action and willingness. No one can make a difference unless “the whole team is in” for a change. The difficulties involved with “getting everyone on the train” is therefore considered as one of the main disadvantages with implementing Blockchain. A solution to this has already been mentioned, information sharing needs to be regulated through statutory requirements. This regards both for information security (aggregating data to protect the information sharer from being traceable) as well as what type of information should be required to share (sharing only favourable data is not sufficient to tackle problems in the agri-food chain).

On the other hand, the tracking and tracing of information implies that users could be tracked and traced down as information is connected to the location of the user node. It would in practice mean that farmers’ production data about antibiotics could be traced down even though they operate anonymously in a public network. Sensitive data being traceable and publicly available could worsen the threat from animal activists.

Box 5. *Blockchain's ability to reduce information costs in the agri-food chain*

Box 5. Blockchain's ability to reduce information costs in the agri-food chain	
+ Free sharing of information *+ Constant update of equal information to all chain actors* *+ Information must be verified by all chain actors* *+ Traceability - combat food frauds* *+ Traceability – real match of supply and demand* *+ Traceability – optimisation of output*	*- High operational costs* *- Risks with traceability* *- Reluctant to share information* *- Depends on other information technologies*

5.1.2 Blockchain's ability to reduce bargaining costs in the agri-food chain

Reducing the need for a trusted third-party in combination with openness and transparency is likely to eliminate privacy risks that come with revealing information to third-party, such as the risk of information being reused outside of the contractual arrangements or information leakage (FAO, 6, 2018). The absence of intermediaries is believed to make transacting more "neutral" and generate legitimacy for Blockchain.

Adverse selection

Because there is a risk that chain actors share only non-relevant data, applying a Blockchain to the agri-food chain would most likely not reduce the risk of adverse selection if users still would have the opportunity to hide information (El Shobaki, interview, 2018). Even though Blockchain facilitates information sharing and enables safe exchanging without the need for trusted third-party to verify transactions, Blockchain prerequires that users are willing to share information. It lies in the *intentions* of the participants for the Blockchain to function (*ibid*.). El Shobaki (interview, *ibid*.) sees that Blockchain could clearly not change people's motivation to share information with each other. It is likely that actors would choose not to share information unless information sharing would be obliged or required.

The recommendation on a statutory requirement on data sharing points at that Blockchain may not have what it takes to encourage combat adverse selection in the agri-food chain (own remark). Blockchain is not complete without any legal requirements that regulates the data sharing behaviour of chain actors. Chain actors will not be motivated to share information with others unless it favours their own business. On the other hand, the Smart Contract can monitor the sharing behaviour of chain actors, by executing a reward if certain information is shared. The fact that many chain actors share the same information and that information needs to be verified and validated results in that frauds are discovered faster before it causes too much damage. All data is linked to a physical product meaning and can only be entered in the Blockchain after one has performed tasks.

Collaboration on common data

Lundin (2018, interviews) sees that farming advisors/consultants and primary producers are likely to initiate a closer collaboration through exchange of a more diversified and detailed farm data. Aggregated data will require a much more holistic view by taking new aspects into consideration, such as information technology, biology and economy, as a basis for decision making in increasing profitability and stimulate growth. Expert knowledge from new areas are likely to be needed, and it is likely that expert knowledge of food will be combined with expert knowledge from other sectors in society sectors. Collaboration will be supported by a standardised system structure, that will enable facilitated information exchange. Integrating different chain actors' systems will create new business opportunities for advisories. Shared beliefs between chain actors, such as standpoint of antibiotics use, are likely to facilitate a more standardised system (*ibid*.).

Catalini and Gans (2017) argue that because Blockchain is a general- purpose technology (GTP) with a broad area of use (property rights, financial assets, contracts etc.), it enables linking different sectors in society. Blockchain therefore has potential to minimise search costs by enabling networking and facilitated information exchange. Blockchain is likely to reshape the market structure and therefore it will have a huge economic and institutional impact as it enables new ways for different sectors in society to collaborate. However, FAO (6, 2018) warns that there are no regulations or policy adjusted to new collaboration forms such as between policymakers and regulators. FAO (*ibid*.) further argues that because public Blockchain does not require users to identify themselves, there is a risk of "malicious users". This implies that because one cannot know the real identity of the user, there may be hidden intentions among users that do not show directly. FAO (*ibid*.) warns that these malicious users risk gaming the network system to gain control. Blockchain is also prone to privacy risks as blockchain does not keep track of the identity that comes with private and public keys. There may be a risk of identity disclosure in permissionless blockchains that require data to be open but past transactions are closed. New data is likely to create new values and also new services as well as new business opportunities. The advantage will be more prominent for primary producers that will have increased control of their production (Lundin, interview, 2018).

Processors are likely to develop a closer relationship with primary producers in assessing the quality of the raw food products (Lundin, 2018, interview). Also, a closer relationship with buyers will lead to more accurate forecasts about raw material supply. This requires that the IT competence is up to date and adjusted to fast technical changes and to increased data of primary producers.

Retailers will have better logistical flows, which will cut waste in the agri-food chain (Lundin, 2018, interview). Data from processors and customers will enable real-time matching of supply and demand. Intermediaries becomes integrated into the network.

Authorities will collaborate with primary producers, for example about data on animal health but will need to complete with special competence from advisors (Lundin, 2018, interview).

Because Blockchain enables traceability of information, real-time matching of supply and demand, logistical flows will be more efficient, cut waste and create efficient product recalls (Lundin, interview, 2018). Facilitated information sharing will enable chain actors to merge resources and to cut costs in real-time. Particularly smaller chain actors with a restrained economy can collaborate with large competitors and merge their resources with them. Information sharing and collaboration will make it easy to merge competences, which in today's situation is complicated because of the many actors and stages of the food supply chain. In general, Blockchain will imply a win-win situation for all parties and will generate an increased value that can be shared more equally among chain actors (*ibid*.).

El Shobaki (interview, 2018) sees that Blockchain in the agri-food chain would provide secure information sharing and a more efficient collaboration and communication between the actors of the supply chain. It is likely that Blockchain through standardised communication will result in a more time saving day-to-day interaction by verifying information in a standardised way. On the other hand, it is likely that standardised communication will lead to decreased interaction with colleagues, which will be bad for e.g. exchange of new business ideas or collaborative innovation. Furthermore, Blockchain is likely to play a transactional role rather than a relational role in the agri-food chain. This because Blockchain will first and foremost enable primary data transfer in the Blockchain to facilitate daily communication. However, a prerequisite for data transfer would be a relation as a transaction requires some sort of relation as well as a contract.

Lundin (interview, 2018) sees that more detailed data from primary production will enable more precisely made product development as well as individual and costumed services. This generates closer bonds and increased trust among chain actors. Information sharing will enable chain actors to merge resources and cut costs. Particularly smaller chain actors with a restrained economy can collaborate with large competitors and merge their resources with them. Information sharing and collaboration will make it easy to merge competences, which in today's situation is complicated because of the many actors and stages of the food supply chain. In general, Blockchain will imply a win-win situation for all parties and will generate an increased value that can be shared more equally among chain actors.

Salmeling (interview, 2018) believes that banks are likely to have a more prominent role in offering new digital services through Blockchain. Blockchain will enable electronic agreements where a digital original works as a source of information. Customers have long demanded electronic and digital bonds in real estate buys, that enables signing contracts at distance. Several parties are involved in signing a digital bond and there are many steps before the buy of the real estate is finally verified and registered. Original information will be shared in a safe and neat way through smart contracts, despite number of parties involved. Lundin (interview, 2018) also share the same standpoint at Landshypotek Bank (interview, 2018) and sees that banks will have better foundations for decision making based on the detailed information.

Salmeling (interview, 2018) believes that consumers are the main drivers behind a more integrated food supply chain as well as the implementation of a transparency system like Blockchain in the food sector. Consumers are likely to continue to set the pace for what types of information chain actors will share. Consumers will decide what information is valuable. Consumers are likely to increase their trust in food as transparency increases (thecurrencyanalytics.com, 2018). However, this presumes that there is access to information and also that information is accurate. If information on labels are consistent consumers can adapt their consumption habits to specified needs, e.g. origin, farming method.
Certifying organs function as the third-party controller verifying that information is accurate and correct. If Blockchain is applicated to the food supply chain, there will be no need for humans verifying that information is correct as the Blockchain will verify information by itself. Therefore, the role of certification organs is likely to diminish or transform as information can be controlled by the system and can be controlled by readers in the Blockchain. A prerequisite is that consumer information inserted in the Blockchain is correct and accurate. Incorrect information will lose its value and consumers will not have faith in the Blockchain system.

Salmeling (interview, 2018) believes that Blockchain is likely to create a more integrated supply chain through collective information sharing. Information sharing will forge closer bonds between agri-food chain actors (producers, distributors, suppliers etc.) but also between different sectors in society (authorities, banks, organisations etc.) to facilitate the operation and the business of the agri-food. Different sectors in society such as banks and authorities will be accessed business-critical information with food supply chain actors' consent. Consequently, shared business-critical information from the agricultural sector is likely to give other sectors a greater understanding of the agri-business, its operation and daily activities.

The Blockchain network is believed to create a more integrated agri-food chain with faster communication and decision making between the different stages of the agri-food chain. For example, farmers can be granted loans or crop insurance faster and proactively tackle unexpected events. The farmer can share weather forecasts to the bank or insurance company as a form of evidence of expected yield output. Let's say that the farmer is warned about a storm coming up in three days, which might adventure the yield production and affect the farmer's income negatively. The weather forecast is done automatically by the sensors that are placed in the field and report directly to the farmer's mobile phone via an app. As soon as the farmer is being noticed about a critical weather event, the farmer can send the weather forecast directly to the farmer's insurance company via a Blockchain network and get a fast decision on financial support to prevent the storm from damaging the crops. In this way, the farmer can act on the problem before it has caused any damage. This is likely to secure the income of the farmer and prevent the yield from being damaged. Also, it will save the government money not having to buy up the farmer's lost yield that was damaged in the storm. If the farmer and the insurance company write the insurance on a Smart Contract, then the insurance company can pay out the insurance directly to the farmer as soon as they receive the farmer's weather forecast. The weather forecast is local and bound to that specific place, which gives a detailed evidence of expected yield output. As it is today, farmers often have to wait for help and support, the farmer often gets help after the damage already has been done. The bureaucracy may delay taking measures on time, and the help may come when it's too late. With a Blockchain and a Smart Contract, faster decisions can be done to save both time and money for all chain-actors. Blockchain and Smart contracts can also be used for granting loans faster to farmers. The sensors mounted on the tractor can collect information about the field status, which is reported to the farmer's mobile phone. This information can then be used as an evidence on expected yield output, and function as an insurance for the bank to grant loan to the farmer. This is likely to increase trust in the relation between the farmer and the insurance company or bank as the farmer provides complete and detailed evidence in the form of a detailed weather forecast.

The possibility of communicating on distance will open up connecting with local knowledge to use in consultancy. This will be an opportunity for consultancy companies that often are decentralised. Lundin (interview, 2018) also believes there will be a need for more IT competence, either acquired by food supply chain consultants or offered from the competing IT branch with smart IT solutions. Farmers' cooperation will have to have access to systems that can process data and satisfy consumer demand of increased traceability and safety. Antibiotics use is a common interest for both advisors and producers that could facilitate the standardisation. All increased collaborations with primary producers will lead to new business opportunities.

Increased dependability on IT competencies

New IoT solutions will make retailers and suppliers more dependent on data from primary producers to develop their businesses. On the other hand, more complex and detailed data available will require cooperation with other chain actors to motivate costs of investment. New services are likely to take form based on increased data availability and efficient information platforms. New business opportunities will arise for suppliers to analyse primary producers' data and new services are likely to develop. Information shared in the Blockchain will be owned by the actors in the Blockchain but not likely by the government.

Access to information is likely to change the bargaining power for several agri-food chain actors. Lundin (interview, 2018) sees that primary producers will have a prominent role in collecting new data and find new insights about how to combine and use data to increase profitability together with advisors. Real-time control of production will enable producers to discover and fix problems on time. For example, batches can be discovered and recalled on time before causing too much economic damage, which will cut waste throughout the whole chain. Producers will have a choice in sharing advantageous information. This will put producers in a better position in the food supply chain because producers will have access to information.

Blockchain provides an exciting new marketing channel for small-holder farmers to reach out to larger and international markets than just local markets (FAO, 6, 2018). Other chain actors can read about previous orders and deliveries from the small-holder farmer and get recommendations from previous customers. The Blockchain then works as a CV and the small-hold farmer can be discovered by new potential customers around the world. This could reduce transaction costs for small-holder farmers.

Box 6. *Blockchain's ability to reduce bargaining costs in the agri-food chain*

Blockchain's ability to reduce bargaining costs in the agri-food chain	
+ Facilitated real-time collaboration between different levels in the agri-food chain *+ Closer bonds and increased trust between chain actors sharing business-related information* *+ Faster communication and decision making* *+ Function as a marketing channel for small-holder farmers*	*- Dependability on IT competence* *- May not encourage chain actors to share too sensitive business information with each other* *- Prerequires that chain actors are willing to share information with each other* *- Access to information becomes vital for bargaining power* *- Adverse selection*

5.1.3 Blockchain's ability to reduce monitoring/enforcement costs in agri-food chain

Moral Hazard

Smart Contracts have the possibility to prevent moral hazard behaviour of contracting parties (Cong & He, 2017). The self-executing mechanism is linked to the contractual agreements that the contracting parties have set up in the contract, and automatically executes a reward if the specified agreements have been fulfilled. If contracting parties fulfil their promise of the contractual agreement (perform what was agreed on to be done), the Smart Contract will be noticed about this and then automatically pay out a reward. If contracting parties instead fail to fulfil contractual agreements, the Smart Contract executes a form of penalty. The Smart Contract is considered promising especially in agricultural crop insurance. In case of extreme weather such as flooding or drought, the Smart Contracts automatically executes a payment to the farmer that is linked to expected weather incidents. A crop insurance linked to a Smart Contract enables the farmer to act on weather incidents *in advance* before weather causes any damage to the yield (*ibid*.).

FAO (6, 2018) advocates that Smart Contracts have the potential to disrupt the traditional contractual infrastructure as well as eliminate the need for centralised intermediaries. Compared to a traditional contract in which parties need to trust each other first, a Smart Contract does not require parties to trust each other first because of the functions of self-executing mechanism, autonomy and decentralisation.

Cong & He (2017) points at that if it was easier to write and enforce performance-based contracts, it is likely that more businesses would apply performance-based pay. Applying a Smart Contract means that a salary bonus is executed if certain actions are performed. The smart contract therefore evaluates the performance as either highly productive (good state) or low productive (bad state). The salary is executed if a good state is reached, meaning that certain actions have been carried out and rewards the actions by paying a salary automatically. Computer programming such as smart contracts can reduce the risk of human error that otherwise occurs in a principal-agent situation. This is also convenient for agents that are risk-averse (afraid of risks) because external shocks outside of their control cannot influence the productivity. If external shocks influence the agent, the agent has to fix this to get its salary paid. Otherwise, the Smart Contract does not pay out the salary.
A further possibility with using the Smart Contract is that the performance can be evaluated and benchmarked against a market or industry index (Cong & He, 2017). Furthermore, smart contracts could effectively allocate decision rights. Cong and He (*ibid*.) claim that: "*the allocation of property and control rights in a smart contract can be codified, so that automated execution is feasible, which reduces enforcement costs.*". This implies that the power given to the agent can be more dependent on the algorithms of the smart contract.

Cong & He (2017) claims that Smart Contracts make contracts more complete because of the following reasons: 1) smart contract reduces unforeseen contingencies 2) smart contracts reduces writing costs 3) smart contracts reduce enforcement costs 4) smart contracts reduce renegotiation.

Smart Contracts can reduce the cost of writing contracts (Cong & He, 2017). This is because the algorithms in the smart contract save time and money writing the contract, compared to traditional contract writing in which too many details and contingencies are many and hard to include to make the contract complete. Enforcement costs can be reduced because of the automated process of the smart contract. The smart contract executes a reward automatically after certain actions have been performed. This is possible due to the decentralised structure that Blockchain provides as well as the fact that details in the contract are codified and protected from others than the contracting parties to view.

On the other hand, Nobel Prize winner Oliver Hart specialized in economic contract theory claims that self-verifying Smart Contracts cannot make contracts more complete than traditional contracts (Frank & Silverstein, 2018). Smart contracts can never be considered more complete than traditional contracts because they still face the same problems of uncertainty as any contract. Neither smart contracts nor contracting parties can predict future eventualities, so it is impossible to have complete information of all potential risks and uncertainties of the future. Hart (*ibid*.) therefore doubts that Smart Contracts would enhance trust and strengthen the quality of long- term business relationships.

Box 7. Blockchain's ability to reduce monitoring costs

Blockchain's ability to reduce monitoring costs	
+ *Smart Contract prevents moral hazard* + *Reduce the cost of writing contracts* + *Performance-based pay*	- *Incomplete contract?* - *Adverse selection - Leave out information in contract*

6 Conclusions

In general, Blockchain holds great potential to reduce several transaction costs in the agri-food chain, by providing a decentralised, disintermediated structure to the supply chain.

Blockchain holds potential to improve transparency and traceability in the agri-food chain and thereby reduce the cost of searching for information. The internal cost of searching for information could be reduced if more information is accessible and traceable for free. However, this prerequires that chain actors are willing to voluntarily share information according to recommended information sharing standards or that information sharing is regulated by statutory requirements. In this respect, Blockchain may not combat the problem with chain actors disclosing information from other chain actors (adverse selection). Unless regulated by statutory requirements, Blockchain risks ending up as a marketing platform in which only non-sensitive data is shared. On the other hand, sharing too sensitive data without aggregating it can expose chain actors and put them in a vulnerable position. If not carefully monitored, chain actors could be exposed to greater risk if too sensitive information is not aggregated. The external cost of acquiring information is high because of the high operational costs and internet consumption. While the internal cost of sharing information could decrease, the external cost of sharing information could increase.

With a Blockchain applied in the agri-food chain, bargaining costs could be reduced by facilitating collaboration between various levels in the agri-food chain. Blockchain would connect various chain actors and therefore provide a real time match of both demand and supply. However, the possibility of increased collaboration depends on the willingness of agri-food chain actors to share information with each other. Blockchain does not seem to have potential to encourage chain actors to share information with each other. However, if chain actors on various chain levels collaborated through standardised information sharing, this would likely increase trust among agri-food chain actors. Access to information is likely to become an important aspect for acquiring bargaining power. Increased dependability on IT competence will give rise to increased need for knowledge on IT. Chain actors with IT competence might have greater bargaining power than chain actors that lag behind on this knowledge.

Monitoring costs could be decreased with Smart Contracts that executes rewards according to performance-based pay. Performance-based pay prevents moral hazard from occurring as chain actors are encouraged to act in a certain way to acquire a reward or payment. The actions and behaviour of chain actors can be monitored. However, Smart Contracts are not likely to prevent adverse selection in the agri-food chain if chain actors can choose what information to share and what information not to share.

In summary, the Swedish agri-food chain could change in many ways if Blockchain was applied. Blockchain would provide a more agile agri-food chain that could adjust to changed conditions or consumer preferences more rapidly. Real time match of supply and demand could cut costs for several chain actors and make decision making faster. Traceability would provide several advantages but also some risks if not carefully monitored. Blockchain requires that data sharing is monitored, e.g. by a statutory requirement and protected through cryptographic Smart Contracts. Also, aggregating data may be vital to protect the privacy of users. However, what type of data chain actors should share must be carefully considered. An interesting field of research could therefore be on what type of information chain actors should share information with each other. What type of information should be traceable to provide transparency on food products? Investigating this field of research, one would have to consider the GDPR (General data protection regulation) and to what extent data is private and protected. A further field of research could be how patents would be affected in case of statutory requirements on information sharing. What information should be considered private and classified, and what information should be transparent? Another interesting research topic could be how different variations of Blockchain would affect data access and transparency for different agri-food chain actors. Different variations of Blockchain regulate access to data for different network members.

Further research on Blockchain is needed on mapping the relationships between various agri-food chain actors in the Swedish agri-food chain. The role of big data and information sharing is likely to change the relationship between agri-food chain actors. It is difficult to predict the outcome of new technology in the agri-food chain, such as Blockchain. However, predicting the possible outcomes may prepare us to tackle problems in advance.

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Appendix 1

How Blockchain works

The Blockchain mechanism starts with that a transaction occurs (blockchaintechnologies.com; Investopedia, 1, 2019). When a transaction occurs, signals are given to all the other blocks in the Blockchain that new information needs to be stored in the network. Before information can be saved in the network, the transaction must be verified by all users of the network. This means that details about the transaction need to be verified (e.g. the transaction time, what was transacted, the amount etc). When new information rushes through all the blocks, the blocks need in turn verify the transaction and verify that the transaction has been made accordingly and that information is correct (*mining*). If all users verify the transaction, the transaction is granted permission to be stored in the Blockchain. After the verification of the transaction from all the users, the transaction with its information need to be stored in a new block. The block is added in order and form a long chain. Details about the transaction are stored in a new block. After a new block has been created in which the transaction can be stored, the block needs to be assigned a hash (an ID code). The block is also hashed with the most recent block added to the Blockchain. When the blocks are hashed together, the block is finally added to the Blockchain and information is saved and transferred to the rest of the blocks. All blocks added in the chain are forever saved and can never be deleted from the Blockchain (Investopedia, 1, 2019).

Different types of Blockchain provide various access to data

Blockchains can take different forms and be digitally built in various ways (blockchaintechnologies.com). The way a Blockchain is digitally built provides the features of a Blockchain network. These features in turn influences the capacity for action (handlingsutrymme) for its network users and rights to access different types of data.

Grasping how various Blockchains differ are vital to understand the opportunities and limitations for its network users (blockchaintechnologies.com). Depending on what purpose a Blockchain is used for and what context it is applied in, some types of Blockchain may provide more benefits for its users than others. A certain type of Blockchain is neither good nor bad until it is applied in its specific context. To decide what type of Blockchain to use, one needs to look at the following variables in the context; what type(s) of data is to be shared (sensitive/non-sensitive data), with whom the data should be shared (e.g. restricted or public), the relation between the users (e.g. power relation or anonymous) and assessing the eventual outcome of sharing certain types of data with particular users regarding the relation between the users (risks or benefits). Different Blockchains have different features and offer various functions. These are presented in the following sub-chapters.

Public Open Blockchain

A public open Blockchain (such as *Provenance*) implies that information is completely transparent and available to all chain actors, whereas a private closed Blockchain network restricts membership and grants permission to access information only for selected members within the network (Medium, 2, 2018; 4, 2018; 5, 2018). A combination of open and closed Blockchain (*consortium Blockchain)* will provide both transparency and privacy for chain actors.

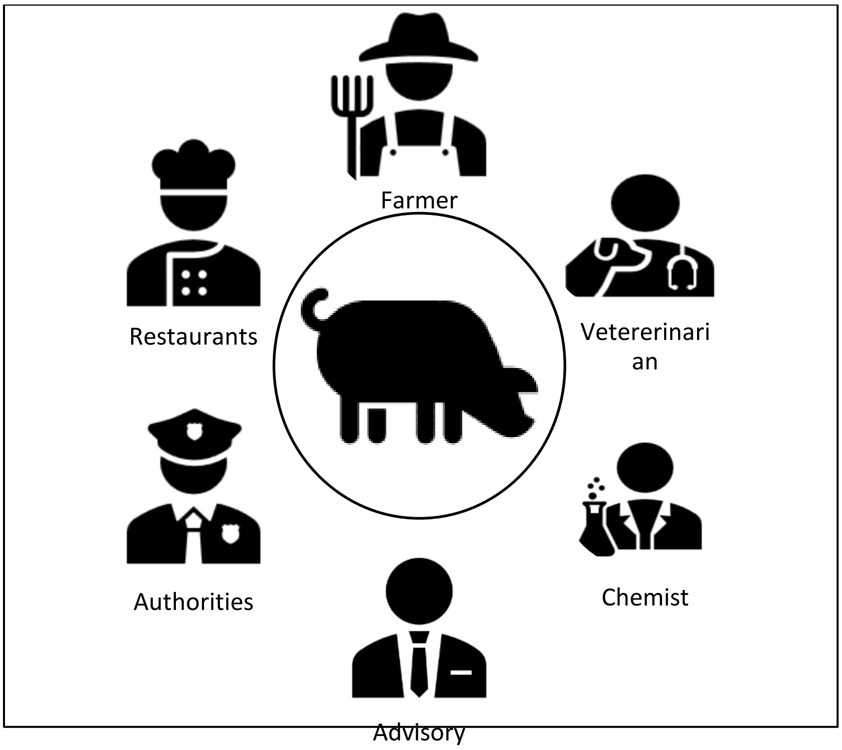

Figure 3*. In a public open Blockchain, all chain actors receive the same information simultaneously and can trace the food product from farm to fork.*

Private Closed Blockchain

A private Blockchain implies greater control of its members (Medium, 2, 2018). Private blockchains are more restrict on participation, an invitation is required to join, and membership is verified either by the creator or by the members. Members have unequal rights on writing, reading and access to information in the network. In a private blockchain there are fewer members, which minimise the energy consumption and Internet consumption.

Verifying transactions in a private Blockchain is done much faster than in an open Blockchain because of the limited amounts of members (Medium, 2, 2018). Also, the restriction on membership and on who can participate means that members are approved from the start.

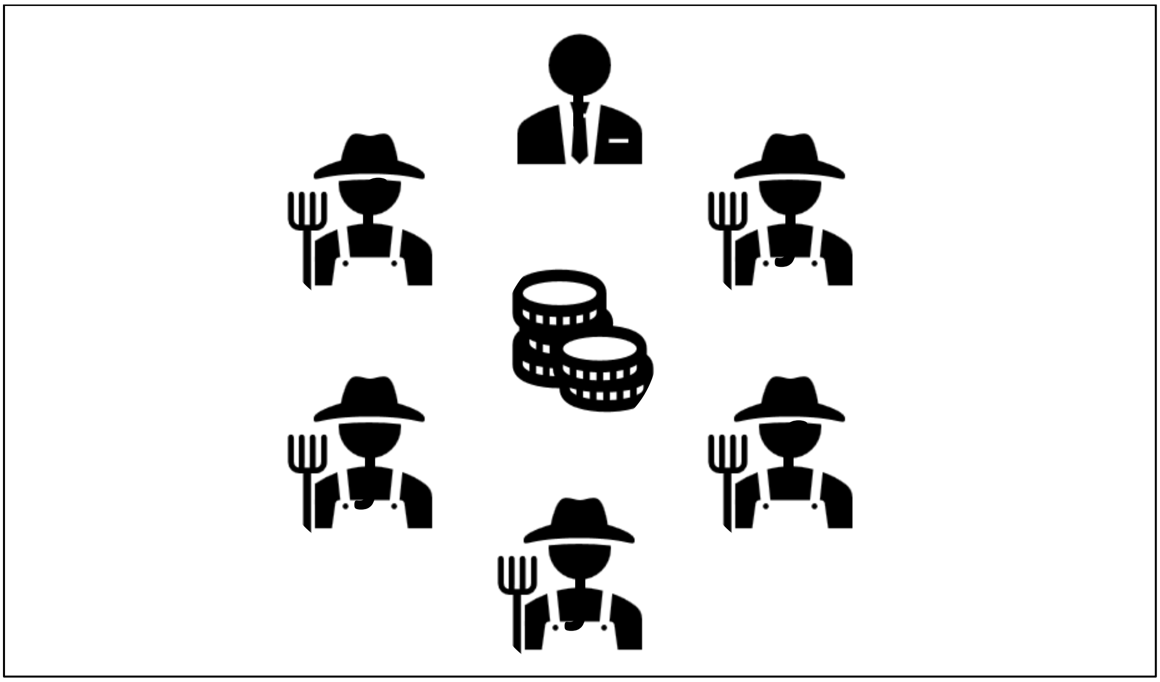

Figure 4. *A private Blockchain shared by a bank and its customers*

Hybrid Blockchain – combining open and private Blockchains

The hybrid private-open Blockchain (e.g. *Etherum*) is restricted on access and on who can transact in the network (blockchaintechnologies.com). According to blockchaintechnologies.com (*ibid*.,n.a.) the hybrid blockchain is considered to be semi-centralised. The hybrid blockchain has restricted permissions like a private blockchain (dragonchain.com).
A central entity controlling the information flow, a group of permissioned peer networkers control it.

Consortium Blockchain

A consortium Blockchain is considered a sub-category of a private Blockchain and is governed by a group, instead of by a single entity (dragonchain, 2019). Consortium Blockchains are used by users that both collaborate and compete with each other (*ibid*.). Consortium Blockchains can be used by large actors such as central banks, governments to supply chains (*ibid*.).

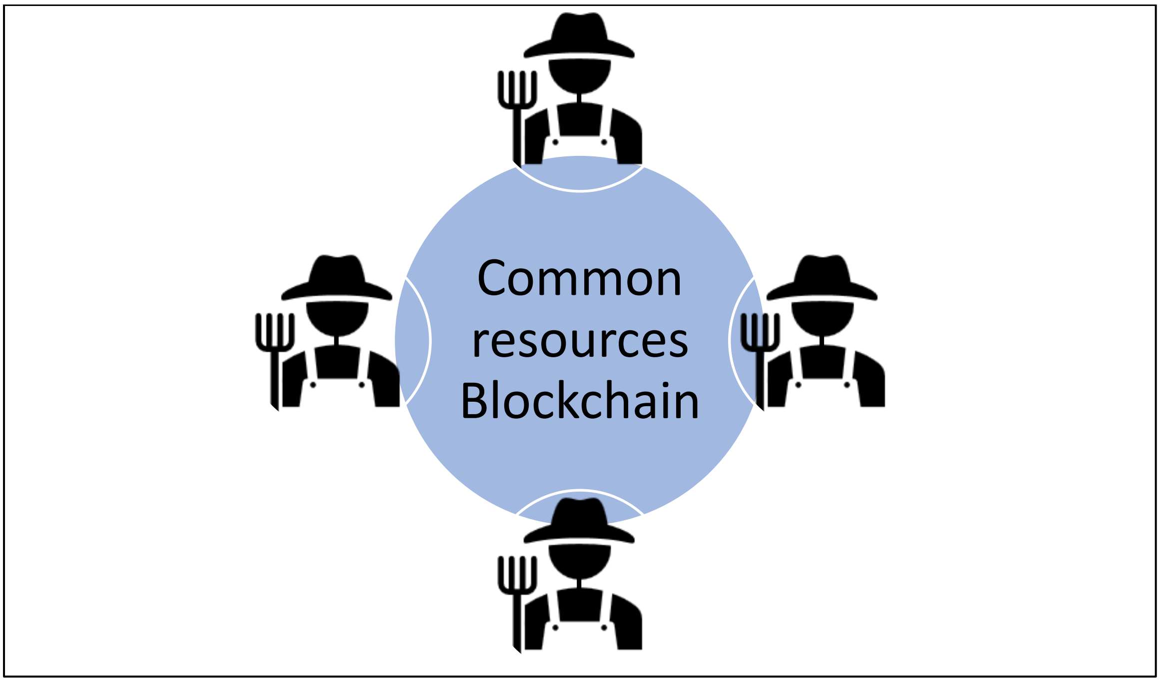

Figure 5. *Competing large scale farmers sharing a consortium Blockchain to split costs*

Box 1. ***Big data in Blockchain***

For Blockchain to function, it requires some sort of information (data), either to be saved and stored in the network or to make a transaction. Because Blockchain can store any type of data, it goes well with *Big Data* that can contain data in different formats. *Big data* implies large data sets that can be analysed computationally to reveal patterns and trends (*ibid*.). Compared to traditional information, Big data provides new characteristics to information that can be summarised as "The six Vs" (Poon *et al*., 2015). The six Vs imply that data or information takes new characteristics in the following six ways; ***volume, velocity, variety, veracity, value and variability***. As the term reveals, Big data means dealing with large quantities of data and information (volume). This is especially useful in a fast-paced food industry or large-scale agriculture, where information needs to be carefully evaluated but seldom gets checked due to the fast pace. These large amounts of data are produced fast and also need to be handled fast (velocity). It becomes even more complicated because information collected is very detailed (variety). Big data needs to be pre-processed and aggregated to a greater extent than traditional information. Big data is therefore not as easy to structure and to fit into databases as compared to traditional data. Big data stretches over both depth and distance, meaning that detailed information can be collected on both micro and macro level, covering the whole field. In agriculture, different types of data can revolve around e.g. sun exposure, humidity, starch and chlorophyll status on the field (Macklean, 2019). Data also needs to be trustworthy and reliable (veracity) as well as be relevant (value) (Poon *et al*., 2015.).

The most complex and diverse data collected in the agri-food chain is on farming level or primary production. On farming level, data on field production or livestock is collected through wireless sensors mounted on the tractor (Macklean, 2019). Using sensors to collect information can be useful on farm level for several reasons. Automated tractors can be monitored and controlled on distance. In this way, the farmer gets noticed in advance and can prevent hinders and proactively provide support to machines on field. Collecting and analysing detailed production data can also help farmers take more optimal decision, because knowledge is created in its local-specific context. Local-specific weather and its influence on local-specific soil can generate a greater output. Uncertainty, risks and unexpected contingencies can be tackled in advance with greater precision. Farmers are looking for new ways to cut costs as well as get better paid for diversity in their different products (Wolfert *et al*., 2017). This can be done through using detailed data in benchmarking, analytics, predictive modelling. Furthermore, collecting information through sensors can create integration of co-operating and co-supporting systems on farm level (e.g. irrigation systems, seeding systems). Sensors are flexible in collecting diverse types of information in different formats e.g. satellite pictures, chart pictures and sensor data. This puts pressure on handling and analysing different types of information.

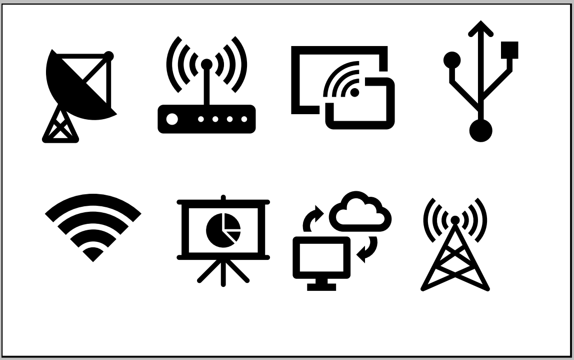

Figure 7*. Blockchain depends on a range of other information technologies and communications infrastructure that may not be available or affordable by everyone. Summarised by the author.*