

Unpacking the Precision Technologies for Adaptation of the Chilean Dairy Sector. A Structural-functional Innovation System Analysis

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Abstract: Precision technologies and smart farming practices are spreading globally. However, there are still limited insights into how these technologies develop in newly adopted countries and adapt to different local systems, especially in emergent economies. This article aims to diagnose the technological innovation system of precision technologies within Chile's dairy sector, focusing on the possibilities of development and co-evolution. A structural-functional innovation system analysis is performed, based upon 41 semi-structured interviews. The main results indicate that precision technologies are in the implementation phase in the Chilean dairy sector, with scarce experience and undeveloped knowledge of their benefits. Moreover, there are insufficient interactions between different actors with limited information sharing due to the lack of trust as a cultural issue, affecting the development of smart farming practices. Some strategies to develop and co-evolve the technological systems are discussed, as is the need to increase trust and cooperation between the actors of the dairy sector.

Keywords: technological innovation system, innovation system analysis, precision technologies, smart farming, dairy, and Chile.

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1. Introduction

The dairy sector faces increasing competition resulting from globalization. This phenomenon has led milk producers to seek new technologies and practices that allow them to be more efficient and respond to the dynamic demands and regulations of the global market (Caja et al., 2016; Challies & Murray, 2006; Moreira & Bravo-Ureta, 2010; Oenema et al., 2014). This situation is observed in the Chilean dairy sector, confronting the United States, Argentina, and New Zealand competition. In Chile, milk production has declined due to the low milk price for farmers and the low price of imported dried milk. This situation pressures the Chilean farmers to innovate towards new technologies with more intensive systems to be more efficient and reduce production costs as the precision technologies (Eastwood et al., 2016; Gonzalez & Katial, 2016; Muchnik et al., 2008).

Precision technologies can improve production efficiency by applying advanced data measured with the technology, targeting resource use, and precise control of the production process in real-time, quickly, and efficiently the decision-making process (Eastwood et al., 2017a; Eastwood et al., 2017c). Moreover, these data can be spread as knowledge with other actors to increase the possibilities of knowledge development and create information that can be used to be more efficient on the farm (Banhazi et al., 2012; Eastwood et al., 2016). In sum, precision farming is *"the use of information and communication technologies for improved control of fine-scale animal and physical resource variability to optimize economic, social, and environmental dairy farm performance."* (Eastwood et al., 2012). Examples of precision technologies are an on-line milk meter capable of measuring mastitis and milk components or automating feeders, irrigation, and fertilizer application.

Complementary to precision agriculture, the smart farming approach has been developed. It is defined as technological practice related to disseminating information received from software spread across the supply chain. This information or data is spread in platforms to diffuse knowledge and make decisions based upon different actors' expertise (Eastwood et al., 2017b; Jakku et al., 2018). The smart farming practices vary from a simple feedback mechanism as a thermostat regulating temperature to deep learning algorithms to develop crop protection strategies, including combination with external big data sources such as weather or market data or benchmarks with other farms available for different sectorial actors (Wolfert et al., 2017). These characteristics distinguish precision agriculture from smart farming. Meanwhile, the first one is focused on farm-level data to support the decision process. The second one advances, enabling individual farm data aggregation with data from other farms and other sources in real-time. Then decision-making process can be at a different level as farm, industry, policy levels".

The development and implementation of precision technologies and smart farming can be analyzed with the approach "technological innovation system – (TIS)" (Markard et al., 2015; Wiecek et al., 2015). TIS is defined as *"socio-technical systems focussed on the development, diffusion, and use of a particular technology (in terms of knowledge, product or both)"* (Bergek et al., 2008, p. 408). It is *"a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of Technology."* (Carlsson & Stanekiewicz (1991, p. 91).

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Furthermore, Wieczorek et al. (2015, p.129) state, “*the core of the TIS perspective comprises the analysis of the emergent structural configuration of the innovation system (actors, networks, technology, institutions) and major processes (also labeled as system functions) that support the formation and development of radically new technological field.*”

The dynamic change and process of the TIS, including its influence of socio-technological configurations, with a change of actors, institutional settings, and infrastructure, is called co-evolutional change (Kilelu et al., 2013; Markard et al., 2012). This dynamic change depends on external landscape factors and spatial and historical contextual situations (Markard & Truffer, 2008). Therefore, co-evolution of all different elements (structures and functions) and on different levels of the network helps to be successful (e.g., institutional changes and legitimacy creation for different actors in the supply chain). This co-evolutional TIS requires learning processes and cooperation of actors in the TIS to be successful (Eastwood et al., 2017c; Klerk et al., 2010), and an understanding that technology can be as a hybrid of social and technical components, and the agency of human actors embedded in a network of social and ecological relationships, expressed in many different cultural and institutional dimensions (Glover et al., 2017).

Innovations are new ideas that are put into practice and involve a collective process with the re-ordering of relations between actors and new actors involved in the social network of the farming system (Eastwood et al., 2016; Hekkert et al., 2007; Klerkx et al., 2012b; Turner et al., 2016). Indeed, inter-organizational cooperation has been a determinant of innovation in the agribusiness sector (Geldes et al., 2015; Geldes et al., 2017a). In fact, in an innovation system, each actor has their tasks within a shared vision. These changes in relations and institutions are an ongoing process that is dynamic and continuously changing. This organizational (re-)creation and change of the system with its elements (functions and structures of different actors involved) is an essential aspect of a technological innovation system (TIS) (Bergek et al., 2008; Markard et al., 2015; Markard & Truffer, 2008; Turner et al., 2016; Wieczorek et al., 2015).

In the specific case of the Chilean dairy sector, there is some research about innovative technologies (Carrillo et al., 2014; Jaime & Salazar, 2011; Moreira & Bravo-Ureta, 2010; Bravo-Moreira et al., 2006; Moreira & Bravo-Ureta, 2016). However, the broader TIS of precision technologies in Chile is less studied, especially for the dairy sector, where precision technologies and smart farming practices are still in their initial stages, needing more efforts to make smart farming well-adapted to innovation in the dairy sector.

Furthermore, the collective process of innovation is unique to each economic sector and territory, and emerging economies have some unique characteristics, such as a high prevalence of informal enterprises, institutional failures such as intellectual property protection, difficulties in obtaining financing, and low levels of inter-organizational cooperation (Geldes et al., 2017b; Heredia et al., 2017; Pérez et al., 2019).

In this context, this study aims to analyze the TIS of precision technologies within the dairy sector of Chile, including smart farming practices, to discuss strategies for its future development. It enables answering the main research question: how is the TIS shaped within the Chilean dairy sector? How is it performing now? Furthermore, what does this imply for further developments? It is addressed with a structural-functional innovation system analysis (SFISA) being performed. It is a well-known method for analyzing technological innovation systems (TIS). This method includes studying functional and structural elements of the TIS (Eastwood et al., 2017c; Jacobsson & Bergek, 2011; Sixt et al., 2018; Turner et al., 2016). Additionally, a timeline of the Chilean dairy sector is constructed to understand the evolution of the technological development under study.

The analyses indicate that the Chilean dairy sector's precision technologies and smart farming practices are an initial implementation. In addition, there are insufficient interactions between different actors with limited sharing of information due to the lack of trust as a cultural issue. Some strategies to develop and co-evolve technological systems are discussed.

The following sections present the methodology and the sector of study, results and discussion, and conclusions.

2. Methodology and the sector of study

The exploratory analysis of the technological innovation system (TIS) of precision technologies within the dairy sector of Chile is addressed by a structural-functional innovation system analysis (SFISA) (Eastwood et al., 2017c; Jacobsson & Bergek, 2011; Sixt et al., 2018; Turner et al., 2016; Wieczorek & Hekkert, 2012). First, a workshop is held with experts to identify the key actors in the technological system. These experts are related to Universidad Austral de Chile, Universidad de Santiago de Chile, Wageningen University, and Instituto de Investigaciones Agropecuarias (INIA, National Agricultural Research Institute). They identified seven groups of actors: i) dairy farmers, ii) associations and cooperatives, iii) governmental institutes, iv) knowledge institutes, v) dairy industry, vi) technology providers, and vii) technology intermediaries.

A semi-structured interview is designed to collect information on TIS's leading actors in the dairy sector. It includes questions on their activities (functional elements), their relations, including the quality of the relationship (institutions and infrastructure used and satisfaction of the relationship), quantity (how often there is an interaction), barriers and opportunities to adapt precision technologies, and blocking mechanisms created by different systematic problems co-evolved in the TIS. (Busse et al., 2014; Eastwood et al., 2017c; Jakku et al., 2018; O'Flynn, Macken-Walsh, Lane, & High, 2018; Planko et al., 2016; Rijswijk et al., 2018; Turner et al., 2016; Yule & Eastwood, 2011). Table 1 lists the functional and structural elements considered in the analysis.

Table 1. Components of the Technological Innovation System

Structural elements	Functional elements
Actors	Guidance of the search
Interactions	Entrepreneurial activities
Institutions	Knowledge development
Infrastructure	Knowledge diffusion
	Market formation
	Resource mobilisation
	Creation of legitimacy

Own elaboration, inspired in Eastwood et al. (2017c), Jacobsson & Bergeck (2011), Sixt et al. (2018), Turner et al. (2016), Wiczkorek & Hekkert (2012)

in which all relevant actors in the agricultural sector contribute to combined technological, social and institutional change. Systemic problems are factors that negatively influence the direction and speed of co-innovation and impede the development and functioning of innovation systems. The contribution in the paper is twofold. Firstly, it combines both innovation system functions and systemic problems in an integrated analysis to assess an AIS at a country level, which has not been done previously in AIS literature. Secondly, it deepens the generic literature on structural-functional innovation systems analysis by looking at the interconnectedness between systemic problems and how these create core blocking mechanisms linked to the prevalent institutional logics (historically built-up and persistent structures and institutional arrangements).

The semi-structured interviews were conducted with 41 actors, including at least four from each of the identified categories of players, using a snowball sampling strategy. The actors were chosen based on their relative importance and a comprehensive understanding of the sectoral structure. Each interview was audiotaped, transcribed, and coded to different subjects for thematic qualitative data analysis. Then, a baseline is established for each of the seven stakeholder groups based on their overall characteristics and relationships.

In order to state the current situation of the TIS of precision technologies within the Chilean dairy sector and its development, a timeline analysis method has been used in order to find out the current stage of the TIS of precision technologies and smart farming practices (Eastwood et al., 2017c; Klerkx et al., 2012a; Reichardt et al., 2016). The historical timeline analysis is a narrative (timeline) of the dynamics and development of the introduction of precision technologies, how the dairy system co-evolved through time, and thinks about the introduction of different functions in the TIS, allowing identify the stage of initiation, implementation, and adoption (Eastwood et al., 2017c). The historical timeline analysis of Chilean dairy is based on literature findings and validated with the interviews (Hekkert & Negro, 2009).

2.1. The sector of study

The fieldwork has been conducted from November 2018 till January 2019 in three regions of Chile: Araucanía, Los Ríos, and Los Lagos, where 76% of all dairy milk in Chile is produced (Gonzalez & Katial, 2016; Uribe et al., 2017). The city of Valdivia is a central point of work, and it is 850 km to the south of Santiago, the capital of Chile. In 2016, Chilean

milk production reached 1.99 billion liters. Moreover, the economic success of a farmer in Chile is continuously more focused on milk solids output per unit of land rather than milk yield per cow (Uribe et al., 2017). In these regions of research, dairy farmers mainly use extensive pasture-based systems while keeping the goal of being efficient, having high milk production and milk solids per amount of land (Oenema et al., 2014; Uribe et al., 2017). With this vision in mind, farmers of this region could be interested in adopting precision technologies and using smart farming practices, thus playing a dominant role in this research.

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3. Results and discussion

In the Chilean regions of Araucania, Los Rios, y Los Lagos, the livestock breeding of milk has a long tradition of consuming dairy products. However, due to the abundance of grasslands for pastures, production is low with a pasture-based system, which is still the dominant technology. Chile is a net importer of milk. In recent years, as a result of several pressures, including climate change and external forces (such as the low milk price), new technological possibilities and technological practices in dairying have emerged. (Carmona, et al., 2010; Gonzalez & Katial, 2016; Carter-Leal et al., 2018; Challies & Murray, 2006; Oenema et al., 2014; Uribe et al., 2016). This can be seen in the composition and characterization of the actors in the technological system presented below.

The farmers are the main actors of the TIS. There are three groups: i) small dairy farmers (less than 100 cows), medium (between 100 and 400 cows), and large (more than 400 cows). The medium ones are the most adopted technologies and see smart farming as exciting. Large farmers prefer a low-cost production system focusing on efficient milk production per hectare. Moreover, farmers of smaller farms feel that the innovation of new technologies is too high a risk and costly for them. Also, Chilean farmers are mostly over 60 years, but the adopters of precision technologies are under 50 years old. However, the farm is not attractive to young people who prefer to go to the cities.

Other actors are the associations and cooperatives. The main are the "Consorcio Lechero (dairy consortium)" is an association formed by the government that articulates the dairy chain's actors, including

public and research institutions; “COLUN” is a dominant farmer’s cooperative with more than 730 members, and “COOPRINSEM” is a cooperative of farmers that works as a technology intermediary. In the case of public and government institutions, the Ministry of Agriculture and its related institutions play a central role in the development of agriculture. Some of the institutions are “Instituto de Desarrollo Agropecuario (INDAP, support institute for small producers)”, “Servicio Agrícola y Ganadero (SAG; agricultural and livestock service)”, “Oficina de Estudios y Políticas Agrarias (ODEPA; Office of Agrarian Studies and Policies; which is part of the Commission Nacional de la Leche), Fundación para Innovación Agraria (FIA; Foundation for Agricultural Innovation; funding governmental institute). Another relevant public-private service is “Instituto de Investigaciones Agropecuarias (INIA, national agrifood research institute).

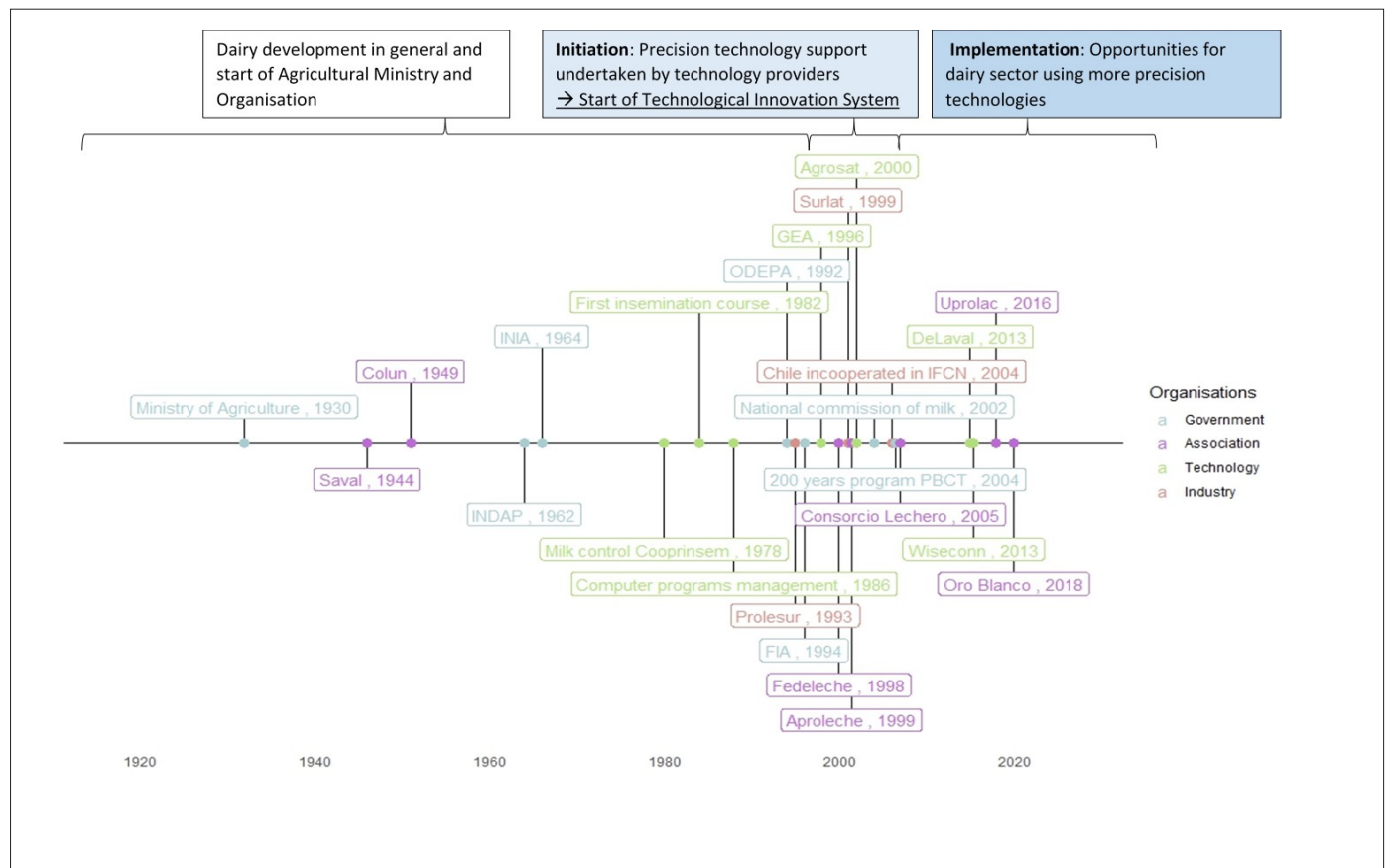
In the TIS, there are several international suppliers as SCR (cow monitoring), ABS (reproductive management), SHOOF (health tests

and technology), Agrinet (farm software), and Lely, DeLaval, and GEA with milky robots. Also, Chilean companies are developing precision technologies as Agrosat and WiseConn, which focus on irrigation (with drones and satellite information). Another actor, COOPRINSEM, plays an intermediate technology selling and advising the farmers. In the case of the dairy industry, companies have their advisors who provide advice regarding milk production for the farmers, milk quality improvement, and measurements for human health. Related to research actors, they are Universidad Austral, Universidad de La Frontera, and INIA.

3.1 Timeline of Chilean dairy sector

In the timeline of the dairy sector in Chile, we identified three periods: i) dairy development and the start of the Ministry of Agriculture and the formation of the associations of farmers; ii) Initiation. The start of the technological innovation system, and iii) implementation, the opportunities for more use of precision technologies. In the following, we describe the three periods (Figure 1).

Figure 1. Timeline precision technologies in Chilean dairy sector.



Initially, the agricultural sector had an impulse with the creation of the Ministry of Agriculture in 1930, and later with its related institutions such as INDAP, INIA, and ODEPA. Complementarily, farmers began cooperating to address common problems through the establishment of associations such as “Sociedad Agrícola y Ganadera de Valdivia” in 1944, and “Cooperativa Agrícola y Lechera de La Unión-COLUN”

in 1949, which was the first agricultural and milk cooperative in Los Rios. Later, that count with 730 members, and it is the leading actor in the dairy sector. Later, in 1998, the “Federación Gremial Nacional de Productores de Leche-FEDELECHE” was formed to compete with the industries, receive better milk prices, and develop a secure economic value for the dairy products of Chile. Another organization is the

“Asociación Gremial de Productores de Leche de Osorno-Aproleche,” founded in 1999 to face barriers together and form a more substantial group of farmers to find solutions. In general, the associations seek to support dairy farmers in improving their quality and productivity, facing high international competition, and securing a fair market price. At the same time, small industries began to develop specific quality products (e.g., Prolesur in 1990, Surlat in 1999).

Furthermore, some of these associations formed so-called GTTs (Technology Transfer Groups) to support technology development, including precision technologies. However, in 1999, the promotion of precision technologies started adequately with GEA and international firms (GEA Group Chile, 2015). Moreover, in 2002, the national commission of milk, named “Comisión Nacional de la Leche-CNL,” was formed to make the dairy sector relevant in Chile, including all the actors (National Commission of Milk, 2018). Later, in 2004, the government wanted to improve technologies with the “Programa Bicentenario de Ciencia y Tecnología-PBCT” with the leading goal of knowledge development and the use of technologies in Chile (Agar, 2018; CONICYT, PBCT, & Gobierno de Chile, 2007). With this program of supporting knowledge development and the use of technologies in the agricultural sector on the farm level, it seems that the implementation phase of using precision technologies in Chile has started.

In 2005, the government created the “Consortio Lechero – Milk Consortium” to develop research programs for the dairy sector, with the participation of all stakeholders, and promote sustainable development to be competitive in the global market. In addition, Chile was incorporated into the International Farm Comparison Network (IFCN) to support sectoral competitiveness (Cooprinsem, 2019; Moreira & Bravo-Ureta, 2010). Furthermore, with the support of these international relations, the implementation of precision technologies was more stimulated, and these global data platforms initiated the possible use of this global data (smart farming practices) in the future. In recent years, more farmers’ associations are seeking to meet the challenges of the dairy sector, including the incorporation of precision technologies and smart farming, as Oro Blanco and Uprolac (2016). The farmers that group together and form associations generate trust and support precision technologies as an innovation system. The stage of smart farming, as sharing data received from precision technologies with other actors in the system, still has to be found out.

In the “implementation” of precision technologies. COOPRINSEM played a central role. In 1978, it introduced the first Holstein Frisian and the first official milk control program in the south of Chile. Also, introduce the first insemination course and the first computer programs for farming management (COOPRINSEM, 2019). Additionally, in the 90s, with the financial support of FIA, different actors began to participate as technology companies with precision technologies arrived in Chile (e.g., the company GEA had its first technological machine in Chile in 1996) or Chileans developed their own companies (e.g., Agrosat in 2000). This period can be considered the initiation phase of precision technologies.

Farms started to grow, and foreign farmers came in to start their farm in Chile, resulting in more technologies of international companies arriving (e.g., national company WiseConn in 2006 and international company DeLaval in 2013), together with more services and courses for farmers. With this development, the implementation phase of using precision technologies in the Chilean dairy sector started.

When comparing the duration of the initiation phase with other countries, Chile took more time than other examples. In Australia, the time between the start of initiation and the implementation phase took only about two years, while in Europe, it took about four years (Eastwood et al., 2017c). In Chile, the initiation phase took about eight years (1996-2004), so the time frame needed to adopt technologies in Chile is quite long.

In sum, the dairy sector of Chile is currently in the implementation phase of using precision technologies. Precision technologies are available, such as milk robots and detection collars, but they need to be accepted by the actors. Knowledge institute INIA is now implementing a milking robot on their test farm, an excellent opportunity for the TIS to use more precision technologies (Opazo, 2018). Moreover, structural innovation (with its needed functions) takes considerable time before complete adaptation into the TIS, especially considering the low-trust Chilean culture, but the same is observed in other countries and within other articles. The time scale from the initiation of a particular activity to complete market saturation is expected to have an average length of 75 years (Jacobsson & Bergek, 2011; Turner et al., 2016). Because the precursor of the practices of smart farming in Europe is also still in the ongoing phase of adaptation (after a developing TIS of about 27 years), it seems that a lot must be found out, and a lot of barriers and opportunities still have to be faced (Eastwood et al., 2017c).

We also need to keep in mind that this process is dynamic and can co-evolve through time while including and excluding different actors, interactions, institutions, and infrastructures (structures) as well as the development of the practiced activities (functions) (Kilelu et al., 2013; Markard et al., 2015). As the TIS is this complex, with different elements interacting dynamically, different actors need simultaneous investments and support (Amankwah et al., 2012; Kilelu et al., 2013; Klerkx et al., 2010; Klerk et al., 2013). Turner et al. (2016) mentioned that ‘systemic instruments should actively work on creating change at the level of innovation programs and projects and engage with influential potential change agents, such as policymakers to create transformative systemic instruments that “disrupt” current institutional logics.’ (p. 110).

Precision technologies seem universal because they can be implemented everywhere, according to different technology companies that spread their products globally and even for local actors who are still unaware of its effects. This thesis has confirmed the statements of Glover et al. (2017), which state the need for unpacking the practices needed to adopt these precision technologies, take what is helpful and needed for the Chilean dairy sector, and reconfigure these elements

by functional activities with structures needed for the local context (Glover et al., 2017). Adaptive research with universities for the local environment could support these steps (Moreira & Bravo-Ureta, 2010).

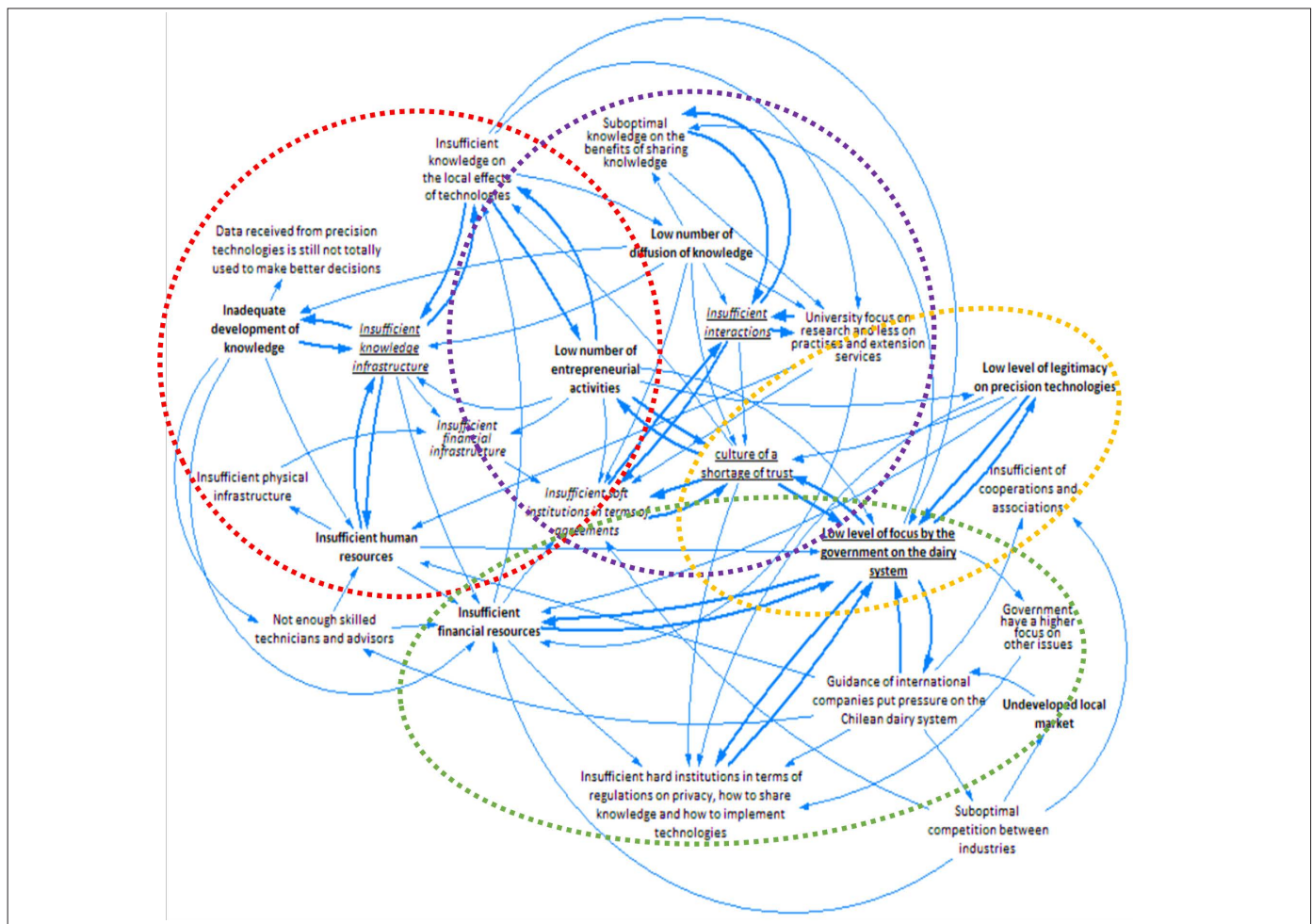
3.2. Systematic problems to the co-evolution of the TIS

The TIS for precision technologies in Chile's dairy sector is formed of multiple actors, and it is currently in the implementation phase, which presents a series of problems for the TIS's co-evolution. In this sense, it is possible to identify specific systemic challenges and opportunities using the structural-functional innovation system analysis (SFISA) completed through the 41 interviews. Because several of

these systemic problems occur in other functions, similarities in blocking mechanisms can affect multiple functional systemic problems concurrently, resulting in a more significant impact throughout TIS. By resolving these systemic issues, enormous opportunities become visible.

Figure 2 shows different TIS blocking mechanisms identified, which are grouped into four systemic problems defined as 1) the systemic problem of insufficient knowledge infrastructure, 2) the systemic problem of a soft focus of the government on the development of the dairy sector, 3) the systemic problem of a shortage of trust and 4) the insufficient number of interactions between actors of the TIS. These systemic problems will be explained below.

Figure 2. Summary of the most common found causal systemic and formed blocking mechanisms within different functions (bold) and structures (italic). Arrows are pointing to its underlying problem. Underlined are so-called blocked systemic problems related to the blocking mechanisms (coloured circles) (own elaboration with the inspiration of Sixt et al., (2018) and Turner et al., (2016).



The systemic problem of insufficient knowledge infrastructure (Figure 2: red circle) is explained as an insufficient number of technical advisors and trainers for knowledge generation, management, and implementation of precision technologies. In addition, there is not enough knowledge about what farmers can do with specific data, as the meaning of measured data from precision technologies is

unclear to actors, especially farmers. In general, there is little knowledge about the benefits of implementing precision technologies and smart farming practices. Simultaneously, the number of current entrepreneurial activities is low because of the insufficient understanding of the effects of precision technologies, including the unknown costs and benefits of using them, especially in the Chilean dairy sector.

The second blocking mechanism is found within the systemic problem of the guidance of the government's search, as there is a soft focus of the government on the development of the dairy sector (figure 15: green circle). The government's support could be expressed in financial resources for research and extension to improve the implementation of precision technologies. This kind of action can create more legitimacy for entrepreneurial activities (Moreira & Bravo-Ureta, 2010; Sixt et al., 2018). Moreover, the government can support the dairy sector with some sectoral laws and implement strategies developed in other countries to increase financial resources for entrepreneurial activities through a low-interest loan regime in partnership with the government and private banks (Sixt et al., 2018).

Furthermore, commercially, Chile is open to the world, and the dairy sector is not an exception. Due to this, the dairy industry is highly dependent on the international market and milk price, and this competition is pushing farmers to be more efficient (Challies & Murray, 2006). Moreover, as lots of dairy industry companies are related to international multinational industries and technology providers in terms of holdings or shared ownership, visions are often shared or decided on without the input of Chilean visions.

There is an increased number of certifications and regulations regarding the milk production export market. According to one of the governmental interviewees, the global market and the global dairy industry "set the rules, and you are obliged to comply with them."

As also explained by Sixt et al. (2018), the international technology donors and institutions of holding companies should be increasingly considered, as they play a role in influencing the direction of the search and in contributing resources towards the knowledge development and diffusion functions with a specific vision. Other research has identified that concerns over data sharing are related to the dynamics of power relations between dairy industry stakeholders and can use that data sharing for different meanings (Jakku et al., 2018; Wolfert et al., 2017).

Because the sizeable Chilean dairy industry has international relationships (holding or shared owners), farmers do not trust the dairy industry, as the internationals make the rules and have the power. The uncertainty of farmers introduces the systemic problem of a shortage of trust.

Thirdly, another blocking mechanism is related to the shortage of trust (Figure 2: yellow circle). Trust in the performance of the technology is highly associated with its support by the government, as they can create legitimacy among different actors in the TIS (by providing funds, projects, and institutions). The government needs to trust the technology itself and trust the farmers to use the (precision) technology in the "right" way. In addition, trust is the basis for cooperative relationships between all the actors; this contributes to technological and non-technological innovations (Geldes et al., 2017b).

Moreover, the government needs to know the benefits of precision technology adoption to trust the technology and provide funds for research and adoption while increasing awareness of the technology.

When the government does not support the technology, farmers or adopters might not trust the technology and refrain from adoption. Both types of trust (of the government in technology and the government in farmers) currently seem insufficient, despite the efforts made by FIA and INIA. Moreover, the government could facilitate the presence of brokers of innovation in the sector (Klerk et al., 2012a). The shortage of trust between actors (when sharing information), as this is discovered as one of the main barriers for the TIS of the Chilean dairy sector, will be explained in the following blocking mechanism on the systemic problem of insufficient interactions between actors of the TIS.

The last blocking mechanism is the systemic problem of insufficient interactions between the actors of the TIS (Figure 2: purple circle). Interactions are essential when sharing data for "shared learning" (Eastwood et al., 2018; Klerk et al., 2010; Sixt et al., 2018), which is the basis of smart farming practices and supports the adoption of precision technologies. In general, this inter-organizational cooperation is a determinant for developing innovations in the agribusiness sector, which has different firms' determinants of innovation than other economic sectors like mining and services (Geldes et al., 2017a, b).

Trust (Figure 2: yellow circle) is one of the main barriers to adopting precision technologies and smart farming practices. The cultural issue of Chile with a shortage of trust is the reason why a low number of positive experiences, information, and feedback is shared. Moreover, because the interactions are primarily active within associations and cooperatives (and lots of farmers are still not connected to one of these associations), there are not enough soft institutions, in terms of agreements of shared benefits, interactions, and the diffusion of knowledge, between the actors of the TIS. The low number of accords between actors is one of the causes of the systemic problem of a shortage of trust (Klerk et al., 2010). According to Geldes et al. (2015), the social dimensions such as previous knowledge, confidence, and reputation are the barriers to cooperation between firms and not the organizational or institutional dimensions.

The low number of interactions between farmers and technology providers forms the core problem of the unknown benefits of sharing information, diffusion of knowledge, and shared learning. Farmers have insufficient knowledge of the meaning of the measured data with precision technologies, and they do not always know how to turn this data into usable information. Because the actors in the TIS do not always know what the benefits could be of sharing data, interactions seem to be inadequate and scarce. Undeveloped knowledge by actors is due to insufficient knowledge infrastructure (as well as insufficient interactions between actors) and is thus related to the systemic problem of insufficient knowledge infrastructure.

Concerning the systemic functions explored in the dairy TIS of Chile, similar situations have been found in other research in different countries. In general, it is needed to increase trust with guided institutions and interactions. This is an excellent opportunity for further development of the TIS of precision technologies for the dairy sector of Chile (Amankwah et al., 2012; Yule & Eastwood, 2011). According to Yule

and Eastwood (2011, p.12), “Trust involves two aspects: whether the technology would do the job it was supposed to when it was needed, and whether the data collected was trustworthy.”

From the point of view of associations and actors of the TIS, sharing knowledge is based on confidence and trust in others, and with the current cultural issue in Chile, the actors do not see the benefits of sharing information with others. However, some interviewees mentioned that it is essential to work together, “as if you work alone, you tend to work on topics the producer criticized years ago,” according to a farmer. So today, there are producers that have determined to generate space, spend time that, in the end, is money, generate trust and come together to be able to, e.g., sell in a better way. In the same way, insufficient agreements with institutions explaining shared benefits for both actors are a barrier to keeping those associations and interactions stable.

More experience and entrepreneurial activities locally on the farm level, as well as increased knowledge infrastructure, knowledge diffusion, and knowledge development on its effects on the local environment, can reduce uncertainty and increase trust (Hekkert et al., 2007; Sonck et al., 2017; Yule & Eastwood, 2011). Sonck et al. (2017) explain the issue of trust with ambiguous uncertainty, which means that when new technologies arrive that are new to all actors, more interactions in terms of inclusive reflection and institutions are needed. This uncertainty highlights the theory of responsible research and innovation with all actors’ mutual responsiveness and trust, including communication within the TIS (Kutter et al., 2011; Sonck et al., 2017). Because trust between actors seems to be a cultural issue in Chile, and because this seems to be a significant barrier for the TIS to co-evolve, the support of guided institutions and interactions is highly recommended. With increasing cooperation and interactions between farmers and other organizations of TI, knowledge diffusion and shared learning are possible, which supports further development of the TIS.

Increased trust can be generated with the government’s support by focusing programs on precision technologies in the dairy sector, financial support, and knowledge development. With governmental support, social acceptance and legitimacy of precision technologies could be increased, with increased trust to try out and commercialize the new technology. The need for policy making with more programs and institutions regarding the innovation of precision technologies is an opportunity in different areas (Specht & Sanyé-Mengual, 2017).

Sixt et al. (2018) mention that coordination of interactions between actors helps make actors see the benefits of shared learning (Sixt et al., 2018). Coordination has started within associations and the governmental association “Consortio Lechero,” and this great opportunity within the association should further support the actors by being a space for joint learning (share of information and knowledge) and co-evolution of the TIS (Sixt et al., 2018).

4. Conclusions and implications

The TIS of precision technologies is in the implementation phase in the Chilean dairy sector, increasing adoption and the number of

actors related to it, such as farmers, suppliers, research institutions, associations, and others. However, implementation is still low, and adaptation is not legitimized, so it must develop and co-evolve in the future. In the case of smart farming practices, they are in the initial phase of TIS development due to the low levels of cooperation between farmers and other actors.

The initial phase of the TIS of precision technologies took more time in Chile (8 years) than in other places like the EU (4 years) and Australia (2 years). It is possibly due to the low levels of cooperation among the actors in the Chilean dairy sector due to distrust as a cultural element typical of Latin American and emerging economies.

The development of the TIS related to precision technologies and smart farming practices in the dairy sector in Chile is necessary to face its blocking mechanism by increasing institutional support for the development of the dairy sector, contributing to strengthening the legitimacy of precision technologies in terms of trust and social acceptance and increasing the interactions and trust between the different actors.

4.1. Implications

In order to develop the TIS of precision technologies and smart farming in the Chilean dairy sector, it is necessary to improve the coordinated efforts to create a culture of innovation that seems like a collective process with the participation of all related actors. In this sense, policymakers’ implications are focused on developing organizations such as the «Consortio Lechero» with funding and encouraging the participation of more actors, thus increasing support for the development of local research on technology and the benefits of precision and smart agriculture. This type of action can strengthen trust and cooperation among stakeholders and generate greater legitimacy among farmers as end-users of precision and smart farming technologies.

The implications for farmers and their related associations are to continue strengthening these organizations and play a role in developing precision technologies and smart farming by identifying farmers’ practical problems and linking them with suppliers, research institutions, and public institutions to face them.

For researchers, some themes can be developed by comparing Chilean sectoral policies with those of other countries such as Australia and New Zealand, evaluating the effects of the promotion programs that have been developed in Chile, and analyzing the causes of the low levels of joint work and trust among the actors in the dairy sector, among others.

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