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Knowledge...Innovation...Action

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Welcome to our December newsletter!

Another year has almost gone and people around the world are already preparing to welcome 2011.

As we end 2010, I recall the political atmosphere that preceded a hung parliament in Australia, not seen since 1940. Inquiries into food production came and went, without any plan of action being developed to maintain the place that Australia has (and will have) in the future of global food production. Sadly, there is little hope to see an increase in food and agriculture R&D, which is a fundamental part of any plan of this nature.

On the positive side, Rabobank awarded the 2010 Agribusiness Leadership Award to Dr Bruce Lee, acknowledging the contribution of the CSIRO Food Futures Flagship to the Australian agri-food sector. The industry cannot afford to ignore innovation as a competitive advantage nowadays.

Successful exploitation of new technologies in the agri-food sector requires a receptive industry that is financially and intellectually able to implement innovations. For example, in the recent political debacle of the Murray-Darling Basin (MDB) Plan, where farmers demonstrated their anger to planned water cuts to save the MDB river system, there was hardly a mention on the role of smart technologies to decrease water use. A particular collaborative effort between IBM and the University of Melbourne is testing the application of intelligent systems and precision agriculture to selectively irrigate sections of a field that really need water, leaving other sections untouched. Problems such as poor irrigation timing and water oversupply could be reduced to the extent of saving 15% to 20% in water usage. The cost? AU$200 million. The benefit? Between AU$420 million and AU$670 million to GDP and the creation of 800 jobs. But, is the agricultural sector ready to implement smart technologies?

The first article entitled “Are Australian food chains ICT-ready ?” tackles this aspect. In particular, we discuss the readiness of farmers to adopt supply chain applications based on Information and Communication Technologies (ICT).

And what about innovations relating to energy efficiency? A recent study by Food Chain Intelligence estimates that a 15% reduction in the electricity spent in cold storage and manufacturing (including freezing, canning and salad production) would save AU$12 million per year to Australian producers of vegetable products (assuming an average electricity cost of AU$0.13/kWh). Technologies to achieve these savings have a strong financial case. The article entitled “Achieving temperature control and energy efficiency in the cold chain” discusses some of these technologies. This article is a summary of an *in-extenso* paper I presented in the 1st IIR Conference on Sustainability and the Cold Chain (Cambridge, UK) this year.

I hope you enjoy this issue. And I wish you an enjoyable Christmas and a prosper 2011.

Cheers,

Silvia Estrada-Flores

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Are Australian food chains ICT-ready?

Introduction

In April 2009, the Australian Government announced the establishment of a new $43 billion high speed National Broadband Network (NBN). The NBN will be the single largest infrastructure investment made by an Australian Government, and it is expected to wirelessly link all premises in regional, rural and remote Australia via satellite.

What has not been clearly defined to date is how rural communities and in particular, farmers, will take advantage of the NBN. Decreased ongoing costs of services relying on internet applications are undoubtedly a factor of interest. According to data from the OECD, Australia's average prices rank as the fifth most expensive services among OECD countries.

Among the applications that stand to benefit from improved rural broadband services are supply chain applications based on ICT (or SC-ICT). SC-ICT offers an excellent platform of improvements for two reasons:

1) Many of the most recent supply chain innovations are based on ICT. From the three major organizational forces in food supply chains (i.e. farmers/growers, manufacturers and retailers), retail-led innovations have focused the most on improving supply chain and logistics through initiatives such as efficient consumer response (ECR), electronic data interchange (EDI), collaborative planning, forecasting and replenishment (CPFR) and traceability, among others.

2) Many of these retail-end processes rely on the joint development of strategic category plans and a collaborative framework between retailers and their suppliers (Dapiran and Hogart-Scott, 2003, Estrada-Flores, 2010). Therefore, a symmetric uptake of technologies by retail suppliers and service providers is essential for the optimum performance of sophisticated food supply chain systems.

Unfortunately, the adoption of ICT in agriculture, which is a pre-requisite for the adoption of SC-ICT, has been highlighted as a problematic area worldwide (Gelb and Parker, 2005, Bourlakis and Matopoulos, 2010). While in developing countries limiting factors relate to infrastructure and cost of technology, in developed countries the lack of understanding on how ICT can deliver benefits to a company is a major impediment to uptake (Taragola and Gelb, 2005).

The latter aspect is further discussed in the Australian context below.

Computer and internet uptake in Australian horticultural farms

Figure 1 shows the internet usage of horticultural farms (i.e. mushroom and vegetable growing and fruit and nuts) in 2007-08, as compared with other types of agricultural farms. This figure indicates that vegetable growers have the lowest internet use among all farm types (52%), while usage in most farm types ranges between 65% and 74%. Deer farming is an exception to these trends, although this sector only represents 0.1% of the total number of farms.

Figure 2 presents the trends on the total number of Australian horticultural farms and the proportion of these using computers and internet for their business activities since 1998. These trends show that over 5,000 horticultural farms have disappeared since 1999, reflecting the strong consolidation in the industry and the shift from family-owned farms to large commercial operations. While consolidation is occurring at a fast rate, Figure 2 shows that the number of computer and internet enabled farms has been stagnant since 2001. At the current rate of consolidation, it is expected that, all things being equal, all Australian horticultural farms should be computer and internet enabled in 2017. However, it is farm consolidation (and not technology uptake) the main factor driving these developments. This observation is supported by a calculation of Spearman's rank-order coefficient between the total number of farms and the number of farms using computers. There is a positive correlation between these two variables ($\rho=0.8929$, $N=7$).

Theoretically, numerous small farmers leaving the horticultural industry should lead to an average increase in industry revenue (due to decreased competition). This extra revenue should enable farmers to invest more funds to upgrade on-farm technologies, including ICT. Further, it would be reasonable to expect that the surviving farms would be more technologically orientated than family-owned businesses. Figure 3 supports these observations: the gap between the total number of farms and the proportion of farms using computer and internet is closing, suggesting that the farms that remain in operation are using computer and internet, while the farms that are leaving the sector were not. Additionally, Figure 3 shows that the gap between computer-enabled farms

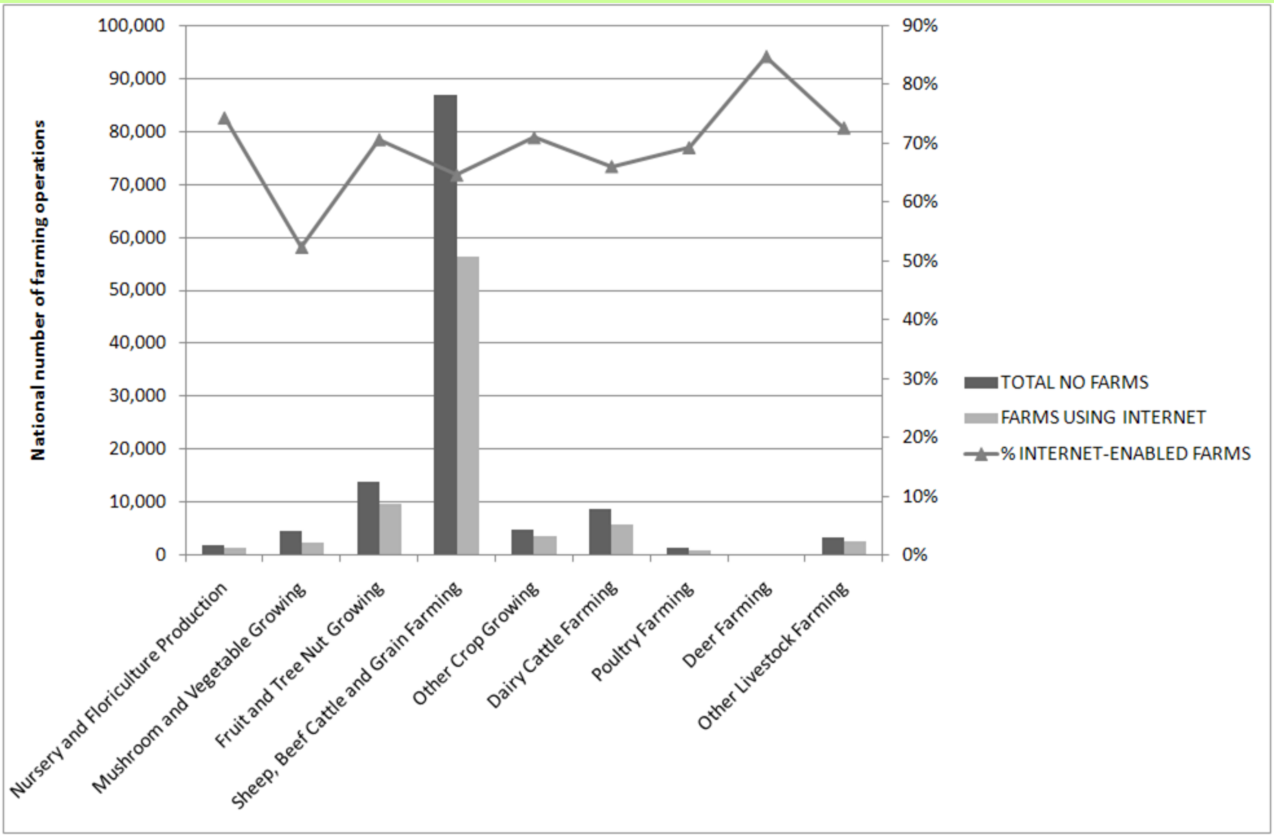

Figure 1. Internet usage of farms per type of activity, 2007-08. Australian Bureau of Statistics.

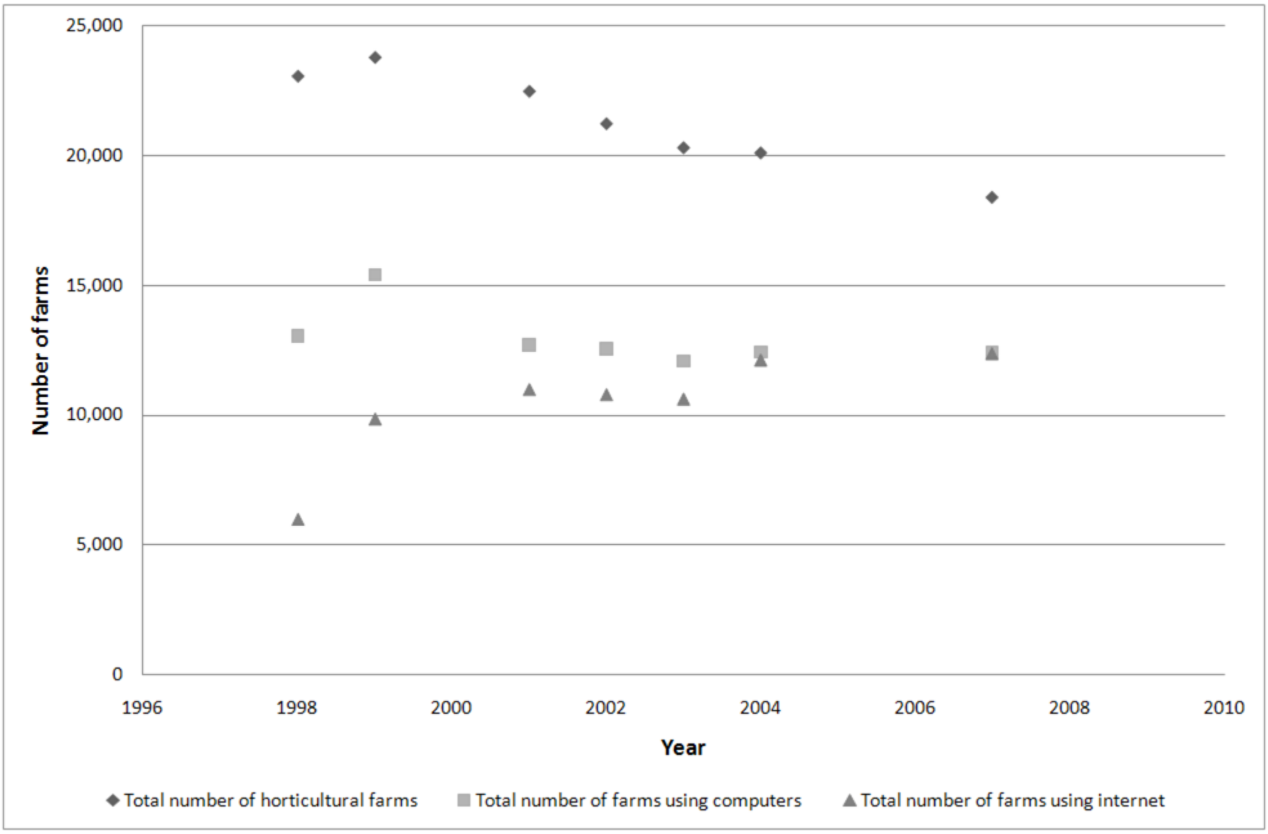

Figure 2. Trends on the total number of Australian horticultural farms, farms using computers and farms using internet for their business activities, 1998-2007.Australian Bureau of Statistics.

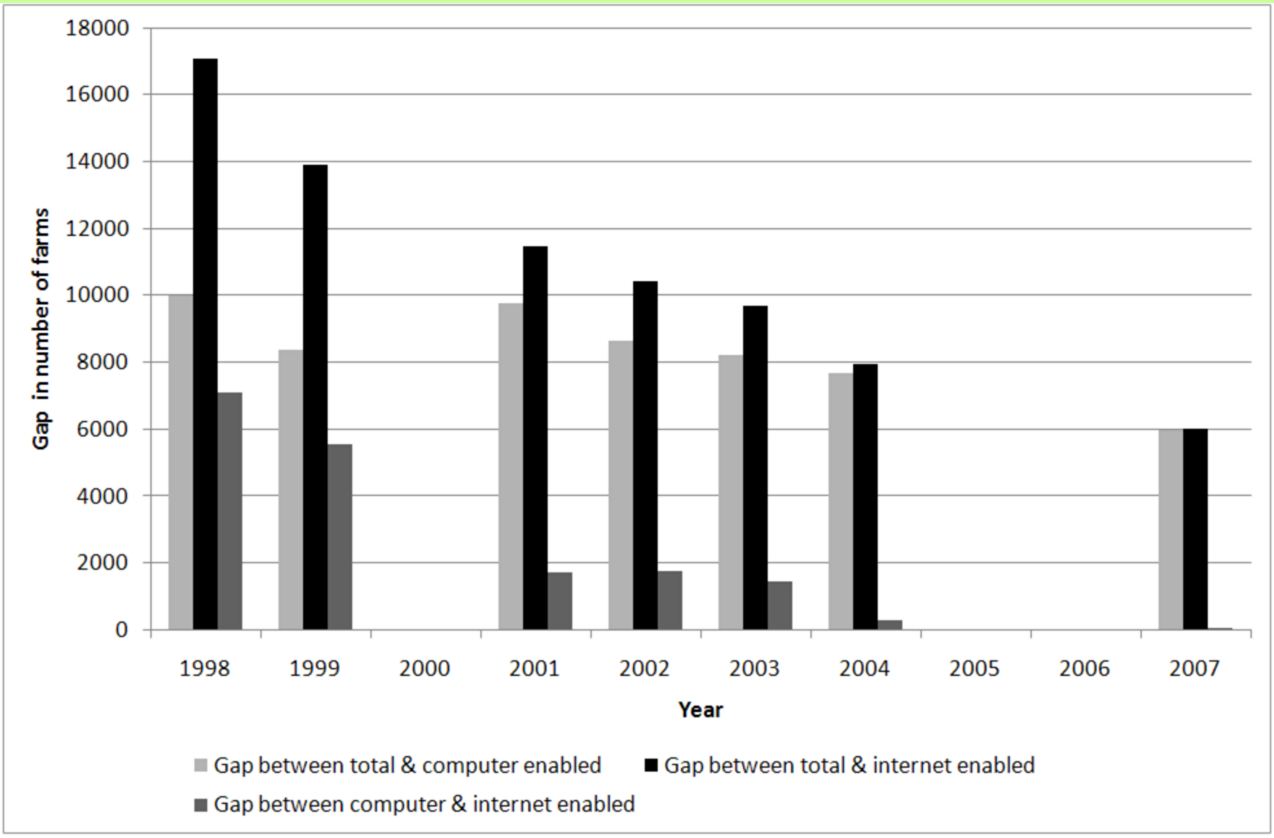

Figure 3. Gap between the total number of Australian horticultural farms and farms using computers / internet in the period1998-2007. The gap between computer enabled farms and internet enabled farms is also shown. Australian Bureau of Statistics.

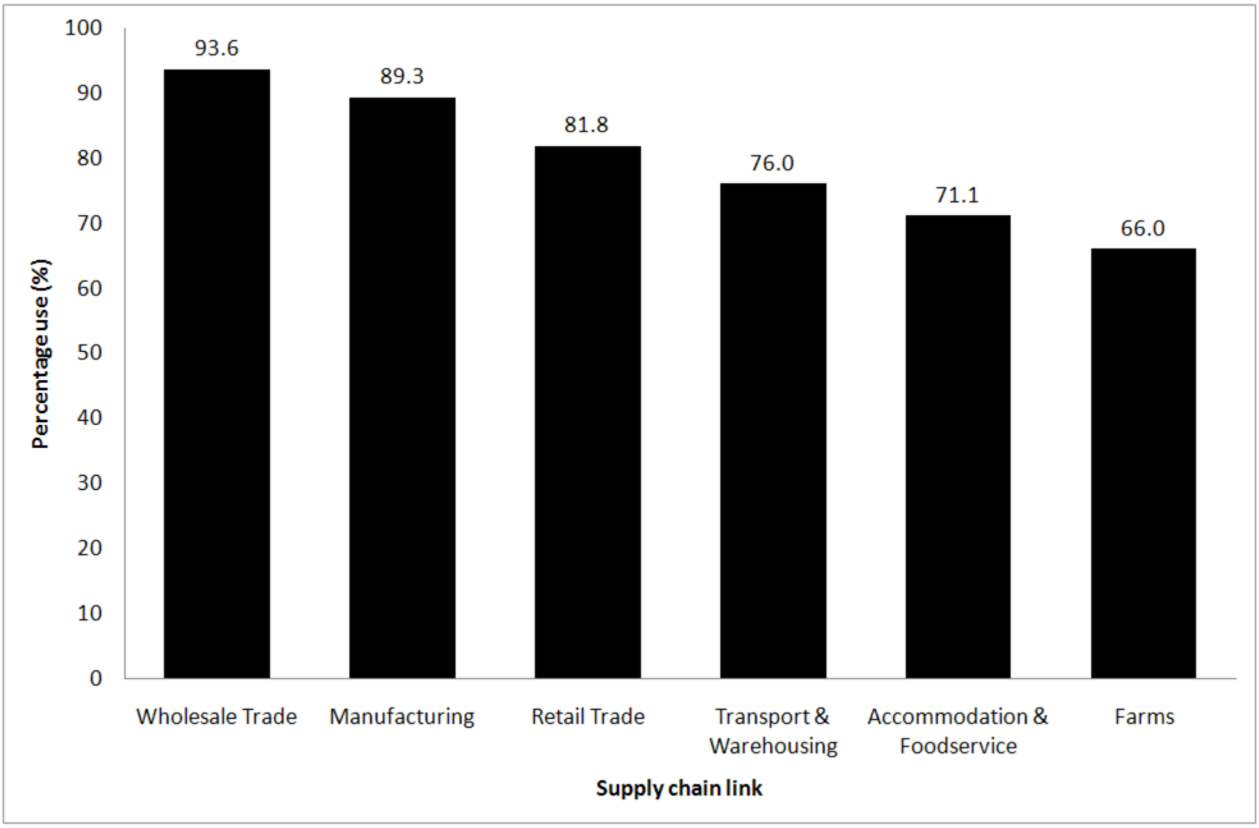

Figure 4. Percentage use of computers and internet in Australian businesses working in horticultural supply chains (2004-05). Australian Bureau of Statistics.

and internet-enabled farms is virtually zero, suggesting that both technologies are now being implemented in parallel.

Figure 4 indicates that there is an asymmetry of ICT implementation between farmers and their supply chain partners (e.g. retailers, transport providers), with the latter having larger internet utilisation percentages than farmers (Australian Bureau of Statistics, 2009a). This asymmetry is likely to affect supply chain relationships at various levels:

a) The costs of business transactions between companies that have different information management systems are likely to be higher than for businesses working with the same systems (Xiaoping et al., 2009).

b) The alignment of demand and supply among business partners becomes more complex to manage if the chain partners do not share updated price and volume data.

c) Several modern traceability, monitoring and food safety initiatives depend on ICT.

d) Supply chain improvements to decrease costs and environmental impacts depend on a whole-of-the-chain flow of information and cooperation (van der Vorst et al., 2005).

The barriers to ICT uptake at farm level were discussed by Molla and Peszynski (2008). The authors investigated the diffusion of e-business in Australian businesses working on the production, marketing, and retail of fruit and vegetables. The study analysed 92 responses, of which 60% were either fruit or vegetable growers. They found that primary producers expect a more supportive role from the government, industry and associations for the uptake of advanced ICT in the form of incentives, norms and promotion.

These results suggest that, either farmers have not yet found sufficient benefits of ICT to justify expenditure in these technologies, or the costs inhibit self-funded improvements in this area. In regards to the former, a previous study indicates that Australian farmers perceive the use of computers as providing high value in budgeting, automation and the market reach enabled by the internet (Rolfe et al., 2003). Therefore, awareness on the benefits of ICT does not seem to be an issue. Instead, the costs of accessing the technology may be the major impediment to computer and internet uptake.

Additionally, the difficult early learning period for farmers switching from an intuitive, experience-based, management style to one supported by information technology has also been recognised as a factor slowing down the uptake of ICT in Australian dairy farms (Eastwood et al., 2006). The authors of this study found that first use of new ICT often coincides with a stressful period for farmers and ICT learning is subsequently not prioritized. Further, service providers have historically focused on technical equipment solutions rather than in ongoing IT support. Limited support also impacts on the utilisation of the farmer's information management, with farmers not fully utilizing the data collected through information technology.

Supply chain technologies based on ICT

A screening of SC-ICT developments (Estrada-Flores, 2009) revealed four areas where ICT has greatly influenced the way agribusinesses operate:

1. Farm Enterprise Resource Planning (ERP).
2. Electronic commerce (e-commerce) and digital pricing.
3. Radio frequency identification (RFID) tracking, traceability and monitoring.
4. The intersection between ICT and precision agriculture.

Historical patenting trends were used to develop technology forecasts for each of the four areas of interest. It was expected that these forecasts would aid understanding on: A) the current state-of-the-art of the selected applications; and B) whether the adoption of these technologies makes commercial sense at the present time. While other indicators were considered (e.g. the number of articles published on the technologies investigated, sales/volumes of units sold), patent activity was selected because it better represents the middle ground between initial R&D and full commercial development, which is the realm of emerging technologies. The patent search was conducted through Delphion ® and included US, European, and World Intellectual Property collections. All patented innovations up to 2008 were considered.

The historical cumulative patenting trends were analysed through the Loglet Lab software package (Meyer, 1994, Meyer, 1996, Meyer et al., 1999, Kuusi and Meyer, 2002). The software applies logistics theory to calculate a growth curve from time-series data sets, in this case represented by the number of patents filled in a period of time. From this curve, the stage of development of the technology (i.e. embryonic, growth, mature, decline) was inferred. This process is also known as technology forecasting. An example of the growth curves is presented in Figure 5.

The principles of each technology and its stage of development are presented below.

Enterprise Resource Planning

ERP is a software-based solution used to manage a farm's resources such as labour, fertilisers, tractors, diesel, field and others (FarmERP, 2009). All the farm's data is placed in a central repository, where it can be matched, cross-matched, and shared across departments and other trusted companies using Internet or electronic data interchange (EDI) (Burt et al., 2003).

An ERP system for horticultural farms can incorporate the following functions:

- Business & activity control
- Traceability practices
- Business profit enhancement
- Cost management and control
- Budget management
- Staff accountability and management practices

The level of adoption of ERP in horticultural farms is unknown. However, the survey of Molla and Peszinski found that 76% of businesses involved in fruit and vegetable chains have adopted computerized accounting systems, which fulfill at least one function of ERP.

The forecasting model for ERP indicates that this area entered technological maturity in 2005. Logistics growth theory indicates that the decline on patented inventions in this area is likely to commence in 2012.

E-commerce and electronic data interchange

E-commerce encompasses the activities conducted using electronic data transmission via the Internet and the World Wide Web. Examples of activities are: (a) consumer shopping on the web or business-to-consumer (B2C); and (b) transactions (e.g. sales or supply chain management) between businesses (B2B) (Burt et al., 2003).

EDI is an enabler of e-commerce and allows direct electronic transmission, computer to computer, of standard business forms between two organizations. Forms exchanged can be purchase orders, shipping notices, invoices and quality assurance forms, among others (Burt et al., 2003). EDI is the predominant SC-ICT development, which allows coordination of activities of several companies in food supply chains (Hill and Scudder, 2002).

The patent trends fit a bi-logistic curve, indicating that there are two waves of developments in the area. The earliest wave seems to correspond to the use of e-commerce for accounting, purchasing, and other typical service-oriented applications. The second wave may be related to electronic biding of agricultural products, integration of electronic coding and traceability and other more sophisticated uses of EDI. The first and second waves entered maturity in 2001 and 2007, respectively. While the 1st wave disappeared in 2003, it is expected that the 2nd wave will reach its peak patent development in 2015.

A concept related to the use of e-commerce is the development of digital pricing, which uses ECR and EDI systems to update the price of goods real-time, based on supply-demand information. The use of electronic labels allows price changes to be automatically (and in some cases wirelessly) sent to the displays. Commonly mentioned advantages of digital pricing at retail include: i) saving costs through decreased labour time formerly dedicated to manually changing the prices; ii) enabling real-time inventory; iii) shortening times for replenishment iv) avoiding out-of-stock situations; and v) fast marking down and promotions of perishable items, as their "sell by" date becomes closer (Sadler, 2006).

Digital pricing is currently being trialled by some US retailers specialized in organic produce and grocery stores. Stores piloting the system have installed an average of two RFID readers to control 25,000 shelf labels deployed across a 4,650 m2 sales floor, with an information updating speed of 10,000 labels in less than an hour (Swedberg, 2009). Electronic/digital pricing technology also follows a bi-logistic behavior, indicating two waves of technology. Further analyses suggest that the 1st wave reflects the development of electronic label technology, which reached its maturity stage in 1999 and is now in full commercial uptake. Current developments seem to focus on individual, one-time use wireless electronic tags (as distinct from fixed wired systems). This innovation wave is still in the growth stage and maturity is expected to occur in 2017, under the current patenting rate.

RFID-based tracking, traceability and monitoring

It is generally agreed that, for a product to be traceable, the following information needs to be known: (1) a Global Trade Item Number (GTIN), which identifies the manufacturer (i.e., the owner of the brand that appears on the

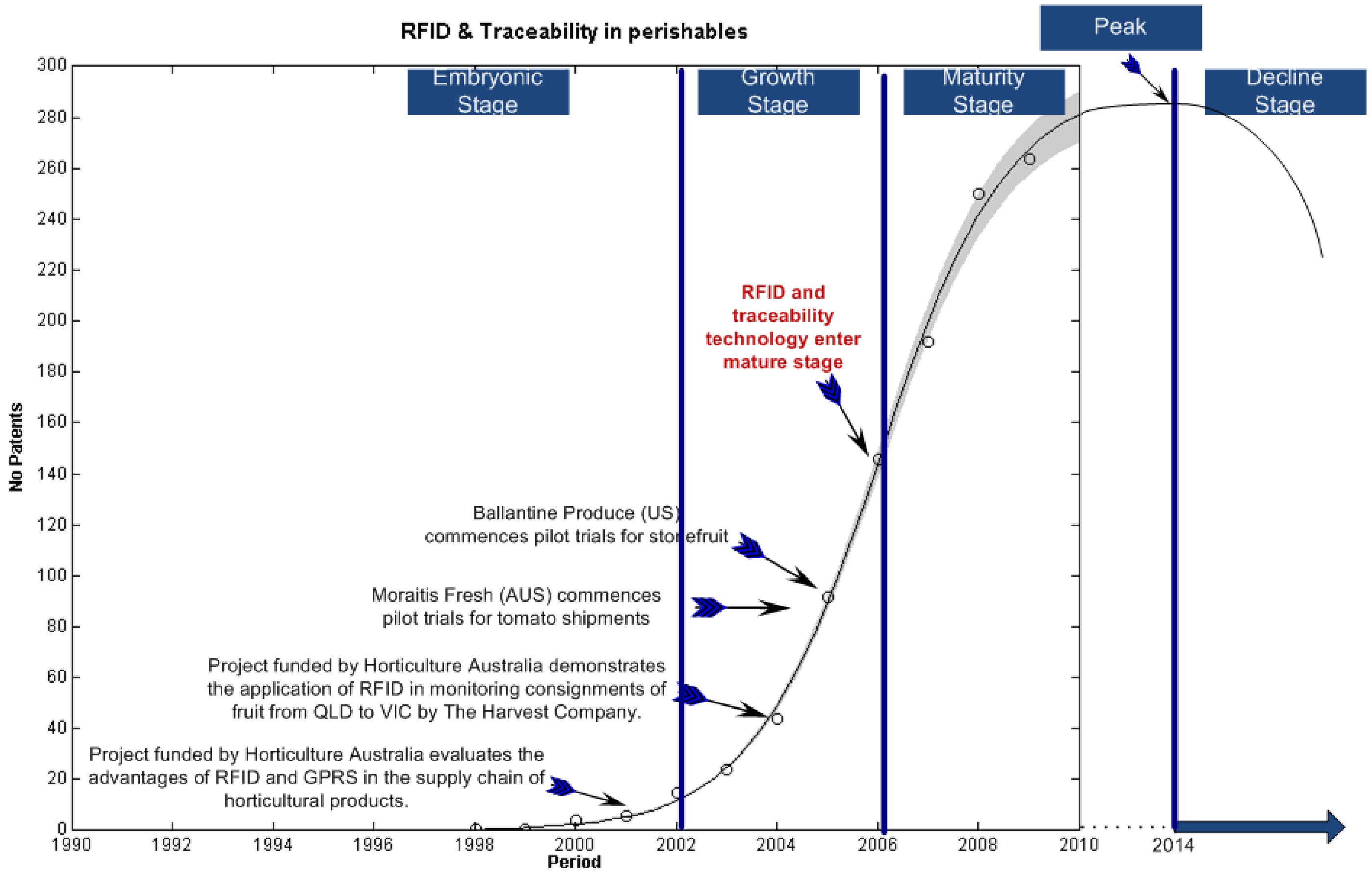

Figure 5. Technology forecast for RFID and traceability technologies applied to agri-food (1998-2009) .

product case) and the type of product inside that case; (2) a lot number that specifically identifies the lot from which the produce came; and (3) the produce's harvest or pack date (if that date is not already incorporated in the lot number) (PMA et al., 2008). This information can be carried across the supply chain in two forms: (a) a label that can be read by a human operator, or (b) a label that can be read by a machine. In the latter category, information can be carried in the form of a barcode or in the form of electronic data contained in a chip. RFID technologies, which identify unique items using radio waves (RFID Journal, 2009), are commonly used in the latter carrying technology.

An RFID-based traceability and monitoring system generally encompasses a sensor, a tag and a reader, that communicate with each other by means of radio transmission. RFID tags can store an electronic product code for logistics management purposes, and, if equipped with the appropriate sensor and battery power, a limited number of temperature readings (Estrada-Flores and Tanner, 2008).

The application of RFID to agri-food supply chains initiated in the 1980s (Anon., 2004). The technology life cycle of RFID in food and agriculture (Figure 5) indicates that this area reached maturity in 2006 and that the peak in RFID patents will occur after 2014, if the current rate of technology development remains unchanged. The notion that RFID technologies for tracking and tracing cases and pallets are now mature and that a full commercialisation of this technology is expected in 5 to 10 years has also been raised by another recent study on emerging ICT (Gartner Consulting, 2009).

Australia was a 'first mover' in testing RFID systems for traceability in the livestock industry. However, fewer examples of commercial uptake of RFID tracking in the Australian horticultural industry are available. These include the pilot trials of Moraitis Fresh and Testarossa Packers to monitor tomato shipments (Head, 2004) an trials developed by Woolworth's, Australia's largest supermarket chain (Friedlos, 2008).

The intersection between ICT and precision agriculture

Precision agriculture combines new technologies with existing agronomic knowledge to maximise farm efficiency (Horticulture Australia, 2008). There are three major SC-ICT that support precision agriculture:

1. Geographical Information Systems (GIS). This is a combination of computer hardware, software, and geographic data designed to capture, store, manipulate, analyze, and display data that is referenced to specific points on the earth's surface. The capacity to perform many sophisticated spatial operations on these data differentiates GIS from simple mapping software (Cowan, 2000).

2. Global Positioning System (GPS). Precision agriculture makes use of satellite systems, which emit radio signals at precise intervals accurate to a billionth of a second. Through triangulation, a ground-based receiver translates the time lag between emission and reception of the signals into precise geographic coordinates on the targeted cropland (Cowan, 2000). In particular, precise positioning technology is a method that performs position determination using multiple frequency Global Navigation Satellite Systems (GNSS) receivers to achieve real-time or near real-time accuracy of two centimeters (The Allen Consulting Group, 2008, Lachapelle and Petovello, 2006)

3. Remote sensing (RS). This term refers to a group of instrument-based techniques employed in the acquisition and measurement of geographically distributed data/information. Remote sensing applications can identify spatial features and variability in a field through differences in colour or solar energy reflectance of water, soil and vegetation. This enables determination of crop health, plant emergence issues, insect infestations, accidental herbicide damage, uniformity of fertilizer or water application, drainage patterns, record of crop type and acres, and other issues affecting crop productivity during the growing season (Watermeier, 2009).

Some geospatial applications of particular interest to horticultural production are (ACIL Tasman, 2008):

- Yield monitoring and crop stress mapping.
- Controlled traffic farming (e.g. self-steering tractors).
- Variable rate technologies for fertilizers application.
- Soil condition mapping.
- Salinity mapping.
- National control strategies for pests and disease outbreaks.

Scientific literature on precision agriculture often cites Australia as an early adopter (Swinton and Lowenberg-DeBoer, 2001, Fountas et al., 2005). A closer look indicates that broadacre systems – wheat, barley, rice, oilseeds, sorghum and similar– are where precision agriculture has been used more extensively. For example, about 30% of all broadacre grain crops in Australia are grown with the use of some form of global navigation satellite systems (The Allen Consulting Group, 2008).

Furthermore, the direct increases on productivity attributable to precision agriculture during 2006-07 were quantified recently. While productivity increases in cereals were estimated to reach 1.8%, "other agriculture" (presumably including horticulture) only achieved 0.01% (ACIL Tasman, 2008).

An econometric modelling study on the benefits of controlled traffic farming and inter-row sowing found that these technologies contribute between AU$152 million and AU$206 million per year to the revenue of the Australian broadacre cropping sector (The Allen Consulting Group, 2008).

At present, there are no surveys on the actual uptake of precision agriculture or estimates in the potential benefits achieved in horticulture. However, it has been suggested that the benefits of geospatial technology on horticulture productivity are likely to be seven to ten times smaller than for broadacre crops (ACIL Tasman, 2008).

The technology life cycles of geospatial and remote sensing applications for indicates that maturity in GPS and GIS applications occurred in 2003, while the number of patented inventions based on remote sensing in agriculture is still growing. The peak of R&D investment in GPS and GIS technologies is expected to occur in 2012.

Case for the adoption of SC-ICT applications

A summary of the status of the selected SC-ICT selected including life cycle, predictability of developmental costs, approximate initial investment and level of adoption in Australia is presented in Table 1. This assessment followed the methodology initially proposed by the management consultancy Arthur D. Little in the 90's, which links the concepts of technological maturity, competitive impact and characteristics of R&D stages (Roussel et al., 1991). Based on these concepts, this methodology provides a simple decision-making framework for investment or uptake of technologies in a commercial setting.

Table 1 need to be placed in the context of the nature of innovation and scientific development. For example, a decline in the number of GIS/GPS patents does not necessarily mean that the innovation push in that area has ceased. GIS/GPS applications will continue to evolve in areas such as computerized navigation and

Table 1. Summary of the status of SC-ICT selected, including life cycle, approximate initial investment and level of adoption in Australia.

EMERGING TECHNOLOGY	**STAGE OF DEVELOPMENT**	**PREDICTABILITY**		**LIFE CYCLE (Benchmark: 2009)**		**APPROX. INVESTMENT (AU$)**	**LEVEL OF ADOPTION**
		Technical	R&D costs	Time to full-scale commercialization	Time to R&D decline		
ERP at farm level	MATURE	HIGH	HIGH	1-4 years (Fair commercial advantage)	3-4 years	$500-$20,000 (farm level)	LOW-MEDIUM
GPS and GIS applications	MATURE	HIGH	HIGH	1-4 years (Fair commercial advantage)	3-4 years	$5,000-50,000 (farm level)	LOW-MEDIUM
Remote sensing	GROWTH	FAIR	MODERATE	5-10 years (Moderate commercial advantage)	70 years	$20,000-$50,000 (farm level)	LOW
RFID	MATURE	HIGH	HIGH	5-10 years (high commercial advantage)	5 years	$100,000 to several millions (packing house, processor and retail level)	LOW-MEDIUM
Electronic commerce	MATURE	HIGH	HIGH	Under way (short commercial advantage)	6 years	HIGHLY VARIABLE (retail level)	LOW-MEDIUM
Electronic/ digital pricing	Electronic labels-MATURE	HIGH	HIGH	Under way (short commercial advantage)	6 years	UNKNOWN (retail level)	NULL
	Wireless price tags-GROWTH	FAIR	MODERATE	5-10 years (Moderate commercial advantage)	50 years	UNKNOWN (retail level)	NULL

the assessment of renewable energy (involving biomass, geothermal, solar, wind and hydro/wave types), among others. However, their impacts in agricultural applications are likely to be more difficult to assess.

From Table 1, the following observations were made:

a) The only SC-ICT areas that are in the growth stage are remote sensing and the application of digital pricing through wireless technology.

b) Excepting the technologies above, investment in all other areas should focus on projects beyond the "proof-of-concept" stage. For example, projects that quantify costs and benefits of the technology in horticultural applications, pilot trials, and commercial improvements.

c) The level of implementation of SC-ICT innovations in horticulture is assessed as low-to-medium (ACIL Tasman, 2008, The Allen Consulting Group, 2008, Molla and Peszynski, 2008). The potential for technology uptake is still substantial.

d) The commercial uptake of RFID, wireless tags for digital pricing and remote sensing for horticultural applications requires investment on implementation projects, cost-benefit studies, and utilisation for supply chain management, as distinct to pure technology development.

e) The costs of implementation of the technologies investigated are highly variable and the specific benefits for companies need to be assessed on a case-by-case basis.

Other influences in SCT-ICT uptake

Undoubtedly, there are other social, technological, economic, environmental and political/ regulatory issues affecting the uptake of SC-ICT innovations at farm level. For example, the power of large supermarket chains is a crucial influence: in Australia, supermarkets sell over 60% of staple foods across several categories. Further, private labels account for about 34% of the total grocery bill paid by low–income consumers (Estrada-Flores and Larsen, 2010). The increase of the market share of private label in the consumer‘s food basket is likely to increase in the short term (Burgio-Ficca, 2010).

Large supermarkets have been generally perceived as a negative influence on food chain innovation (Ferguson, 2009, CDI Pinnacle Management, 2008). For example, large retailers demand that product be delivered on pallet sizes that suit the retailer's distribution centre pallet racking, which sometimes leads to under utilization of a truck‘s capacity. As a consequence of this sub-utilisation, the transport cost per kilogram increased (CDI Pinnacle Management, 2008). Therefore, retailers have a significant effect on the introduction of supply chain practices that may not be innovative or fair to trade partners.

Having said that, there is no true consensus on the role of large supermarkets on innovation and some research suggests that large companies that deal with several suppliers/ buyers tend to introduce more innovations per year (Karantininis et al. 2010).

The effect of enterprise size (economies of scale) is another significant factor in the uptake of SC-ICT innovation. Mid-size and large companies have more financial and human resources to withstand the risks associated to innovation than small firms (Karantininis et al., 2010, Alfaro et al., 2008). In Australia, about 82% of fruit and vegetable growing operations that produce over AU$1 million per year in value use computer-based technologies, in comparison to 51% growing operations with revenues below AU$50,000 (Estrada-Flores, 2009). This indicates that ICT technology uptake is likely to occur unevenly across the sector.

Conclusions and Recommendations

Information and Communication Technologies for the operation of agricultural supply chains are ideal innovation platforms to achieve substantial improvements in more than one operational area. Value chain projects that determine the profits to growers integrated in ICT-enabled chains, as compared with those integrated to traditional marketing channels, are required. With the exception of one reference (Molla and Peszynski, 2008), most Australian studies focus on the benefits for companies situated downstream food supply chains. Technical, economic and social research to increase understanding on how ICT can affect profit margins and costs for all chain partners are needed.

However, there is little hope in achieving an ICT-enabled chain if farmers do not increase their computer and internet use. Some solutions that could improve this situation are offered below:

1) Access to computers and internet. Government funding to support purchase or lease agreements of basic IT equipment in farms and packing houses should be given consideration. Rental arrangements that provide software, installation and maintenance services to horticultural growers for a reduced fee would be highly valuable. Further, contract arrangements with service providers that allow a number of farmers to access software at reduced costs should be sought. This same strategy could be used for internet services (e.g. farmer web pages, electronic auctions, trading posts and others).

Small and medium-sized farming enterprises can also use their industry associations as platforms to develop ICT initiatives. By joining forces in the association platform and attracting ICT consultants, small farms can increase their ICT uptake while remaining independent enterprises. An example of this approach is the successful project undertaken by 35 potted-plant growers in the Westland region of the Netherlands (Hofstede, 2007).

2) Access to training. The training courses offered by horticultural industry associations focus mostly on leadership and business skills. Few courses that cater for the knowledge required to run SC-ICT (e.g. e-commerce, supply chain management, demand forecasting and ERP) are offered through industry associations. The development of rural ICT centres in primary production areas to develop awareness of the value of SC-ICT innovations and that can provide support to farmers on the application of these should also be considered. Further, industry leaders could engage with software and supply chain service providers to generate training programs addressing knowledge gaps. While there would be a need to monitor the contents of such courses to ensure a balance between marketing and substance, there is also great potential in promoting discussions between farmers and supply chain service providers to enhance both the services offer and the understanding of what benefits IT technology can bring to horticultural growers.

3) Improved supply chain relationships. A significant barrier to the uptake of these technologies is the low level of trust and transparency among supply chain partners in current commercial conditions in Australia. The development of a mechanism to overcome this barrier is essential for the implementation of technologies that reveal sensitive commercial information from suppliers and retailers. The establishment of a watchdog organisation, which may be a Government department of another party, may help to overcome the barriers to uptake of ICT that involves information exchange among trade partners.

Acknowledgments

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Achieving temperature control and energy efficiency in the cold chain

The cold chain concept

Refrigeration technology consumes about 15% of all electricity consumed worldwide (Coulomb, 2008). One of the major applications of refrigeration technology is the maintenance of temperature-controlled conditions required to maintain food quality, from harvest to domestic storage. This temperature continuum concept is generally known as “cold chain”.

The cold chain starts at the point of production of raw materials, where immediate cooling ensures optimum quality for primary and secondary processing. Primary processing involves operations that prepares the raw materials for a second processing stage. Cold chain operations in this stage are represented by carcass chilling, precooling of fruits and vegetables or milk cooling. Secondary processing involves transforming primary agricultural products into manufactured foods and the cold chain continues in the form of freezing or chilling of foods, either in bulk or in packages. Food distribution and handling need to be performed at controlled temperatures and planning of routes and schedules need to take into account the location and capacity of refrigerated distribution centres, the refrigerated modes (sea, air, land) and the volumes to be transported. Loading and unloading operations may be performed in refrigerated docks. Food at retail needs different levels of refrigeration: cold storage is required in supermarket distribution centres; preparation rooms (e.g. slicing and secondary packaging of deli and meat products) need to be air-conditioned; walk-ins and display cabinets need to be refrigerated. Finally, consumers store purchases of perishable products in domestic refrigerators.

Optimising energy use in the cold chain

Commercial and industrial refrigeration and air conditioning consumes around 11% of all UK electrical energy (Maidment et al., 2007). This figure is closer to 15% when domestic use is added (Hundy et al., 2008).

A mapping of energy consumption in British cold chain operations (Swain, 2006) revealed that the top ten food refrigeration sectors in terms of energy savings potential (including primary and secondary cold storage, refrigerated transport, retail and domestic refrigeration) consume between 16,339 and 24,343 GWh per year. Similar studies performed in Australia (Estrada-Flores and Platt, 2007, Energy Strategies, 2007) indicate that in 2006 the electricity used to power refrigeration equipment dedicated to food ranged from 19,000 to 20,000 GWh.

The most significant energy savings in British cold chains lie on the optimisation of retail display cabinets, which represent between 35% and 52% of the estimated energy usage of the top ten food refrigeration sectors (Swain, 2006). In Australia, retail and domestic refrigeration are the most significant opportunities to decrease refrigeration energy use (Figure 1).

The observations above indicate that electricity consumption increases dramatically towards the final stages of the chain. Therefore, energy saving technologies that target retail and domestic refrigeration can significantly decrease the financial and environmental impacts of energy usage worldwide. Having said this, companies operating in the refrigerated storage sector and the processing sectors are very receptive to energy efficiency measures because the survival of these industries depends on a reasonable pricing of services combined with the assurance of the required conditions for food quality preservation (Estrada-Flores, 2007).

The unrealised potential of refrigeration innovations for energy savings in a global scale is illustrated in the following examples:

- McNeil et al. (2008) estimated the maximum potential of efficiency improvement for household refrigerators, window air conditioners, motors and distribution transformers in India, which cumulatively account for 27% of the national electricity consumption. The energy baseline of refrigerators has potential to decrease by 45% if high efficiency refrigerators are adopted, representing energy savings of 80 TWh between 2010 and 2020, an emissions avoidance of 77 Mt CO2-e and net present financial savings of US$1.3 billion.
- In the last five years, China’s refrigerator market has grown rapidly to the point of saturation in urban markets, with ownership rates in urban households of 92%. Lu (2006) estimated that the application of a revised standard GB12021.2-2003 (which specifies maximum allowable values of the energy consumption and energy efficiency grades for household refrigerators) could lead to energy savings ranging from 494.6 TWh to 1,292.9 TWh in a 20-year period. These savings represent emissions avoidance of 614.7 Mt CO2-e – 1,607.0 Mt CO2-e.
- It is estimated that retail refrigeration in the UK could potentially save 30% – 50% of the actual energy consumption, which represents 6,349 GWh annually (Swain, 2006).
- In Australia, Estrada-Flores (2007) estimated that an average energy reduction of 15% can be achieved across all land-based cold chain equipment through the use of intelligent controllers and the avoidance of peak electricity periods. These strategies are summarised in Tables 1 and 2. Such a reduction would lead to savings of 2,893 GWh per year, using the estimates of 2006 as a baseline.

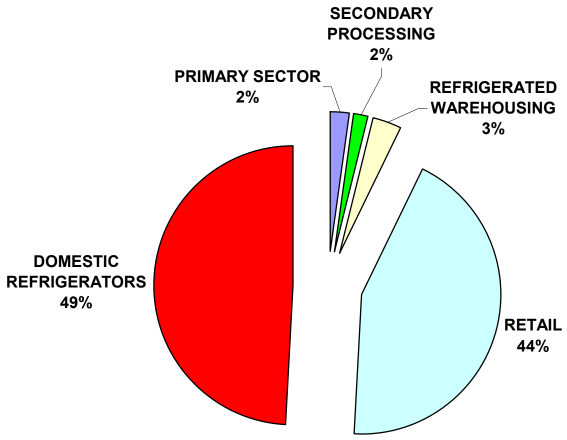

Figure 1. Contribution of primary sector, secondary sector, refrigerated warehousing, retail and domestic refrigeration on the Australian cold chain electricity expenditure (excluding refrigerated transport) in 2006 (Estrada-Flores and Platt, 2007).

Other heat load reduction measures based on preventive maintenance include: utilising air curtains to avoid the entrance of hot, humid air; optimising compressor performance; providing maintenance to the refrigeration plant components; ensuring the integrity of door seals and insulation of refrigerated equipment and adjusting defrost conditions to ensure a complete melting of ice without adding unnecessary heat into the equipment (Evans, 2007; Evans and Gigiel, 2007; Chen et al., 2002).

Optimising refrigerated distribution

Transport is one of the largest emitters of greenhouse gases (GHG) due to its direct use of fuel and its role in road congestion (Spedding, 2008). Although the exact proportion of emissions corresponding to global food transportation is unknown, is is believed to be a significant contributor. Contributing factors include inbound and outbound logistics from farms, factories, wholesalers and retailers. Travel by consumers in cars or public transport to buy their weekly groceries from stores also needs to be accounted for.

In a global scale, the refrigerated transport fleet encompasses more than 1.2 million of refrigerated road vehicles (Gac, 2002), about 830,000 reefer containers (Containerisation International, 2008), 80,000 refrigerated railcars and about 1,300 specialised refrigerated cargo ships (Heap, 2007). Further, the amount of perishables transported by air freight globally is about 8% of all air cargo shipped (Catto-Smith, 2006).

The contribution of refrigerated transport to global warming is mainly derived from the following components:

A) The direct and indirect emissions from the use of fuel and oil for motion and refrigeration purposes.

B) The use of ozone depleting substances such as hydrochlorofluorocarbons (HFCFs) and hydrofluorocarbons (HFCs) as cooling agents in the refrigeration circuit and as foam blowing agents in the manufacture of insulation of refrigerated equipment.

C) The role of food transport on road congestion.

One strategy to decrease the impact of refrigerated transport is the implementation of energy labelling schemes and Minimum Energy Performance Standards (MEPS), which can drive the market towards the development and uptake of more energy efficient products (Prabhakar, 2007). Similarly to the domestic and retail refrigeration sectors, the application of MEPS could improve the energy performance of refrigerated equipment.

In Europe, at least one detailed proposal on the development of voluntary energy labelling standards in refrigerated transport has been published (van Gerwen et al., 1999).

At 11 years of this proposal, the debate on the need and application of energy labelling schemes continues. Although the ATP standard has been considered to account for a balance between energy expenditure and insulation effectiveness, an actual measurement of energy is not included in the standard. Further, testing costs would almost certainly increase at some extent if an energy measurement is necessary to comply with ATP.

In terms of technical innovations, a crucial opportunity in reducing refrigerated transport emissions is the development of systems that increase the coefficient of performance above the current range of 0.5 – 1.5 for vapour compression systems (Tassou et al., 2008). There are two ways to achieve this: decreasing the heat loads entering the system or optimising the compressor's energy use. This author believes that the 'low hanging fruit' opportunities lie on reducing the heat loads entering the system.

Following the rationale above, incremental reductions in the use of fuel for refrigerated transport can be achieved by decreasing the maximum acceptable insulation effectiveness coefficient (or k-value). The International Agreement for the Transport of Perishables (ATP) Agreement establishes a maximum k-value of 0.4 W m^{-2} K^{-1} for insulated bodies Type I (class b), Type II classes B and C and Type III classes B,C,D and F. This is the lowest k-value required in the ATP and the value was established since the ATP's inception in the 1970 's (Chatzidakis and Chatzidakis, 2004). Indeed, it is now rare to find any ATP certificate from any manufacturer with a k value of lower than 0.35 W m^{-2} K^{-1} (Heap, 2008). Nevertheless, it has been argued that in practice, the ATP re-approval process for in-service equipment allow insulated bodies with k-values above 0.4 W m^{-2} K^{-1} to operate (Chatzidakis and Chatzidakis, 2004).

A decrease of 0.1 W m^{-2} K^{-1} in refrigerated containers would decrease the carbon footprint of the global refrigerated container fleet in 0.7 million tonnes CO2 –e (Estrada-Flores, 2009). Similar improvements in refrigerated transport vehicles are possible through the use of better performing materials (e.g. vacuum panels, nanomaterials). Additionally, improvements in the performance of door seals have been tackled by the use of double and triple seals, but research on new materials that maintain performance at low

Table 1. Summary of smart demand management strategies for refrigerated processing equipment

Sector	Focus of electricity saving strategies	Temperature-related heuristics for quality preservation
Precooling (primary processing)	Matching of compressor capacity with refrigeration load (in air forced cooling) Decreasing evaporator capacity towards the end of precooling.	The objective in this operation is to achieve cooling as fast as possible. Any strategy that leads to slow cooling will have detrimental effects on the quality of the product. Wide optimum storage temperature variations exist between commodities. Optimum temperatures are commodity-dependant and temperature variations above or below the recommended temperature will have a significant impact on quality. Therefore, the use of peak load shifting/sub-cooling should be carefully assessed in laboratory and pilot trials.
Freezing (secondary processing)	<u>In continuous freezers:</u> Intelligent matching of freezing capacity and freezing loads Adaptive defrost <u>In batch freezers:</u> Peak avoidance techniques Turning off freezer during weekends, if not in use.	The objective in this operation is to achieve freezing as fast as possible. Any strategy that leads to slow freezing will have detrimental effects on the quality of the product.
Chilling (secondary processing)	As per precooling.	As per precooling.

Table 2. Summary of electricity saving strategies for refrigerated storage

Sector	Focus of electricity saving strategies	Temperature-related heuristics for quality preservation
Refrigerated storage sector	<u>In frozen products:</u> Peak avoidance techniques Sub-cooling of the warehouse during weekends Intelligent matching of load (variable and fixed compressor's capacity) Adaptive defrost <u>In chilled products (dedicated storage):</u> Peak avoidance techniques (see heuristics) Intelligent matching of loads <u>In CA storage:</u> Increasing evaporation temperature above the recommended storage temperature is a possibility (see heuristics)	<u>In frozen products:</u> Peak avoidance and sub-cooling techniques should maintain product temperatures within -18 and -25 ^{o}C <u>In chilled products:</u> Sub-cooling to temperatures below 0 ^{o}C is not recommended for horticultural products (or others susceptible to freezing damage) Sub-cooling to -2 ^{o}C can be well tolerated by some dairy products (e.g. milk, butter, cheddar cheese) In CA storage, tolerance of commodities to temperatures above the recommended storage temperature needs to be investigated experimentally. No temperature tolerance guidelines have been fully established for CA storage.

temperatures while being subjected at pressure differences and mechanical stress could be furthered.

More radical innovations that can lead to higher payouts have been reviewed recently (Tassou et al., 2008). Technologies that have an unexplored energy savings potential and that merit further investigation include adsorption and absorption systems, thermoelectric cooling and power generation, air cycle refrigeration, cryogenic systems and eutectic systems.

This author also agrees with Tassou et al. (2008) on the potential for the use of phase change materials to increase the thermal storage capacity of refrigerated vehicles, thus enabling the internal structures to 'buffer' temperature changes. Liu et al. (2007) evaluated the use of phase change materials in a design similar to an eutectic plate system. Preliminary estimates with respect to a mechanical refrigeration system suggest that the hybrid electric-PCM system would decrease refrigeration energy costs in 60% to 80% (at peak electricity prices in South Australia).

Trigeneration and smart demand management for optimisation of energy use

The use of alternative refrigeration systems has been recently reviewed on the context of energy use and climate change (Tassou et al., 2010; James and James, 2010). In this paper we focus on two specific technologies: cogeneration/trigeneration and smart demand management.

Cogeneration/Trigeneration

Cogeneration and trigeneration systems (CHP and CCHP, respectively) combine heat and power (in the former) or are integrated with a thermally driven refrigeration system to provide cooling as well as electrical power and heating (in the latter).

CHP and CCHP systems have been in operation since the 1880's. The renewed interest on CHP and CCHP plants is based on the fact that these systems can use a variety of fuels such as coal, light fuel oils, natural gas, waste fuels and solid or gaseous biomass. In view of new environmental legislation and raising energy costs, there has been an increase in the commercial uptake of these technologies in industrial sectors that previously preferred conventional heating and cooling systems (i.e. based on direct use of fuel or electricity).

Large scale (above 20 MW) and medium scale (between 1 and 20 MW) cogeneration applications are well developed and established in paper, chemicals, food, primary metals, and petroleum refining. However, trigeneration systems from 4 MW to 9 MW and small plants (less than 1 MW) are less developed. Trigeneration systems have been applied in food manufacturing applications such as margarine and vegetable oils, dairy, vegetable and fruit processing and freezing, and meat processing (Worrell et al., 2004). Trigeneration applications to the food retail sector is only recent, mainly been due to the unavailability of commercial size low temperature and low cost absorption refrigeration systems off-the-shelf (Sugiartha et al., 2009). While recent applications in the retail industry in the UK have been for space heating and cooling, retail food chains and equipment suppliers are now considering trigeneration systems for refrigeration applications.

An example of the recent application of trigeneration in supermarkets is the Tesco installation of a CCHP system that uses biofuels and an adsorption (as distinct of absorption) chiller at Colney Hatch, north of London. This system can generate 800 kW of electricity and it simultaneously produces chilled water for air-conditioning and refrigeration systems.The adsorption chiller uses recovered heat from generating electricity to drive the refrigeration cycle. Water is adsorbed onto a bed of silica gel and evaporated under low pressure to generate chilled water at temperatures as low as 4°C. The energy saving for refrigerators alone is 30%, as compared with traditional arrangements (Anon., 2009).

Smart demand management

The 'smart' use of alternative energy sources (e.g. CHP, CCHP, ice banks, eolic/solar energy, phase change materials) to power cold chain equipment has two main requisites:

The application of data collected from electricity grids to optimize the performance of refrigeration systems based on electricity rates.

Intelligent controllers designed to balance product quality, cooling demands and power available.

A novel demand management strategy has been successfully tested for a controlled atmosphere (CA) cold store for apple storage in Australia (Smale and East, 2007; Trujillo et al., 2008). This strategy consists in sub-cooling the cold stores during low-cost energy rates periods down to a threshold established in terms of the physiological response of the specific apple variety under CA conditions. The power is switched off for some hours during expensive electricity rates periods, allowing a calculated warming period before switching the power on again. The temperature oscillations in the cold store are managed through the careful evaluation of apple quality during these conditions.

Preliminary calculations indicate that shifting refrigeration to off-peak periods results in product temperature oscillations of less than ±0.5°C, with savings ranging from 40% to 45% of refrigeration energy costs. Preliminary studies did not show significant detrimental effects on apple quality during the application of this peak avoidance strategy (Trujillo et al., 2008). Based on these results, intelligent controllers using algorithms that include the temperature and CA thresholds can be developed to automate the on/off periods, according to the dynamics of the electricity grids.

Another recent example of 'smart' demand management is the system created for the Night Wind project (The Netherlands), which combines eolic energy and grid electricity to power cold stores. The idea is to sub-cool refrigerated facilities using wind energy produced at night and avoid energy expenditure during daytime peak hours (van der Sluis, 2008). Preliminary cost benefit calculations indicate that the implementation costs per system are in the order of €12,500 and the payback period is only a few months (van der Sluis, 2008).

The link between energy saving strategies, temperature control and product quality

The effect of temperature oscillations on food quality factors (discussed in the June 2010 'Chain of Thought' newsletter) should be kept in mind in the context of the recent calls to raise the storage temperatures of frozen foods to save energy. As the British Frozen Food Federation aims to raise the maximum frozen food storage temperature from –18 °C to –15 °C in an attempt to reduce the industry's environmental impact (Byrne, 2008), many industry experts anticipate a similar effort in other countries. For instance, experts in industry forums in the US have discussed this measure and have estimated that an increase of 2–3 °C can lead to a 5% savings in refrigeration energy costs (Schoeni et al., 2009). However, traditional kinetics models used to predict product shelf-life indicate that a storage temperature of –15 °C can lead to a decrease in shelf-life of up to 36% in frozen hamburger patties (Chen et al., 1989) and up to 45% in frozen prawns (Tsironi et al., 2009), in comparison to products held at –18 °C. Additionally, vitamin C degradation can be 25% faster for each 3 oC increase in storage temperature (Giannakourou and Taoukis, 2003). These quality losses would have repercussions on other supply chain players, and potentially on consumers.

Balancing energy savings and product quality

The use of alternative refrigeration systems and peak avoidance strategies that are based on the sub-cooling of products followed by a controlled temperature increase leads to cyclic temperature variations. This inevitably affects the biochemistry and physiology of the products stored. Moderate product temperature fluctuations may be only slightly detrimental to some products and alternative control strategies may provide energy reduction benefits outweighing the reduced value as a result of product quality deterioration (Smale and East, 2007). Examples of potential applications that may suffer acceptable quality losses under temperature regimes oscillating ±1.5 °C or less include cold storage of frozen products (e.g. meat, fish, potatoes, carrots, vegetable mixes) and products with a postharvest shelf-life that extend over months, rather than weeks.

However, the use of variable temperature conditions can significantly affect the quality of more perishable products, even when stored under modified atmospheres conditions. For example, Tano et al., (2007) investigated the effect of temperature fluctuations on modified atmosphere packages containing mushrooms, broccoli and tomatoes. The packages were subjected to various combinations of temperature fluctuations, simulating storage and transport conditions. The quality of the products stored under temperature fluctuating regimes was severely affected, as indicated by colour changes, loss of firmness, weight loss increase, increased ethanol concentrations in the plant tissue, and infection due to physiological damage and excessive condensation, relative to products stored at constant temperature. The authors concluded that temperature fluctuations, even if they occurred only once, seriously compromised the quality and safety of the packaged produce.

Even in frozen products, temperature variability can lead to measurable quality changes. For example, the Night Wind project investigated the effect of the eolic/electricity power generation and electricity-only power generation on the quality of frozen goods (van der Sluis, 2008). The products tested were bacon, smoked mackerel fillet, fruit pies, strawberries, tomatoes, melons and ice cream. A control group was stored at a steady temperature of –19 °C while the eolic/electricity temperatures varied between –16 °C and –28 °C. The quality parameters followed included texture, colour, drip losses. Additionally, a consumer panel assessed appearance, colour, flavour and consistency. The results showed that the quality of foods stored at variable temperatures was comparable, but generally inferior to products maintained at a constant temperature.

In some cases, quality deterioration under variable temperatures is not measurable right after cold storage.

However, storage stages are followed by several other supply chain links that may amplify any quality loss to unacceptable levels once the product reaches the consumer. This risk depends on the cold chain management of the product throughout the entire chain.

Final remarks

As any industry in present times, the refrigeration sector is reviewing its role in three major aspects that affect modern food supply chains: minimising environmental impacts, decreasing energy costs (and oil dependency) and assuring food safety and quality. These aspects are interrelated and the three priorities should be equally important to the refrigeration sector.

The maintenance of cold chain conditions is an energy-intensive endeavour. Given the significant financial and environmental impacts of refrigeration energy expenditure, it is tempting to assume that the world is “over-cooled” and that the solution to a global excess of refrigeration capacity is to decrease the use of refrigeration. However, recent IIR figures indicate that about 360 million tonnes of food are lost annually due to insufficient refrigeration worldwide (IIF-IIR, 2009). Furthermore, climate change impacts include warmer climatic conditions and refrigeration would be a much needed technology to ensure food safety and maximum shelf-life (Estrada-Flores, 2008; James and James, 2010). As production from agriculture is projected to decline over much of the southern hemisphere by 2030 (IPCC, 2007), the value of perishables could increase and cold chain maintenance may become even more important than it is now to preserve food security (Estrada-Flores, 2008). Therefore, decreasing the dependence of food chains on refrigeration is unlikely to be a viable solution.

A more realistic approach to decrease refrigeration energy usage is the development and implementation of practices and technologies that achieve energy savings at different stages of the cold chain.

Systemic industry change for a low-carbon future could be achieved using a multi-tiered approach, whereby the ‘low hanging fruit’ opportunities prepare the industry for more radical actions. In the former tier, emphasis on preventive maintenance, review of refrigerated equipment standards, certification processes, food safety standards and maximum safe temperatures for cold chain management could be considered. In the second tier, the implementation of new energy labelling and MEPS in all links of the chain, the introduction of alternative refrigeration systems and the development of smart management systems could be considered.

Finally, the importance of science-based decisions in all the measures described above cannot be stated enough. In particular, cost-benefit calculations for energy saving technologies require a full investigation on the effects of variable temperature regimes on product quality and safety. The latter factors cannot be compromised in the name of environmental and financial pressures. Otherwise, the cold chain industry runs the risk of losing its very reason of existence.

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About Food Chain Intelligence

Food Chain Intelligence (FCI) is an Australian-based, niche consultancy business founded in 2007 by Silvia Estrada-Flores, Principal Consultant.

Our services reflect Silvia's background in food engineering, refrigeration and commercial R&D. Silvia has over 17 years of experience working in areas such as:

- Assessing the penetration and impact of emerging technologies in food chains.
- Safety and quality during the distribution of perishables, including risk analyses pinpointing the weakest links in perishable supply chains.
- Performance evaluation of refrigerated equipment (land-based and transport).
- Technology roadmaps.
- Feasibility of emerging industries (e.g. waste-derived bioactives).

Our clients are organizations working at any stage of the food supply chain, including growers, consumers and R&D organisations. If you would like to find out more about FCI, please contact us.

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