Global agri-food supply chains in an inter-connected world: a systems approach

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Introduction

Agri-food supply chains (AFSCs) are complex, interconnected networks that span the world, yet they are highly influenced by regional contexts, as the chapters from this book have illustrated. From large-scale farming in countries like the United States to small and medium-sized farmers in Latin America and Africa, each region presents its own set of challenges and opportunities. These do not only result from regional environmental conditions but also political, economic, social, technological, and regulatory aspects. Using the framework introduced in Chapter 1, this closing chapter synthesizes the content of this book by differentiating between the managed system, the managing system, and the information system to provide an understanding of AFSCs across the world.

The Managed System

The managed system is where the transformation of raw materials into finished goods occurs. Farms, (cold) warehouses, transportation resources, as well as retail and foodservice points all relate to this system, ultimately making up for the network structure of the AFSC. This system has become increasingly intricate due to technological advancements, regulatory changes, climate change, and consumer demands for the availability of a wide range of products throughout the year, while also increasingly emphasizing higher quality, sustainability, and traceability.

Throughout the book, we learned that the configuration of the managed agri-food system differs per region. For instance, the AFSC in the United States is dominated by large players, benefiting from economies of scale and advanced technology, which results in higher productivity. An example of this reality is highlighted in Chapter (insert chapter number of “Agri-food supply chains in the U.S.”)

with the use of automated harvesting equipment in the Midwest grain belt, which allows for rapid and efficient collection of crops. In contrast, regions like Mexico rely heavily on small to medium-sized farmers, particularly in the sugarcane industry, where regulatory constraints also play a significant role due to the past role that the government played in controlling the production of several strategic industries in the country. In countries like Colombia, coffee is often grown by smallholders who face challenges related to market access and price volatility due to financial constraints. On the other hand, the agricultural sector in Europe is highly organized and mechanized, focusing on both crop and livestock farming, where the Netherlands is a clear example with its prevalence of greenhouse farming and its dairy industry. Additionally, AFSCs in Asia face significant challenges as the food supply system is under strain due to various factors including regional conflicts such as the war in Ukraine, a shift towards more calorically dense diets, and the global pandemic of COVID-19. In India, for instance, the rice and wheat supply chains are often disrupted by monsoons, while in Singapore, there is a high reliance on imported goods, which has ignited a significant investment in agri-food technologies to increase their self-sufficiency for some critical products.

The Managing System

The managing system is responsible for ensuring that the output of the managed system meets certain targets. This involves making decisions on production volumes, sourcing strategies, quality control points, and other tactical and operational aspects. Planning and control in agri-food supply chains involve complex decision-making at various stages, including production, harvesting, and processing. Furthermore, the planning and control of agrifood supply chains are complicated by the perishable nature of agri-food products. Recent events, including the need for more sustainable food systems and increased resilience, have intensified the challenges supply chain managers face and have changed the focus of supply chain managers from maximizing profits (or minimizing costs) subject to some quality/safety constraints toward more systems-oriented objectives, such as robustness, sustainability, and food security considerations.

Due to the different levels of technological and planning capabilities, the managing system also differs significantly between regions. For example, in the United States and Europe, the managing system is highly advanced, benefiting from technological innovations that allow for better planning and control. However, uncertainty in production yields (for the US particularly in corn and soybean farming) often complicates the planning process. Latin America, on the other hand, faces challenges related to regulatory constraints and the perishability of products due to the large percentage of goods going all the way to the US, the EU, and even Japan (the most lucrative markets). For example, the perishability of tropical fruits like bananas and pineapples creates logistical challenges to make them reach the (northern) markets in optimal conditions. In Spain, olive oil production is often subject to strict quality controls to meet EU standards. However, unpredictable weather patterns can affect olive yields, making it difficult to plan production and react to changes in the plan, as shown by the 2022 droughts in Spain (*BBC News* 2022). In Asia, the managing system faces the challenge of balancing the need for nutritious food with the high cost of such diets, especially given the income disparities in the region. In China, while the demand for pork products has significantly increased due to the increase in purchasing power, the pork supply chain has been disrupted by African swine fever, requiring stringent management measures. The perishability of seafood in countries like Japan adds another layer of complexity to the managing system due to safety concerns.

The managing system faces the challenge of incorporating various regional particularities into the planning and control of the agri-food supply chain. Factors such as unpredictable weather patterns, regulatory constraints, and economic disparities add layers of complexity to the planning process. For instance, while the U.S. may rely on advanced data analytics for decision-making, such technologies may not be readily available or applicable in major parts of Latin America or Asia. Similarly, the perishability of products like seafood in Japan or fruits in Latin America requires specialized planning that may not be as critical in other regions. This makes the task of creating a unified, efficient managing system a complex endeavor that requires a nuanced understanding of these regional specificities.

It is worth noting that the managing system might behave differently in steady-state (normal) conditions than under the effect of disturbances, as Chapter (insert chapter number of “Supply chain resilience capabilities in food supply chains: A study of the impact of COVID-19 in the Netherlands”) demonstrates by showing the approaches that different actors in AFSCs took to overcome the disruptions created by the COVID-19 pandemic. In contrast to normal circumstances where processes and strategies are well-established and predictable, the pandemic needed a more reactive and flexible approach. Companies had to leverage capabilities that would normally be difficult to utilize, such as rapid reallocation of personnel and changes in product packaging, which were accepted due to the collective effort to deal with the exceptional circumstances. This shift highlights the need for the managing system to be agile and adaptable, capable of responding to unforeseen challenges while maintaining food safety and quality. However, it also reveals the limitations due to informational constraints, as many companies lacked specific plans for such unprecedented disruptions, highlighting the importance of contingency planning and risk management in the managing system.

The Information System

The information system collects data generated during the transformation process in the managed system. This data is crucial for the managing system to make informed decisions. The ability to measure and monitor AFSC performance is a pressing issue, particularly considering that, due to climate change, crops might need closer monitoring due to unexpected changes in their maturation process and, consequently, their final quality and safety. Also, due to the large contribution of AFSCs to many key environmental indicators, clear and comprehensive performance measures are needed to be able to decide on and follow up on initiative towards the reduction of these environmental impacts. The complexity of these supply chains, the multitude of inputs and outputs, and the lack of consensus on determining performance make the selection and discussion of appropriate measures (ranging from the economic value generation to environmental and social measures) a challenging task. Nevertheless, performance measurement is crucial for informed decision-making and end-to-end supply chain design.

In some value chains in the United States and Europe, advanced information systems utilize technologies for real-time tracking and analytics, aiding in better decision-making. For example, blockchain technology is increasingly used for traceability in the European meat industry. On the other hand, information systems in Latin America and Asia are still in the process of incorporating more advanced technologies for better monitoring and traceability. In Thailand, for instance, QR codes are being used to trace the origin of certain fruits, providing consumers with more information about their purchases.

Performance measurement plays a crucial role in ensuring the quality and safety of food in agri-food supply chains. However, the planning system often faces limitations due to informational constraints. In regions with less developed technology infrastructure, the lack of (real-time) data can hinder effective planning and compromise food safety and quality. This is particularly challenging in a global network where regional differences and mismatched infrastructures can create gaps in the managing system but also when the supply networks face significant disruptions. The COVID-19 pandemic exposed the need for real-time data and analytics to make informed decisions quickly. However, the lack of preparedness and the absence of relevant historical data made it challenging for many companies to adapt their performance measurement strategies effectively. This situation underscores the dependency of the information system on technology and its capabilities as well as the need for robust and adaptable information systems capable of supporting the managing system under both normal and disrupted conditions.

Future Research Directions

As we conclude our exploration, it is evident that agri-food supply chains are at a critical juncture. The ongoing need to meet the food demands of a growing global population, to adapt to shifting consumer preferences, to decrease environmental impacts, and to respond to disruptive events like pandemics and geopolitical conflicts highlights the need for innovative solutions. Future opportunities for research in agri-food supply chains are then also abundant. Given the complexities and challenges identified in the agri-food supply chains across different regions, several avenues for future research can be suggested.

Supply chain design for sustainability

Research should focus on the impact of environmentally sustainable practices. There are many initiatives with the aim to be more sustainable, e.g., agroforestry (Lillesø et al. 2011), within the agri-food supply chain, particularly in regions where intensive farming is prevalent as the impact of this type of agricultural production can significantly influence soil contamination and productivity in the future (Gaffney et al. 2019). This research could help us understand the value of sustainable practices (either positive or negative) and what could be the optimal configuration of different agri-food

Commented [RA1]: I'm wondering if we need to broaden this up. A lot of the initiatives towards smaller scale, organic, etc decrease yields and end up being less sustainable. But this is a bit of a larger discussion on things like land sharing vs land sparing. Also sometimes a bit of a controversial topic, but I don't think we should just position 'smaller' as more sustainable.

supply chain networks based on a holistic analysis of the demand and nutrient requirements, geographic supply constraints, and impacts on sustainability. In regions where small farms are prevalent, such as Latin America and Africa, research on sustainability should also consider the social aspect of sustainability as it is critical to attain economic and environmental sustainability due to the challenges regarding the living standards of small farmers (Giller et al. 2021). Thus, future research of AFSC networks where small farmers play a significant role should consider a triple-bottom-line lens (Carvalho, Relvas, and Barbosa-Póvoa 2022), which incorporates the social, economic and environmental aspects of sustainability, in order to find the optimal network configuration (using multi-objective mathematical programming, for example) that finds a balance between these three aspects of sustainability (see Zhanguo Zhu et al. 2018 for a review of operational research approaches focusing on these issues).

Technological innovations

The role of emerging technologies such as blockchain, IoT, and AI in enhancing the efficiency and traceability of agri-food supply chains warrants further investigation, as highlighted in Chapter (insert chapter number on "Information and communication technology in agri-food supply chains"). Furthermore, more studies on the role that digitalization might play in some regions to optimize processes and increase efficiency across the supply chain (Annosi et al. 2020). This efficiency ideally also extends to the environmental dimension, in which an efficient use of resources is arguably even more important. This is especially the case due to the large share of the global food production that is lost or wasted somewhere in the AFSC, clearly leading to many supply chain challenges to address (see also Akkerman and Cruijssen 2024). These challenges related to the managing system and the information system however also extend to the managed system, in which technolological developments in for instance alternative protein production might significantly alter AFSCs in the future, in turn requiring the managing systems and information systems to adjust.

Performance measurement analytics across regions and supply chain echelons

The development of standardized performance metrics and indicators to facilitate the traceability, monitoring, and control throughout the supply chain considering a minimum technological denominator, which could be supported by the incorporation of new technological standards such as blockchain, as suggested by Chapter (insert chapter number for chapter "Information and communication technology in agri-food supply chains"). In addition, the multi-criteria aspect of performance measurement in AFSCs due to the many stakeholders and systems involved in the production and distribution of food results in a very complex system to measure; thus, advanced analytics tools that integrate different measures into a single framework of analysis such as data envelopment analysis (see, e.g., Priyadarshini and Abhilash 2023) could be very helpful to better understand which are the key characteristics of well-performing AFSCs across economic, environmental, and social criteria.

Supply chain financing in agri-food value chains

While research on supply chain finance is abundant (Xu et al. 2018), its role in the performance of AFSCs has not been sufficiently investigated, particularly from the point of view of the economic viability of small and medium-sized farms (Oostendorp et al. 2019) in the face of large-scale operations as well as increasingly uncertain yields due to climate change. Research on AFSC finance could provide insights into better financing options to reach more equitable, heterogeneous, and, ultimately, resilient, agri-food supply chains, helping to reach a better triple-bottom-line for the entire network and, overall, better food security for different regions. To this end, simulation has shown to be a powerful tool for modeling the various interactions between actors as well as the system uncertainties that are present in AFSC (Utomo, Onggo, and Eldridge 2018). New technologies such as blockchain offer a lot of opportunities for further development in this area, as exemplified by recent studies using a game-theoretic approach (Choi 2023; Dong, Qiu, and Xu 2023).

Resilience and risk management for climate change adaptation

Given the increasing impact of climate change on agricultural yields (Jägermeyr et al. 2021), research into adaptive and resilient agri-food supply chains is crucial. Thus, understanding and developing strategies to enhance the resilience of these supply chains in the face of global uncertainties, particularly in regions that are most likely to suffer the consequences of climate change (Giorgi 2006), is necessary to ensure global access to safe food as well as the viability of future agrifood networks. Due to its capabilities to analyze and understand complex, intertwined systems as well as their feedbacks and delayed effects, future studies could use system dynamics as a modeling approach as it has proved to be a suitable tool for modeling resilient and sustainable aspects of AFSC (Aboah et al. 2021; Amiri et al. 2020; Kotir et al. 2024).

The role of supply chains in food systems

Due to their differing scope and scale, as characterized in Chapter 1, research that considers the interplay between food systems and food supply chains could provide a better understanding of the design of current and future agrifood supply networks. For instance, future research could focus on investigating how government policies and regulations influence the efficiency and resilience of food supply chains. Furthermore, since AFSC modeling can be focused on various levels of decision-making (e.g., network configuration, production site) and transactions (e.g., production lots, truck dispatches, or inventory units) more detailed interactions between logistics decisions and the biological systems could be modeled to understand the impact of certain policies on land and water use, biodiversity conservation, nutritional content, and the impact of agricultural practices on ecosystems.

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