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Scope for Industry 4.0 in Agri-food Supply Chains

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This study investigates the current capabilities and technologies adopted in the agri-food industry in Australia and the scope for transition to Industry 4.0. Data were collected from 360 firms representing suppliers, producers, manufacturers, wholesalers, logistics providers and retailers to represent a supply chain perspective. The technologies and strategies were grouped based on the various supply chain players against the maturity stages of Industry 4.0 as prescribed by Schuh et al (2017) in order to discern the integration efforts and degree of interoperability in the supply chain. We establish that upstream players tend to adopt technology mainly for internal operational efficiencies and B2B transactions. We propose that the individual orientation, interoperability and capabilities of these firms will need to be reassessed to derive a systematic plan for progression into a technology architecture for the overall supply chain. Despite the fragmented adoption of advance technologies evident at various points of value creation in the supply chain, we recognize and highlight the vulnerability of many small businesses and upstream players in the food industry who appear to be lagging behind in the fourth industrial revolution as well as the disruptive changes entailed to keep up and compete in the digital age.

Keywords: Agri-food supply chain; Industry 4.0; Maturity stages; Survey methodology

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1 Introduction

In the agri-food industry, logistics and supply chain management activities are deemed more challenging due to the need for time-based approaches, integral quality control and associated tracking and tracing systems of food products along the chain. These include meeting temperature control requirements, product perishability issues and the variability in agri-food quality (Soosay 2008, Sahin et al 2007). These products include grain, livestock (beef and dairy) and horticulture. Inter-organizational technology systems offer the potential to improve operational efficiency, responsiveness and traceability by supporting transactions and material flow more efficiently (Kim et al 2018, Johnston & Vitale, 1988). Consequently, integrative efforts are needed between supply chain members to reach new levels of competencies where firms can willingly share data and business applications.

Industry 4.0 requires supply chains to not only adopt modern technologies and engage in capability development, but also to transform their business models and network structures to achieve coherent vertical integration. This is likely to change traditional relationships between suppliers, manufacturers, wholesalers, retailers and customers. There are already some industries such as electronics and fast moving consumer goods (FMCG) adopting state of the art technologies and moving along the supply chain 4.0 continuum at present; while other industries are still lagging behind. There is concern that the diffusion rate of modern technologies in the agri-food industry has been much lower than anticipated, suggesting that their implementation may involve challenges or lack of collaboration (Costa et al 2013, Vlachos 2004, Salin 1998).

There are various empirical studies on supply chain technology adoption in the literature (Aydin & Parker 2018, Krishnan et al 2015). While the authors have established reasons why firms and some industries struggle with technology implementation, the theories, concepts and practices developed in the context of food supply chains need greater understanding as this industry faces distinct economic settings, such as market imperfections, heterogeneity of actors, information asymmetries, technology infrastructure, immature supply chain networks and the perishable nature of food products (Solanki & Brewster 2014, Xu et al 2004). As a result, this study examines the current capabilities, technologies and interoperability strategies adopted in agri-food supply chains and the scope for transition to Industry 4.0. The central research question is 'How is Industry 4.0

distributed across the stages of value creation in the agri-food industry in Australia?'

2 Theoretical Framework

Industry 4.0, also known as the fourth industrial revolution, is a collective approach to digitalization, interconnectedness and new technologies. It is increasingly gaining consideration from policymakers, businesses and academia worldwide. The term 'Industrie 4.0' became popular in 2011 with a Working Group offering the German federal government a vision for the future of industrial manufacturing. It subsequently formed part of the government's 'Action Plan High-Tech Strategy 2020' to ensure technological leadership with digitalization, smart factories and Internet of Things (IoT) (Klitou et al 2017). Industry 4.0 is expected to result in four long-term relationship paradigm shifts and changes to the landscape of European manufacturing: Factory and nature, Factory and local community, Factory and value chains (distributed and responsive manufacturing through collaborative processes, enabling mass customization of products and services); and Factory and humans. These will have impacts on technology implementation in a wider manufacturing and distribution environment (Santos et al 2017).

Schuh et al (2017) articulate that the fourth industrial revolution extends beyond ICT integration in industrial manufacturing to include transformations in organizations and their culture. Businesses will need to become more agile and adapt to changing environments. These authors prescribe the acatech Industrie 4.0 Maturity Index model which delineates the successive maturity stages for Industry 4.0. This model assists companies identify which stage they are currently at and their potential capability development and transformation to fully implementing Industry 4.0. The stages span from 'Computerization', 'Connectivity', 'Visibility', 'Transparency', 'Predictive Capability' to 'Adaptability'.

Industry 4.0 should not only be discerned at the organizational level, but will also revolutionize manufacturing supply chains with new products, services and business models through IoT from product design right through to customer delivery (Roblek et al 2016). For instance, it emphasizes the global network of machines in a manufacturing environment capable of exchanging information, knowing variations to be made to the product and being able to control each other. This is possible with collaboration between suppliers, manufacturers and customers to increase the transparency from when the order is initiated, manufactured and dispatched until the end of the product's life cycle. Hence, it is important to analyze how supply chains are impacted by Industry 4.0.

Supply chain networks today depend on a number of key technologies that enable integrated planning and execution systems, logistics visibility, autonomous logistics, smart procurement, smart warehousing, spare part management and advanced analytics (Schrauf & Berttram 2016). Lee et al (2014) highlight how technology is the key to 21st century global supply chain management for operational competitiveness. By tracking the evolution of supply chain technologies in the textile and apparel industry, these authors classify the technologies adopted in achieving superior supply chain performance and competitive advantage.

It is evident that digital networks offer higher levels of resilience and responsiveness with more efficient and transparent service delivery. Mussomeli et al (2017) report the shift from linear, sequential supply chain operations to interconnected, dynamic and integrated networks. Predictive shipping is another emerging concept, where according to Alicke et al (2017), a shipment which is already in the logistics network is matched with customer order at a later stage. Resultantly, demand management will need to be implemented at a more granular level using techniques such as micro segmentation, mass customization, innovative distribution concepts and more sophisticated scheduling practices. The emerging trends in Industry 4.0 can pertain to warehouse robotics, autonomous road transportation, logistics and technology services, supply chain social responsibility, the race for the last mile, and the rise of the virtual logistics team (O'Byrne 2017). Hence, businesses will need to reframe their business models and invest in how they can digitize their products and systems, starting with the supply chain. They will also need to reassess their capabilities, technologies and interoperability strategies in order to transition to Industry 4.0.

In this paper, we examine Industry 4.0 in the context of agri-food supply chains in Australia using the maturity phases from Schuh et al (2017) to understand the extent of technologies used by firms throughout the value creation. These phases are grouped as 'Computerization & Connectivity', 'Visibility & Transparency', 'Predictive capability', and 'Adaptability & Self-learning'.

3 Methods

Data were collected in three stages over a 12-month period as part of a larger study on supply chain integration. An online survey was sent to over 2,000 organizations obtained from various databases and industry associations. During the first phase, we collected data from suppliers, producers, manufacturers, wholesalers and retailers associated with the agri-food industry. Subsequently, we implemented a second phase of data collection after identifying the secondary players in the supply chain comprising input suppliers, packaging suppliers and third party logistics providers who also service the food industry. Input suppliers include firms who provide equipment, machinery, feedstock, fertilizers and other related products to farmers, growers and agri-food producers. Packaging suppliers include an array of firms who produce and supply paper, plastic, fibre containers, foam food trays, cartons, boxes, glass, closures, foil, film and other products used in the food industry. Logistics providers were largely transport companies, although some provided warehousing, light assembly and secondary packaging services. The third phase of data collection were reminders sent to firms in order to increase the response rate. As a result, a total of 360 usable questionnaires were received, constituting a response rate of 18% and where these firms represented a whole of chain perspective. These firms are illustrated in the following table showing their position in the supply chain as well as the firm size as prescribed by the Australian Bureau of Statistics classification. Majority of the firms were small and medium sized accounting for 74% of the sample population.

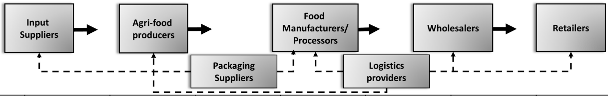
Table 1: Profile of firms

		n	%
Position in the Chain			
	Input suppliers	30	8.3
	Growers/Agri-producers	68	18.8
	Packaging suppliers	20	5.6
	Food Manufacturers	54	15.0
	Wholesalers	67	18.6
	Logistics providers	63	17.5
	Retailers	58	16.1
	Total	360	100
Firm size			
	Small (5-19)	81	22
	Medium (20-199)	186	52
	Large (>200)	93	26
	Total	360	100

In the survey, firms were required to rate the extent of usage for a list of technologies using a 7-point Likert scale (7 = to a very great extent; 6 = to a great extent; 5 = to a fairly great extent; 4 = to a moderate extent; 3 = to a small extent; 2 = to a very small extent; 1 = not at all). In this paper, we have categorized these technologies into four main maturity stages of Industry 4.0 using Schuh et al's (2017) framework. Table 2 depicts the means and standard deviations of the technologies. The reliability is reported using Cronbach's alpha which ranged from 0.76 to 0.93, indicating moderate to excellent reliability.

Table 2: Extent of technologies used

Items	Description	M	SD	α
Computerization & Connectivity				
		0.86		
CC1	Barcoding systems	5.31	1.14	
CC2	Customer Relationship Management	5.68	0.95	
CC3	E-business/ e-marketplace	5.76	0.98	
CC4	Electronic Data Interchange	5.76	1.00	
CC5	Electronic Point of Sale	5.73	0.97	
CC6	E-procurement	5.54	1.08	
Visibility & Transparency				
		0.93		
VT1	Global Positioning Systems	5.61	1.31	
VT2	Time Temperature Integrators	5.74	1.24	
VT3	Data Loggers	5.68	1.20	
VT4	Transport Management Systems	5.76	1.23	
VT5	Warehouse Management Systems	5.72	1.26	
Predictive Capability				
		0.87		
PC1	Enterprise Resource Planning Systems	3.85	1.42	
PC2	Manufacturing Execution Systems	4.12	1.32	
PC3	Radio Frequency Identification Systems	4.03	1.61	
Adaptability & Self-learning				
		0.76		
ASL1	Collaborative Planning, Forecasting and Replenishment	2.19	0.77	
ASL2	Efficient Consumer Response	2.07	0.78	
ASL3	Vendor Managed Inventory	1.99	0.82	



	Input suppliers	Agri-food producers	Packaging suppliers	Food manufacturers	Logistics providers	Wholesalers	Retailers
Computerization & connectivity							
Barcode	53.3%	29.4%	80.0%	24.1%	91.0%	76.2%	100.0%
CRM	20.0%	2.9%	60.0%	64.8%	34.3%	17.5%	75.9%
E-business	83.3%	86.7%	45.0%	77.8%	65.7%	12.7%	70.7%
EDI	0%	4.4%	0%	79.6%	28.4%	30.2%	81.0%
EPOS	30.0%	0%	0%	0%	0%	3.2%	100.0%
E-procurement	43.3%	41.1%	80.0%	90.7%	80.6%	15.9%	89.7%
Mean	*38.3%*	*27.4%*	*44.2%*	*56.2%*	*50.0%*	*26.0%*	*86.2%*
Visibility & transparency							
GPS	0%	0%	0%	0%	80.6%	49.2%	3.4%
TTI	0%	7.4%	0%	0%	44.8%	46.0%	12.0%
Data loggers	0%	16.2%	0%	13.0%	52.2%	30.2%	3.4%
TMS	0%	0%	15.0%	9.3%	80.6%	7.9%	0%
WMS	13.3%	0%	70.0%	9.3%	10.4%	39.7%	75.9%
Mean	*2.7%*	*4.7%*	*17.0%*	*6.32%*	*53.7%*	*34.6%*	*18.9%*
Predictive capability							
ERP	0%	1.5%	55.0%	79.6%	70.1%	66.7%	75.9%
MES	0%	0%	75.0%	77.8%	0%	0%	0%
RFID	10.0%	0%	40.0%	27.8%	80.6%	36.5%	79.3%
Mean	*3.3%*	*0.5%*	*56.7%*	*61.7%*	*50.2%*	*34.4%*	*51.7%*
Adaptability & self-learning							
CPFR	10.0%	0%	0%	44.4%	28.4%	3.2%	58.6%
ECR	10.0%	0%	0%	29.6%	0%	6.3%	60.3%
VMI	0%	0%	10.0%	44.4%	4.5%	0%	29.3%
Mean	*6.7%*	*0%*	*3.3%*	*39.5%*	*11.0%*	*3.2%*	*49.4%*

Figure 1: Technologies used in the agri-food supply chain

4 Findings and discussion

The range of technologies and collaborative strategies adopted depict varying levels of value co-creation, supply chain visibility and traceability. It is apparent that these organizations employ technologies and strategies to improve business processes and decision-making. In food supply chain operations, technologies are predominantly used as a means for communication and information exchange between partners, facilitating uninterrupted flows. Prior to information sharing, the technology used needs to be linked and integrated between their upstream and downstream members in supply chains (Bhatt et al 2017). For this study, we investigated the strategies, technologies and integration efforts between two or more companies to understand the degree of interoperability in the supply chain. Figure 1 presents a full picture of the technologies used and percentage of firms at the value creation stages in the supply chain.

Additionally, in order to further discern the realization of Industry 4.0 maturity stages for each group, we obtained the mean scores for the various technologies and initiatives based on the number of firms that adopted them.

4.1 Computerization and connectivity

Computerization is the basis for digitalization and encompasses the deployment of information technologies. This is the first step and basic prerequisite for Industry 4.0. At this stage, many of the technologies appear to be used in isolation either within the organization or to assist in digitally supported B2B processes and transactions. When firms replace their isolated technology usage with connected business applications, a shift to embedded systems is facilitated (Schuh et al 2017).

Our findings depict that barcoding identification technology was used at all stages in the supply chain. There is a lesser extent of usage by upstream growers, farmers and other food producers; particularly those dealing with fresh fruit, vegetables, meat and seafood which are generally sold by weight. This technology facilitates inventory control and information sharing with suppliers upstream through electronic data interchange (EDI) (Kinsey and Ashman 2000) and often integrated with Warehouse Management Systems (WMS) (Patterson et al 2004).

Electronic point of sale (EPOS) was found to be only used by input suppliers (30%), wholesalers to a small extent (3%) and all retailers (100%) in our sample. This technology is usually incorporated with barcoding, and allows food retailers, manufacturers and packaging companies to collaboratively discern purchasing patterns and develop new products (Cox & Mowatt 2004). Customer relationship management (CRM) appeared to be used throughout the chain as a strategy. It is believed that firms utilize data warehousing and mining techniques to segment customers for improved customers service and retention (Chen & Chen 2004, Cox & Mowatt 2004), which is particularly critical given the nature of the food industry.

The e-business enabled supply or commonly known as e-marketplace is becoming an increasingly popular business model for firms to source, trade and collaborate with chain partners (Howard et al 2006, Le 2005). Our findings depict that 87% of agri-food producers, farmers and growers were using this, arguably to diversify their business opportunities and enhance profitability. Such platforms allow firms to expand globally and enter new markets that were previously inaccessible due to geographical barriers (White et al 2007).

Electronic data interchange (EDI) is most used in manufacturers and retailers with 80% and 81% respectively. This computer-to-computer exchange of business documents in a standard format between supply chain partners enables firms to reduce transaction costs, improve information transparency, efficiency and achieve integrated efforts (Leonard & Davis 2006, Hill & Scudder 2002). EDI in the food industry is also known to reduce the bullwhip effect, although being a complex and expensive system to implement especially for many small businesses (Vlachos 2004, Kinsey & Ashman 2000).

E-procurement technologies include e-sourcing, e-auctions and EDI to trade with suppliers online. Our findings depict that this technology is apparent in all stages in the supply chain, and more so among packaging suppliers (80%), food manufacturers (91%) and logistics providers (81%). Firms can respond more effectively using real-time information to meet demand patterns and supplier prices, while reducing delivery times and procurement costs (Chibani et al 2018, William 2003). Many organizations operate e-procurement in the food industry to assist with JIT strategies.

Based on our findings, we draw inference that majority of the firms in our sample have embedded digitally supported processes and transactions for computerization and connectivity. Based on the mean scores, this is more apparent in retailers, followed by food manufacturers and logistics providers. We had expected growers and food producers to be less likely to be digitally connected owing to the nature of this industry; however, discovered that the wholesalers in our sample were the least connected.

4.2 Visibility and transparency

The second phase of maturity in Industry 4.0 is visibility and transparency. In the context of supply chains, we argue that this should extend beyond B2B transactions and result in end-to-end visibility. The real-time capture of events from several data points in the supply chain enhances visibility, based on information availability and quality. Schuh et al (2017) postulate that by aggregating this information and a corresponding contextualization, transparency is enhanced for faster decision-making. We identified four main types of technologies used in the food supply chain for this phase which are primarily in the area of logistics activities.

Global positioning system (GPS) was found to be used by 81% of third party logistics providers and 49% of wholesalers in our study. The use of radio signals from satellites is widely implemented to manage logistics and transportation activities. Firms can locate and monitor the direction of fleet operators and vehicles, further allowing for optimized vehicle scheduling and routing (Theiss et al 2005). This is also prevalent upstream in the food industry where food producers can collect data on crops, soils, environmental and climate data, and monitor the movement of livestock in paddocks, facilitating precision agriculture and farming practice (Opara 2003). However none of the upstream players in our sample adopted this technology.

Transport management system (TMS) on the other hand, was used to a greater extent by firms in the chain including packaging suppliers, manufacturers and retailers. As expected, a large proportion of logistics providers (81%) adopted this technology which is closely related with GPS. TMS optimizes distribution activities, particularly in the area of fleet planning, truck scheduling and vehicle routing (Pokharel 2005). The real-time information enables firms to monitor turnaround time, driver productivity and fleet utilization. It could further facilitate cross-docking in warehouses, which is highly pertinent in the food and grocery sector, where the timely flow of perishable products is critical (Apte & Viswanathan 2000).

Warehouse management system (WMS) is also another technology adopted throughout the chain except for growers, farmers and food producers. We establish that the sale of agri-food products occurs almost immediately or using JIT after harvest for optimum freshness and quality. Most growers and farmers do not have adequate storage facilities or keep much inventory. Retailers (76%) and packaging suppliers (70%) adopted WMS to a greater extent given the volume and variety of products they deal with. Surprisingly, WMS was only used in 25 out of the 63 wholesalers (40%). It equips firms with the capabilities in monitoring stock levels, the inbound and outbound flows of inventory and exact location of items stored in the warehouse. WMS captures data on product dimensions and characteristics to optimize warehouse space, personnel and material handling equipment (Patterson et al 2004). It is often interfaced with TMS, RFID and barcoding technologies to enhance logistics operations (Mason et al 2003). We argue that most food products tend to be highly perishable; hence their inventory management is critical at all stages.

Our findings highlight that time-temperature integrators (TTI) and data loggers are being used predominantly by logistics providers (45% & 52%) and wholesalers (46% & 30%). These devices or tags are placed within a storage container to record the temperature of food products throughout the distribution process. Data are used to monitor temperature stability, product quality or identify breaches at various points in the supply chain. This is critical for temperature sensitive or perishable food products. Such technology enables optimum quality, shelf-life and handling throughout the supply chain (Soosay 2008, Sahin et al 2007, Koutsoumanis et al 2005). However, only 7 out of 58 retailers (12%) in our sample had adopted this technology.

Overall, information integration is required for tracking and tracing, ensuring visibility and transparency in the chain to meet food safety and regulatory requirements. The mean scores shows a varied extent of visibility and transparency among various supply chain players. It appears that logistics providers adopt these technologies the most, followed by wholesalers, manufacturers and retailers. We discern that upstream players (farmers, growers and input suppliers) tend to adopt technology to a lesser extent as compared to downstream players; and that these were used mainly for internal operational efficiencies and B2B transactions. Our finding is also in line with Solanki and Brewster's (2014 p. 46) study on agri-food supply chains; where they confirm and highlight how the "flow of data is restricted based on a very conservative 'need-to-know' attitude such that information flows only 'one up, one down'". Moreover, due to cultural barriers and despite technological solutions, the firms do not appear to use or integrate data across the supply chain, "thereby greatly increasing the possibility of interoperability issues arising between supporting applications". Technology should be viewed as the key for SCM development and transformation of the food industry 'from dyadic, material management oriented relationships into complex, collaborative, networked, web-enabled, extended architectures' to enable visibility, transparency and food integrity throughout the chain (Akyuz & Gursoy 2013).

4.3 Predictive capability

The third phase of maturity lies in the ability of firms to use shared data from end to end supply chain partners to prepare for future scenarios. At a network level, the visibility and transparency of operational data, inventory levels and production plans provide focal firms with relevant and real-time information for supply chain decision-making. Unexpected events such as the bullwhip effect, forecasting errors, production variations or delays in distribution could be minimized to a large extent. These result in time-based approaches to reduce costs, waste, inventory and other supply chain inefficiencies. We identify three types of technologies in the food industry that are used to attain this predictive capability.

Enterprise Resource Planning (ERP) systems were evident in 188 firms or over half the sample surveyed. These consist of integrated modules that support not only various functions within the organization, but also across supply chain operations. The IT systems of suppliers and customers could be interfaced for seamless operations. Alongside ERP, there are also manufacturing execution systems (MES) used to manage factory operations and production systems. 78% of food manufacturers and 75% of packaging suppliers adopted this technology. MES controls the movement of materials from point-to-point, assigns and schedules resources, and tracks the costs and status of materials being processed (Beavers 2001). When production plans are shared with suppliers, retailers and wholesalers, the flow of food products in the supply chain could be better streamlined.

Radio Frequency Identification (RFID) technology was adopted throughout the supply chain in our sample except for agri-food producers. RFID in food supply chains can determine the location and history of products, which help to maintain quality and prevent breaches in food integrity (Van Der Vorst et al 2007, Opara 2003). When combined with other technologies, RFID equips firms with predictive capability to achieve reliable and accurate data forecasts, reduced inventory and labor costs (Wu et al 2006).

From the mean scores, the area of predictive capability shows a stark difference between the upstream and downstream activities. Manufacturers, retailers and logistics providers generally possess the capacity to engage in big data and supply chain analytics, given the extent of technologies adopted, scale and scope of operations. These firms are generally larger in size and have better resources to obtain value from large scale data to gain competitiveness in terms of demand volatility, cost fluctuations and inventory management. We argue that the utilization of supply chain analytics is still at an early stage in the food industry currently; but has the potential to assist in strategic demand planning, sourcing, manufacturing, logistics activities, inventory management, and overall network configuration to advance into a supply chain 4.0 continuum. The use of time temperature sensors, RFID, tracking devices and ERP systems generates big data for the supply chain, which serve as a new frontier for process improvement, demand management and decision-making.

Our findings show that upstream players in the supply chain are generally lagging in this maturity stage of Industry 4.0. Hence it is proposed that the individual orientation, interoperability and capabilities of upstream players will need to be reassessed to derive a systematic plan for progression into a technology architecture for the overall supply chain. Bryceson and Yaseen (2018) illustrate how various disruptive technologies have been changing the landscape of the agri-food industry including upstream farming and production activities. IoT systems are conducive to agri-food firms in environmental monitoring, precision farming, precision livestock and cold chain logistics. For example in livestock management, IoT technology coupled with RFID can be used for real-time monitoring of cattle health and behavior. These authors also emphasize how big data analytics can assist businesses overcome environmental degradation, food safety and food security. Smart farming is increasingly being used with tailored seed varieties, crop nutrients, pathogen monitoring, and improving crop yields and addressing food safety concerns. New types of data can be used to measure biophysical characteristics (such as climate, soil alkalinity, seed cultivation, fertilizer and pest control) from the paddocks and farms upstream through to food processing, facilitated storage and food retail downstream (Bryceson & Yaseen 2018). Additionally, smart packaging is gaining prominence in food supply chains today. They not only help to meet HACCP and QACCP requirements, but also detect real-time biochemical changes occurring in the food and its environment to help extend shelf life. Another feature of Industry 4.0 is blockchain technology which offers huge potential for food traceability solutions. This technology works as a technical schema of databases which could contain information of all activities, processes and transactions in the chain forming a digital form of fingerprinting; and through interoperability mechanisms, this could ultimately provide visibility and traceability of the product's entire life cycle.

4.4 Adaptability and self-learning

The fourth maturity stage occurs when firms are able to take corresponding measures autonomously based on shared data. According to Schuh et al (2017), this delegation of decisions allows for rapid adaptation to changing business environments. Applied at a broader level, we establish that the combination of technologies achieves supply chain agility for customization and responsiveness to end consumers. We considered various supply chain strategies and classify three initiatives for this category.

Vendor Managed Inventory (VMI) was the least adopted technology in 13% of firms only. It was apparent mainly in manufacturers (44%) and retailers (29%). VMI is a powerful initiative based on technology integration and established transparency and visibility. Upstream suppliers or manufacturers are authorized to monitor retailers' real-time inventory levels and replenish accordingly (Waller et al 1999).

Its low uptake in the food industry could be attributed to the effects of inventory holding costs or high shortage penalty costs (Ru et al 2018). Closely linked to this initiative is efficient consumer response (ECR) applied in the food industry to alleviate supply chain inefficiencies. Once again, this was apparent mostly in food manufacturers (30%) and retailers (60%). This initiative requires retailers to share point-of-sales data with supply chain partners for not only better store assortment, promotion, product development and replenishment (Harris et al 1999), but also better financial and operational performance (Martens & Dooley 2010).

Collaborative Planning Forecasting and Replenishment (CPFR) is another shared IT system to project demand patterns. These were adopted by over half the retailers (59%), followed by manufacturers (44%) and logistics providers (28%). By using real-time data in the supply chain, this initiative facilitates demand forecasting, inventory management, production and replenishment planning, and order fulfilment (Hill et al 2018). CPFR is critical given the price points of food commodities, time-sensitivity, perishability and shelf-life. In this context, firms make autonomous decisions on a breadth of areas including timely supply, food production, processing, wholesale, distribution, marketing and retail. Our findings suggest that these factors are highly considered by downstream players due to their proximity and reliance on end customers and food consumers' demand preferences. This is further confirmed by the mean scores, showing the disparate heterogeneity in the supply chain for adaptability and self-learning. The other stages in the supply chain (input suppliers, agri-food producers, packaging suppliers, logistics providers and wholesalers) had very low values for this maturity stage.

These three powerful initiatives applicable in the food industry require the establishment and mastery of the first three maturity stages. This fourth maturity stage of adaptability and self-learning represents an autonomous supply chain. Characterized by robotics and automated networks, the concept of autonomously delivering products is becoming a reality. Heard et al (2018) claim that connected and autonomous vehicles (CAV) will be embraced first in the food distribution industry, given the interplay between transportation logistics, food perishability and cost. Enabled by logistics innovations and e-commerce, these authors state that autonomous trucks could one day displace grocery stores, and change the business model of distribution by delivering ordered foods directly to consumers instead. Similarly, MES and ERP systems have been around for a while; and possess the intelligence to organize and control manufacturing processes and job sequencing. They mandate using appropriate technologies, achieving streamlined visibility and transparency across supply chain partners and facilitating the autonomous and continuous adaptation to changes individually at the firm level as well as collectively as a network of partners.

5 Conclusions

Considering an end-to-end supply chain model, we deem the autonomous supply chain to be far from achievable in the food industry at this stage, given the presence of traditional labor intensive methods in some farming and agri-food production activities, especially for fresh and perishable food produce. Despite the fragmented adoption of advance technologies at various points in the supply chain (such as in manufacturing and logistics), we establish that agri-food supply chains still have a long way in reaching this milestone for Industry 4.0. This is because a true autonomous supply chain does not require human intervention (River Logic 2018).

Industry 4.0 requires firms to develop agile capabilities for rapid adaptation to changing business environments where customization and responsiveness come into play to fulfil end consumers' needs. We argue that the technology infrastructure provides integrated, empowered and more responsive decision-making; hence enabling a new frontier for customer receptiveness and market changes. The evolving and dynamic nature of food consumption means that customers expect high quality sensory properties, more variety and better food security (Castro & Jaimes 2017). Additionally the perishability of food products requires more advanced handling, transportation and storage solutions that requires firms to be flexible, efficient and responsive. Today's supply chain transformation involves the use of digital technologies, predictive analytics and artificial intelligence. To compete and survive, firms must embrace new business models, digital transformation and interoperability aspects. With this in mind, supply chains of the future should be viewed as an autonomous ecosystem of firms rather than traditional linear structures.

6 Limitations and further research

This study has several limitations, which must be taken into account when interpreting the results and their implications. Firstly, it presents preliminary findings from a larger study on supply chain integration in the agri-food industry. Notwithstanding that, it extends our knowledge on the issues relating to the impact of relevant technologies with respect to different stages of the supply chain and their activities. It uncovers the breadth of technologies used and the impacts of technology interface in agri-food supply chains. Secondly, we acknowledge the reliance on cross-sectional data, which measured technology adopted at one point in time that has weaknesses in establishing any causality inferences. Also market factors and stakeholder pressure may differ for various food groups. Further research could be more informative by investigating market configurations pertaining to the types of food products (e.g. fruit, vegetables, meat, seafood) and proximity of chain members to end consumers. Additionally, by employing a larger dataset, there is scope to perform measurement invariance across supply chain nodes and/or multi-level analyses. These could then provide better insights into the technology interface at specific points in value creation in the supply chain in more detail. Additionally, we recognize that our sample comprises a significant proportion (74%) of small and medium enterprises which is characterized by the food industry predominantly. We do not intend to generalize our findings, but highlight the vulnerability of many small businesses and up-stream players in our sample who appear to be lagging behind in the fourth industrial revolution as well as the disruptive changes entailed to keep up and compete in the digital age due to their size, resource constraints, scope and scale of operations. Despite these limitations, this paper offers discernment to supply chain researchers and practitioners by illustrating the maturity phases of Industry 4.0 in the context of agri-food supply chains in Australia.

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