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Digital Technology and Agriculture: Foresight for Rural Enterprises and Rural Lives in New Zealand

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Abstract

The sustainability and resilience of rural communities in New Zealand in the face of changing circumstances and conditions is gaining increasing media and academic attention with trends towards, and prediction of, rural decline. New and emerging digital technologies are an important driver of global change, offering both opportunities for, and threats to, business, welfare, and social-ecological sustainability, including rural enterprises and rural communities. Some of these technologies will have incremental influences on changing enterprises and supply chains, however, others may potentially be very disruptive to the current New Zealand agricultural system, rural enterprises and value chains, and rural lives. The purpose of this paper is to 1) contextualise factors influencing technology development and adoption, 2) survey new and emerging digital technologies and, 3) foresight some potential implications for agricultural enterprises and rural communities in the next 20 years. Precision agriculture, agricultural robotics, computerised farm management decision support, and the digitisation of agriculture are changing the nature, efficiency and transparency of agricultural production. However, the digital farming revolution is occurring in the context of a wide range of co-evolving technologies (many also digitally based), and social and political change, which open up new meaningful possibilities for living and working in rural and remote locations. At the same time, the requirements of consumers are changing to reflect a greater focus on sustainable agriculture, ethical food production and delivery, the social conditions of employees, and quality assurance, nutritional value, and provenance of food.
There will be interplay between the evolving nature of rural lifestyles and rural enterprises wrought through technological development. Foresight endeavours, though fallible, may act as a springboard for rural residents to recognise and realise emerging opportunities and mitigate potential threats. Awareness of technological trajectories may help communities to strategically prepare for an increasingly digital future, enhancing their resilience and adaptability to inevitable change. Responsible technological development and responsible business practices will be key to engendering the increased trust and collaboration required amongst agricultural value chain participants in order to fully realise the potential benefits of digital agriculture.

Keywords: technology foresight; digital agriculture; precision agriculture; digital disruption; robotics; artificial intelligence; rural enterprise; rural lifestyles

1. Introduction

Recent media and academic attention to trends towards, and predictions of, rural decline, are raising questions about the sustainability and resilience of rural communities in New Zealand (Hawke et. al., 2014; Small et al., 2015, Spoonley, 2016). This issue is also a concern for other developed countries, including the US, England, Ireland, Australia, Japan and Canada. New and emerging technologies are an important driver of global change, offering both opportunities for, and threats to, business, welfare, and social-ecological sustainability, including rural enterprises and rural communities (Sustainable Development Solutions Network, 2013).

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New and emerging technologies, create the potential for new rural enterprises, enable rural residents to participate remotely in virtual work teams and environments, and enable new health, education, entertainment, recreation and life style opportunities in rural communities. Some of these technologies will have incremental influences on changing enterprises and supply chains; however, others may potentially be very disruptive to the current New Zealand agricultural system, rural enterprises and rural lives. An emerging theme in academic literature is the disruption caused in the business sector by digital technologies.

For example, Brody & Pureswaran (2015) identify five vectors of disruption created by the Internet of Things (IoT): 1) unlocking of excess capacity of physical assets, 2) creating liquid, transparent marketplaces, 3) radical re-pricing of credit and risk, 4) improving operational efficiency, and 5) digitally integrating value chains. Digital agriculture has the potential to utilise all five of these vectors.

Wayland (2015) claims that epistemological and ontological boundaries are redefined during revolutionary or disruptive technological system change. Philosophers of technology (e.g., Bunge, 1977; Jonas 1985; Lenk, 1983; Long & Blok, 2017; Luppicini, 2008; Moor, 2005; Small, 2011a), also propose that axiological boundaries may also be redefined by disruptive technologies). This implies that our understanding (epistemology) of what is (ontology), and what ought to be (axiology), are modified by new knowledge and new technological capabilities. I first consider some general influences on technological development, adoption and impact (Section 2), and then select a range of technologies to discuss at a broad systems enabling level (Section 3.1) and then identify technologies with a more proximal relationship to rural enterprises and rural lifestyles (Section 3.2).

The purpose of this paper is to 1) contextualise factors influencing technology development, adoption and impact,2) consider some new and emerging digital technologies and,3) foresight some potential implications for agricultural enterprises and rural communities in the next 20 years. An awareness of the types of technologies, the threats they might pose to the current agricultural system, rural business enterprises and practices, the opportunities they might open up for them, and their disruptive potential for both business and for rural living, will help rural enterprises and communities to strategically prepare and enhance their resilience to future change. Note that the focus of this paper is primarily on digital and related technologies – emerging biotechnologies, although very important for agricultural futures, are not the focus of this paper.

2.0 Factors Influencing Technological Development, Adoption and Impact

Individual technologies such as drones, robotics, driverless vehicles, remote sensing, Internet of Things (IoT), artificial intelligence (AI), virtual reality (VR), augmented reality and mixed reality (MR), will undoubtedly each play an important role in future rural life and rural business enterprises. However, perhaps the most significant impacts will be a consequence of disruption caused by the co-evolution, convergence and integration, miniaturization, cost reduction, and the adoption of a wide range of similar and complementary related technologies. An important crosscutting factor behind technological impact, which also needs to be recognised, is the exponential rate of development that is currently occurring in science and technology. Due to the pressing need for the development of a long-term sustainable agricultural system which respects planetary boundaries (Lal, 2007; Pimental and Sparks, 2000; Rockström, 2009;Steinfeld, 2006; Vitousek et al., 1986; Vorosmarty et al., 2004),and supports rural communities and market demands, technological development in these systemic areas will need to take into consideration local, regional, national and international values and ethics (Sustainable Development and Solutions Network, 2013). The technologies, and social ecological systems within which they are embedded, will need to, demonstrably, be morally and socially responsible.

Thus, according to the Sustainable Development and Solution Network "Countries can no longer pursue national policies independently of global standards. National governments and multinational companies have responsibilities regarding climate change, biodiversity, technology transfer, transparency and mutual assistance" (Sustainable Development and Solutions Network, 2013, p.4). This indicates the need for international collaboration in addressing the issue of agricultural sustainability. In order to foresight potential technological impacts on rural living and rural enterprises, technological co-evolution, convergence, integration, technological acceleration, disruption, collaboration, and moral responsibility, must be considered holistically.

2.1 Technological Co-evolution

Modern technologies do not develop in isolation from one another, rather they co-evolve or emerge together in an evolving or emergent technological innovation system (Hekkert et al., 2007; Lee, Olsen & Trimi, 2012).

Take for example the smart phone; in order for the smart phone to become a reality a range of different technologies were required and developed either in series or in parallel. These included, small superfast processors, high resolution touch screens, extremely tough gorilla glass, voice recording, voice recognition, voice synthesis, solid state digital data storage, miniaturised digital cameras, applications and interfaces appropriate to small screens, mobile broadband technologies (3G and 4G), optical fibre cable technology, the Internet, cloud based computing, sensors, GPS, and satellite communications.

A related example, documented in academic literature, is the co-evolution of software, hardware, network systems, web browsers and applications (D'Hondt et al., 2002). Similarly, technology co-evolves with industries and institutions (Nelson, 1993), and socio-cognitive constructs (Grodal et al., 2015). It has also been proposed that innovation is a product of the co-evolution of science and technology networks (Murray, 2002).

2.2 Technological Convergence

Nor do modern technologies remain independent of each other in innovative applications and technological developments designed to address business and social challenges or enhance human wellbeing and living conditions. Rather, technological co-evolution allows a space for technologies to **converge** around real world activities and pragmatic convenience (Lee, Olsen & Trimi, 2012; Jenkins, 2006). Thus, in the case of the smart phone, the technologies mentioned above converge around the need for human communication. Some of them, such as high resolution touch screens, voice recognition and synthesis, applications and interfaces, converge around how humans communicate, gather, process, and distribute information, and how they communicate and interact with machines. Other technologies, such as, superfast processors, mobile broadband, optical fibre technology, the Internet, cloud based computing, and satellites converge around rapid data processing and worldwide distribution of data and information. An important area for digital convergence is interoperability between applications, operating systems, network protocols, multiple cloud processing and data storage systems and proprietary organisational systems and data handling protocols.

There is a range of acronyms scholars have proposed to describe areas of current technological convergence. These include NBIC - Nanotechnology, Biotechnology, Information technology, and Cognitive sciences (Roco et al., 2004) and GNR - Genetics, Nanotechnology and Robotics (Joy, 2000).Technologies, such as the Internet, can enable innovative convergence to occur, creating new business models. This may occur through the grouping of services from different organisations under a single umbrella service, or along value chains, through collaboration between suppliers, manufacturers, banks, financial services, partner outsourcing firms, transport providers, distribution companies and consumers (Lee, et al. 2012).

2.3 Technological integration

These co-evolving, converging technologies may be **integrated** into innovative devices, systems, platforms, practices, and behaviours which increase human power over nature and the social world, enable new efficiencies, create new ways of doing things, and potentially, enhance the human condition. Smartphone integrate a range of the technologies discussed above enabling humans to virtually collapse space and time, instantly communicate with anyone (phone, text, social media, video) and anything (e.g., IoT) anywhere across the entire planet. We can instantaneously search databases worldwide for any recorded information, process data, observe distance places, persons and machines, remotely control machines, record conversations, take dictation, translate languages, watch and listen to entertainment, and augment reality with data and information.

In the field of agriculture a range of technologies (e.g., sensors) on different machines or devices may collect data on moisture, soil fertility, weather conditions, plant health etc. wirelessly streaming the data to cloud servers for analysis and prediction of harvest dates, yield quantities and quality. The cloud may provide feedback and decision-support to the farmer on his/her smart phone and send pertinent information to other clouds or parts of the value chain, where data from many different farmers may be collated and processed into information useful for transportation and marketing logistics, and the management of financial markets (Buckmaster, 2016; Clifford, 2016).

In order to implement an agricultural system such as that just described, integration of information from a wide range of different providers and different industries, using different cloud systems, different platforms, proprietary software and proprietary sensor technologies is required. Similarly, a wide range of different actors own or control different components of the value chain, different information and knowledge sets, and different parts of the overall systemic process.

Therefore, in this agricultural setting, collaboration is required amongst these actors in order for integration to occur (Buckmaster, 2016). To secure the collaboration of all necessary actors, integration must create mutual value for all the actors (Lee, Olsen & Trimi, 2012).

2.4 Miniaturization

When it comes to technology "small is beautiful", particularly in the digital world. Miniaturization of digital devices offers higher speed, lower cost and increased capacity (U.S. Congress, Office of Technology Assessment, 1991). Smaller size means devices occupy less space, can be transported more easy, have less resource and material requirements, lower energy requirements and can be mass produced in batches (Hsu, 2002). For example, Moore's Law predicted that the number of transistors on an integrated circuit doubles every (roughly) 18 months (Moore, 1965). Co-evolution of miniaturization of various devices means that they can be integrated together into a single devices. A consequence of this is that a modern smart phone, which fits easily in a person's pocket, contains a wide range of sophisticated sensors and functions, and has many times the processing power and storage capacity that the first computers (such as ENIAC – made in 1946),which occupied the space of several large warehouses. Indeed, Hsu (2002) claims that a palm-top computer from 2002 (much larger and slower than today's smart phones) had 10^8 reduction in size and a 10^8 increase in computational power over ENIAC.

Miniaturization helps makes technology available where and when it is needed. Nanotechnology is a relatively new area of science which takes miniaturization to its extreme, by focussing on the development of technologies at the nano scale level. Inspired by biology and the recently discovered DNA structure, the concept of scientific and technological miniaturization was first elucidated by the physicist Richard Feynman, in 1959,in a presentation to the American Physical Society. Nanotechnology is currently a major area of rapid technological growth. As well as a chemical synthesis or manufacturing processes (which nanotechnology is largely focussed on today) Feynman also speculated about the possibility of building small devices to make smaller and smaller devices eventually building devices molecule by molecule or even atom by atom (Feynman, 1960). The nano-technologies that are currently being developed are likely to have profound and disruptive effects on society that will spill over into the agricultural sector (Drexler, 1986; Mulhall, 2002).

2.5 Cost reduction

Over time, particularly as digital technologies miniaturize, not only has performance become exponentially better, but costs have dramatically reduced in real terms. Kurzweil (2004) argues that technological cost-effectiveness increases at an exponential rate. Solar PV cells are an example of a technology that is reducing exponentially in cost. Between 2009 and 2014 the cost of PV solar power reduced by 75% (IRENA, 2015).

Another example is the Human Genome Project. It took over ten years and cost nearly $US3 billion to sequence the first human genome. Originally the project was expected to take much longer, however, the development of new technologies enabled its early completion. Since the project finished in 2003, the science and technology to sequence genomes has continued to undergo exponential development. In 2014, a Californian company, Illumina released a state of the art sequencer, the HiSeq X Ten which it claims can sequence a whole genome, to industry gold standards, for a cost of US$1000. It is also claimed that the machine can sequence up to 18,000 genomes a year (Hayden, 2014). Oxford Nan pore Technologies have recently developed a miniature, handheld DNA sequencing device called the MinION. Carlson's Curve is the name given to the exponential (sometime hyper-exponential) cost reduction and performance that is currently occurring in DNA sequencing technology (Carlson, 2003).

Cost reduction of digital technologies is also following an exponential path(Kurzweil, 2004).However, the pace of cost reduction of semiconductors has varied over time dropping "…at an average rate of 22.5 percent per year over 1975-94 and at roughly double that pace over 1994-2001, before reverting to an average rate of about 28 percent over 2001-04" (Aizcorbe, 2006, Section 2).The exponentially decreasing cost of chip technology means that digitally based sensors, with application in rural enterprises, will rapidly become very cheap, making them an affordable enhancement for agriculture. Examples of other technologies which are currently undergoing exponential cost reductions are, battery technology, digital cameras, electric cars and Lidar (Seba, 2014).

2.6 The Law of Accelerating Returns

Some futurists claim that the rate of growth of scientific knowledge and technological development has been exponential throughout human history (Toffler, 1971, 1980; Kurzweil, 2004). Kurzweil calls this the Law of Accelerating Returns. This is a kind of generalisation of Moore's Law (which was originally only proposed for the density of transistors on an integrated circuit) to all technological progress. Supporting this concept, studies have found "…exponential relationships between performance and time or equivalently the fractional (or percentage) change per year is constant"(Benson, 2015, p.1).Nagy et al. (2013) found this to be approximately true for 62 different technologies for which they conducted an historical analysis.

Kurzweil (2004),who also conducted an historical analysis of technology progress, argues not only that technological progress is exponential, butfurther, speculates that progress during the 21st century will be equal to 20,000 years of progress at today's (i.e., 2004) rates. He claims that, although the empirical evidence shows that technological progress is actually exponential, our common-sense mind set is one of linear technological progress, and that this is why we generally tend to vastly underestimate technological change into the medium and distant future. Consistent with this analysis, Bill Gates claims "we always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next ten" (Gates et al., 1996).

2.7 Adoption follows a Sigmoidal Pathway

Adoption follows a sigmoidal pathway; exponential growth until approaching market saturation at which point it levels off. Prime examples of exponential adoption rates are mobile phones, Internet and mobile broadband adoption. World mobile phone adoption in 1985 was 750,000 or 0.02% of the then population of 4.9 billion people; by 1995 mobile penetration had reached 91 million subscribers or 1.6% of 5.7 billion people. By 2002 mobile phone subscriptions surpassed fixed landlines. By 2005, there were 2.21 billion mobile phone subscriptions, 33.9% of the 6.52 billion world population. In 2015, there were 7.1 billion mobile phone subscriptions approaching 95% of the world's 7.3b population (ITU, 2015).

In August 1991 the first World Wide Website (i.e. website = a unique host name) was created by Tim Berners-Lee. By March 2016 there were more than 1 billion websites. In 2013alone the number of websites grew by one third from 630 million to over 850 million. Internet use has followed a similar exponential pattern. In 1993 there were 14.2 million users, by 2000 this number had increased 413 million users, by 2008 there were 1.6 billion users, and by 2015approximately 3.2 billion users or 43% of world population (Internet Live Stats, accessed 2016).These figures suggest that digital technology adoption has reached the late majority of adopters and that the world is now 'digitally turned on' – digital technologies are no longer the preserve of innovators or early adopters.

Currently the Internet is transforming into the Internet of Things (IoT). Although estimates vary, as do the definitions of connected devices, estimates for 2012 were 8.7 billion connected devices (Statista, 2016). In 2015estimates were15 billion connected devices, with projections of up to 50billion connected devices by 2020 and value estimated at $19 trillion from 2013 to 2022 (Bradley et al., 2015). Despite this incredibly rapid adoption, the futurist Keven Kelly (Editor of Wired Magazine) claims that currently the Internet is only at the very beginning of the services that it will offer, that is, it has not begun to reach full potential yet (Kelly, 2016).

Mobile broadband (broadband access across cellular networks) has become increasingly popular since the advent of 3G and 4G networks and the smart phone. Faster network speeds enable a faster and more pleasant user experience for surfing the net or downloading content on mobile devices. It is estimated that approximate 69% of the world's population had 3G coverage in 2015. On a global basis the cost of mobile broadband decreased by 20-30% between 2013 and 2014. Adoption of mobile broadband is proceeding even more rapidly than the adoption of mobile phones did. From a beginning in 2007, by 2015 approximately 47% of the world's population had a mobile broadband subscription (ITU, 2015)

This section and the sections above on miniaturization and cost reduction provide examples of exponential technological acceleration in digital, genetic, solar and energy fields, in terms of size, power, density, speed and cost. These factors converge and integrate into the development of new innovations and technologies for accomplishing old tasks better or for doing new desirable things that were not previously possible. As the use benefits, convenience, power, and cost of the new technologies converge to appropriate levels, their adoption starts to accelerate in the typical sigmoidal adoption curve.

Once a product or technology reaches this point of market readiness, as can as seen above, adoption can be extremely rapid in the 21st century. The sigmoid function of adoption exhibits exponential growth until approaching a ceiling caused by market saturation of the product.

2.8 Sustaining or Disruptive Innovations

The theory of technological disruption is generally attributed to Bower and Christensen (1995). They made a distinction between sustaining technologies and disruptive technologies. Sustaining technologies "tend to maintain a rate of improvements; that is they give customers something more or better in the attributes they already value" (p.45). Disruptive technologies "introduce a very different package of attributes from the one mainstream customers historically value" (p.45). Initially, the new disruptive technology may be inferior on the historical market valued attributes, or introduce new attributes not generally desired by existing markets, and only be attractive to niche markets or for new applications and new markets. Christensen et al. (2015) claim disruptive innovation can take hold in two different types of markets; niche low-end markets where a low cost good-enough product satisfies less demanding customers, and new markets where the innovation is targeted at a market that is not currently catered for. If the new technology makes very rapid gains in performance, either for the old valued attributes or for new applications, then the new technology has the potential to undermine and overtake the old technology, and in some cases, make it obsolete.

A good example of a disruptive technology is digital photography. This technology was invented by Kodak in 1976, but initially the quality of a digital image was far inferior to film and did not fit with the performance requirements of Kodak's main customer base. Because of this, Kodak did not aggressively pursue the introduction of digital photography. Nonetheless, the just good enough image, the ability to review images immediately on camera, and to store and transfer images digitally, was attractive to a niche market. Overtime, the performance quality of digital photography rapidly increased to the equivalent of film while also rapidly falling in cost. The consequence was that digital photography has nearly completely disrupted and overtaken the photography industry to the point now where film is almost obsolescent. Kodak, because of their focus on their profitable paper and chemical photography business, were late to the digital photography platform, missed the opportunity to capitalise on their invention, and as digital photography took over from film, Kodak went bankrupt in 2012 (Diamandis, 5th June, 2016).

"Digital disruption refers to changes enabled by digital technologies that occur at a pace and magnitude that disrupt established ways of value creation, social interactions, doing business and more generally our thinking" (Reimer, 2013). Thus, digital technologies will disrupt both business and lifestyles. In the business world digital technologies present both a threat and an opportunity. The threat to existing businesses is that they may be undermined, out-competed and have their current business models invalidated. The opportunity is for the creation of new innovative business models that compete with established organisations or industries. According to the Global Center for Digital Business Transformation "digital disruption now has the potential to overturn incumbents and reshape markets faster than perhaps any force in history" (Bradley et al., 2015, p1).

Digital technologies have already had a major impact on business and business models in the 21st Century. The largest, fastest growing and highest value companies in the world are primarily digital technology companies or companies with a business model enabled by digital technology (Carter, S. cited in Kennedy, 2015).

- Uber – world's largest taxi company owns no taxis (founded March 2009), 2016 value - $US62.5b
- Airbnb – world's largest accommodation supplier owns no real estate (founded August 2008), 2016 value- $US25.5b
- Skype (founded August 2003), Wechat (founded January 2011) – world's largest phone companies own no telco infrastructure, value when purchasedby Microsoft in 2011 - $US8.5b
- Alibaba – world's most valuable retailer has no inventory (founded April 1999)
- Facebook – world's most popular media owner creates no content (founded February 2004),2016 value - $US212B
- SocietyOne – fastest growing banks have no actual money –peer2peer lending (founded May 2011), value 2016 - $US100m
- NetFlix – world's largest movie house owns no cinemas (founded as a mail order DVD service in 1998, became a streaming service in 2007)2016 value -$US32.9b

- Apple (founded April 1976, 2016 value - $US535b) and Google (founded January 1996, 2016 value -$US650b) – largest software vendors don't write apps

Note that despite the rapid rise of these companies, enabled by the advent of digital technologies, they do not necessarily fit the criteria of "disruptive innovations" as described by the theory of disruptive innovations.

In a recent article considering developments to the theory over the past twenty years, Christensen et al., (2015), discussed the case of Uber. While noting that Uber is almost always described as disruptive, they argued that it is a sustaining innovation, in that it did not enter the market through a niche market or through a new market, and then, as improvements occurred, capture the traditional taxi market, as prescribed by the theory. Rather, the Uber digital innovation provided a service to the traditional taxi market from the beginning.

Christensen et al., (2015) classify Netflix as a disruptive innovation, in that the initial mail order DVD service was not attractive to Blockbuster's mainstream impulse customers, only attracting a niche market. However, the transition to a high quality, cheap, on demand, streaming service met the requirements of Blockbuster's mainstream customers, disrupting their business model. Christensen et al. (2015) do, however, note that Uber may be disruptive to the limousine or "black car" business. This suggests that innovations can be disruptive with regard to some industries or sectors of industries but not to others.

Nonetheless, it is clear that digital technologies have enabled completely new business models, in all the above industries, which have revolutionised how their services and products are marketed and delivered. Despite the dominance of these businesses in their particular industries, with the exception of Apple, all of these business megaliths began life after 1996 and most did not start until the 21st century. What this makes clear is that, once the conditions are right, digital technologies can cause mega-changes to the business environment in less than a decade. The Global Center for Digital Business Transformation claims that "the difference between digital disruption and traditional dynamics comes down to two main factors: the velocity of change and the high stakes involved" (Bradley et al., 2015). This is a slightly different interpretation to Christensen et al. (2015), who assert that disruption is a process involving evolution of the product or service and that this occurs over time and this temporal element means that incumbents frequently overlook disrupters.

In regard to agriculture, much of the innovative application of digital technologies could be classed as "sustaining innovations", that is, digital technologies are primarily being used to enhance and improve current agricultural practices and products making them and current farm systems more efficient and productive. Thus, digital and precision agriculture may not necessarily be classified as disruptive, in the sense prescribed by the theory (Christensen et al., 2015). However, digital agriculture will change how farmers work (e.g., farmers as knowledge workers), the type of education and training requirements they need to operate in a digital environment, where they get their information from, the amount of human labour required on farm, and how they reach and communicate with consumers of their products. Although digital agriculture may be largely a sustaining innovation on-farm, it may be disruptive with respect to agricultural value chains, allowing farmers to by-pass some of the current actors and shorten value chains (Buck master, 2016; Whitehead, 2016).

An example of this approach which ties together the use of the Internet, a web-based computer application, ethical farming, animal welfare, transparency, provenance, and shortened value chains, is the company Crowd Cow. Crowd Cow uses the crowd funding concept to enable a group of people to purchase a cow from a local rancher (meeting the appropriate requirements) by ordering on-line the amount and cuts of meat that they want. Once enough people have lodged an order to purchase a whole cow, it is butchered, the meat aged, and then specified cuts are delivered to their purchasers, with no supermarket involved (Duggins, 2016). Crowd Cow illustrates how digital technologies may enable new business models and reshape value chains, bringing the producer and consumer closer together.

2.9 Collaboration and trust

The agriculture/food supply chain has four main sectors: 1) Input (e.g., seeds, feed, chemicals and equipment) and production (field crops, horticultural crops, animals, and seafood), 2) food processing (manufacturing and packaging), 3) distribution and retailing (wholesalers, supermarkets, and retailers) and, 4) consumption (restaurants, institutional food services, and households) (Berti & Mulligan, 2015). There are a large variety of different companies and actors in each of these sectors of the agricultural supply chain.

Different companies compete with different software platforms, different clouds, different applications and programs along with data and information from a variety of other sources such as weather, financial markets, benchmarking, expert knowledge and advice, and auditing including compliance and quality assurance. This means that in order for digitisation of the agricultural value chain to successfully occur, inter-operability standards must be developed between platforms and software (to enable data integration) and companies and individual actors must be prepared to collaborate and share data and information.

Collaboration and information sharing requires trust between the various participants and trust that the technologies (e.g., sensors for data collection, decision-support software, cloud based computing services etc.) are secure and perform their functions reliably and accurately (Buckmaster, 2016; Henry, 2016; Whitehead, 2016). Trust between value chain participants (and perhaps continued participation) will only be maintained as long as each participant perceives that they receive their fair share of the added value (Lee, Olsen & Trimi, 2012).

2.10 Responsible technological development

New technologies, by opening up new, previously unachievable possibilities and behaviours, also create new moral dilemmas regarding the applications that the technologies could potentially be used for (Jonas, 1986;Lenk, 1983; Luppicini, 2008, Moor, 2005;Small, 2011a&b; Small & Fisher, 2005; Small & Jollands, 2006). For example, in order to enhance resilience of rural communities and enterprises the use and application of relevant new technologies needs to fit within the moral imperative of sustainable development (Small, 2007; FAO, 2012). Sophisticated markets and food retailers are beginning to insist that the products they purchase must be produced in a sustainable and ethically acceptable fashion(Isenhour, 2012).Within academia there is growing interest in 'Responsible Research and Innovation' (RRI) which is defined as: [A] transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society) (von Schomberg 2011, P.9).

Over the past few decades growth in ethical food consumption (e.g., high animal welfare standards, sustainable environmental practices, fair trade certified, organics, and locally grown) has increased (Dowler, 2008). New experimental evidence is increasingly undermining society's Cartesian mechanistic norms regarding animals i.e., the denial of internal experiences and consciousness in animals and the consequent lack of attribution of moral status to them (De Waal, 2016). Thus, science is slowly beginning to force a revision of human attitudes to animals and the manner in which humans use and treat them and our moral relationship with them (Singer and Mason, 2006).

Although still a relatively small percentage of the market, global fair trade sales outpaced the growth of conventional food, growing by 20% in 2012 (Fairtrade International, 2013). New digital technologies offer the potential for increased traceability of products from their place of origin to consumption, giving tools for moral choice to food consumers (i.e., paddock to plate, field to fork) (IFCITP, nd; Spelitis, 2015, 17th March). Although traditional customer values such as price, quality, speed and customization remain essential, customers are now requiring additional product attributes like experience, emotional fulfilment and public good (Lee, Olsen & Trimi, 2012).Food safety, sustainability, provenance and animal welfare are rapidly growing consumer concerns. Therefore, in technological foresight, with respect to resilient rural enterprises and communities, there must also be a focus on responsible technological development, ethical practice, and their application to produce ethical products, acceptable to wealthy and informed consumer markets.

3.0 Relevant emerging and future technologies

In the sections below, some existing and emerging technologies and practices, that may have significant impacts on rural communities and rural enterprises, are identified. These technologies may affect the lifestyles of rural residents and their access to services, rural enterprises and business practices, future farm systems, and producer to consumer marketing systems. The co-evolution, convergence, and integration of emerging technologies may have profound implications for rural businesses and lifestyles, and need to be taken into account when planning and strategizing for resilient rural communities across the social, economic, ecological and cultural domains.

Of course, it is difficult, if not impossible to predict the future. Unknown, unforeseeable conditions and events arise, and they cannot be factored into future projections. However, a famous quotation attributed to the cyberpunk author William Gibson suggests a method through which an attempt at future projection may be made "The future is already here, it's just not very evenly distributed" (cited in Rosenberg, 1992).

What will later be the future for the majority is now largely the province of visionaries, and innovators at the edges of mainstream business and in laboratories around the world providing demonstration of 'proof of concept'. The minority who are currently developing or using new and emerging technologies in potentially disruptive ways can give us an idea of where the majority's future lies. Nonetheless, a degree of caution in this endeavour is required, as Christensen et al. (2015) remind us that "success is not built into the definition of disruption: Not every disruptive path leads to a triumph, and not every triumphant newcomer follows a disruptive path" (p.4).

Before considering new and emerging technologies and the use to which innovators are putting them, first I draw a distinction between 1) technologies that have a very broad enabling function for, 2) a whole range of other new or emerging technologies more proximally useful for rural life and rural enterprise.

Enabling Technologies

Consistent with the concepts of co-evolution, convergence and integration is the idea that some technologies enable other technologies to operate or function (and conversely that some technologies require other enabling technologies). Sometimes enabling technologies are referred to as General Purpose Technologies (Lipsey et al., 2005). Once these enabling technologies are developed and implemented, rapid development and adoption of other useful dependent technologies occurs, often from diverse technological fields. The Internet is an example of an enabling technology.

In contrast some emerging technologies have more immediate or proximal effects on rural enterprises or rural life. Thus, decision support software helps a farmer decide what to do, social media and business software enhance personal and business communications. Admittedly, this distinction is somewhat artificial, in that most technologies enable something else to be done. Thus, while high speed computers and broadband enable Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) technologies, these technologies enable new education, health, recreation, business, and social activities. The distinction also suggests a linear relationship between the technologies which will not always be the case as feedback loops will exist. Clearly, high speed computers and broadband connectivity is a necessary or enabling technology for a large range of emerging digital technologies with application in agriculture and rural life.

Universal Ultrafast Mobile Broadband

Currently, the Internet does not serve some New Zealand rural populations well – their connectivity is hampered by low reliability, poor quality and low speeds. Good quality broadband connectivity (i.e., reliable and high speed) is essential for digital agriculture. Once rural areas have access to high speed broadband then use of the Internet of Things (IoT) and cloud data storage and processing technologies become practical and useable to rural enterprises and rural residents. This will enable context relevant measurements (e.g., from animals and the environment) through embedded wireless sensors uploading to the cloud. Once in the cloud, the use of Artificial Intelligence (AI) to interrogate the voluminous data generated will help model development for use in decision support software, automation technologies, and producer- value chain-consumer communications across a range of digital devices (e.g., phone, tablets, notebooks, desktop PC's) (Buckmaster, 2016; Clifford, 2106; Henry, 2016).

The use of these digital technologies has the potential to increase efficiency of current agricultural practices and disrupt agricultural value chains, enabling relatively small business enterprises to compete both locally and globally through the "creation of reliable, secure, robust and economically sustainable 'short' supply chains" (Berti and Mulligan, 2015, p. 5). High speed broadband also makes technologies such as social media, VR, AR, MR, tele-health, tele-education, tele-recreation and virtual democracy usable and convenient for rural populations. These technologies, which help reduce the tyranny of space and time, will help remove the isolation and inconvenience that currently makes rural living unattractive to many people.

It likely that the next ten years will see the development of high quality, ubiquitous, world-wide broadband connectivity. For example, the OneWeb project aims to have a system of 648 low earth orbit satellites providing universal world-wide broadband coverage. They plan to start launching their satellites in 2018. Their goal is to: "To fully bridge the Digital Divide by 2027, making Internet access available and affordable for everyone."(OneWeb, 2016, Para 3). Elon Musk's Space X rocket company has similar plans to provide universal mobile broadband with a network of 4,425 satellites proposed to be launched between 2019 and 2024 (Galeon, 2017a). Samsung has proposed a similar plan with 4,600 satellites, and both Facebook and Google are also developing their own plans for universal mobile broadband (DiStasio, 2017).

The current standard for fast mobile broadband is 4G. However, 5G is being tested by IT companies and it is claimed that 5G networks will start appearing in 2020. 5G will be between 10 to 100 times faster than 4G. Entire movies will download in a second; such speeds will be fast enough to support data intensive virtual, augmented, and mixed reality, immersive Internet and autonomous vehicles. It will have sufficient bandwidth to enable the exponential growth of connected devices to the Internet (the IoT), wearable devices and smart homes.

The main tenets of 5G development are extremely low latency, multi-user and multi-stream connections and pervasiveness - superfast broadband everywhere (GSMA Intelligence, 2014).Currently, in the laboratory, new wireless technologies are being trialled that offer speeds up to 100 Gb/sor 10 times as fast as 5G (Nordrum, 2017). This proof of concept indicates data transmission speeds will continue to increase exponentially for at least the next ten years.

Wireless Technologies, Wireless Sensor Networks And The Internet Of Things

Wireless technologies and wireless sensor networks are also an essential underlying part of digital agriculture. As noted earlier, the IoT will connect almost every imaginable machine and device to the Internet, building data collection and intelligence into the connected devices. With estimates of 50 billion connected devices by 2020 and a total value at stake of $19 trillion from 2013 to 2022, the IoT, or as it is sometimes referred to, the Internet of Everything (IoE), is poised to revolutionise all aspects of industry and human life (Bradley et al., 2015).

Sensor technology performance is developing rapidly and cost is declining exponentially. Accurate and reliable sensors will enable measurement of a wide range of farm and environmental data. With smart sensors embedded in devices on animals, in fields, in soil, in buildings, in machines, in drones, and in phones, enormous quantities of data will be able to be collected and wirelessly transferred to cloud storage and processing systems. Through the use of big data analytics, I learning algorithms, Deep Learning, machine learning reinforcement and interdisciplinary science models, the data will be transformed into sophisticated models of agricultural systems and useable information for timely decision making and decision support by people and business all along the value chain, from farmer to consumer (Buckmaster, 2016; Clifford, 2016).Development of the IoT is currently occurring at an exponential rate. This expansion of the IoT will see the amount of data available for big data analytics increase on a similar exponential function.

Cloud Computing – Cheap Data Storage and Information Processing

The cloud provides a convenient medium on which to store and process large amounts of data. The National Institute of Standards and Technology (NIST) defines cloud computing as "…a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell & Grance, 2011).

The cloud provides Software as a Service (SaaS) to consumers. This means that the cloud provides network infrastructure and software that consumers can access and use without needing to own themselves. This is akin to the concept of a computing utility service provider. Cloud computing can also provide Platform as a Service (PaaS) and Infrastructure as a Service (IaaS).

There are four main models of cloud deployment: Private Cloud (owned and managed by a private company e,g., John Deere, Monsanto), Community Cloud (setup and managed for exclusive use by a specific community of consumers), Public Cloud(available for public use provided by business, government, or universities e.g., Dropbox, Amazon Web Services and Elastic Compute Cloud, Google App Engine, Microsoft Azure) and, Hybrid Cloud (multiple, standardized, inter-operable clouds enabling portability of data and applications) (Mell and Grance, 2011).

The advantages of cloud Computing are listed by Zang et al. (2010)as: no up-front investment by the consumer, lower operating costs, it is highly scalable, easily accessible by multiple devices, and it reduces business risks and maintenance expenses. An issue with cloud computing is concern about the security of data and information. Essentially, this is a question of service provider competence and care, and consumer trust in the security systems of the infrastructure, platform, and application service providers.

Cloud technology and services are developing very rapidly and their uptake and value is currently in hyper-growth. There is a range of estimates and projections of the value of cloud computing. Forrester believes that business spending on cloud computing will expand from $US72 billion in 2014 to $US191 billion by 2019 (Cited in Pardo et al, 2016). International Data Corporation (IDC) projects that the market in 2017 will be $US107 billion, twice the value it was in 2013(Cited in Pardo et al, 2016).

3.1.1 Artificial Intelligence, the Singularity, and Super Intelligent Machines

Artificial intelligence (AI) can be defined as the science of making computers do things that require intelligence when done by humans.

Early work in AI was based on the conjecture that "…every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it" (McCarthy, Minsky, Rochester, & Shannon, 1955, p. 1). Turing (1950)was one of the first to address the question, "Can machines think?" by 'machines' Turing was referring to digital computers – not the ones available in 1950, but rather whether it would be possible for any digital computer to ever think. To answer this question Turing proposed the "imitation game" now referred to as the 'Turing test'.

Stimulated by Turing's ideas, the project to create AI has since taken many paths, had numerous setbacks, but since the beginning of the 21st century has experienced exponential growth and success. Many of the different paths and approaches to AI have contributed knowledge or solved specific types of AI problems, but even in combination, none has so far been able to produce a computer with the general intelligence capability of humans (Kelly, 2014). Current AIs are classified as narrow (NAI), which means that they are good (often better than humans) at learning a particular task (e.g., interpreting radiology images, diagnosing skin cancers and eye diseases, recognising human faces). General AIs (GAI) is the term for an AI that can learn across a wide range of areas (as can humans).

Nonetheless, striking progress has been made. Machine learning, the convergence of parallel processing, big data sets and learning algorithms, to find patterns and meaning in unstructured data, is having significant success. Major digital technology companies, such as Microsoft, Amazon, Google, Facebook, Twitter, Pinterest, Yahoo, Intel and Drop box are investing large sums of money into creating AI. More than $US17 billion was invested in AI between 2009 and 2014.

Neural networks and advanced statistical techniques (referred to as Deep Learning) and machine learning reinforcement are achieving feats once believed to be science fiction. IBM's supercomputer, Deep Blue, beat Kasparov, the world champion chess player at the time, in 1997. Watson, another IBM supercomputer defeated the two world champion humans at the game of Jeopardy in 2011(Kelly, 2014).Just recently Alpha Go, utilising Google's Deep Mind AI, beat the world champion human at the more complex, less structured game of Go, not by being programmed with the rules of Go, but rather by playing games against humans and learning to play through reinforcement as a human would (Metz, 2016).

Data volume is one of the keys to advancing AI capability. It is estimated that the digital universe contained 4.4 Zettabytes of data (1 Zettabyte equals one trillion Gigabytes) in 2013 and that the volume of digital data doubles every 2 years, meaning that by 2020 the digital universe will contain 44 zettabytes of data (IDC, 2014). However, 70-80% of the data is in the form of unstructured images and text, referred to as dark data, and has been difficult to use in data analytics. Recent developments in AI (e.g., Stanford's DeepDive dark data project) are enabling dark data to be classified making it useful for analysis.

Artificial Intelligence has enabled pattern and image recognition to a point where facial recognition software is as accurate as the best humans at the task and is being adopted for security purposes such as making payments, entering buildings, and securing devices. Recently the Australian Government announced that it is planning to usefacial recognition technology to remove the need for passports (Hunt, 2017).AI will become increasingly pervasive, for example, a Russian facial recognition software company, NTechLab, claims to be able to detect emotions (anger, stress, nervousness) on faces on surveillance cameras that may enable the detection of people about to commit criminal acts (McGoogan, 2017). The concept of ultra intelligent AI was first suggested by Good (1965), who proposed that once computers surpassed human level intelligence their ability to create smarter computers would surpass humans. Good claimed there would then be an exponential explosion in machine intelligence as the computers designed better computers and these computers designed even better computers, leading to what he described as ultra intelligent computers. This process is referred to as 'recursive self-improvement'.

This concept of the exponential explosion of machine intelligence to super intelligence is frequently referred to as 'the singularity' a term coined by Vinge (1993). Bostrom (2014, ch. 2) defines super intelligence as "any intellect that greatly exceeds the cognitive performance of humans in virtually all domains of interest". Based on Moore's Law, Kurzweil (1999, 2005) predicts that desktop computers will reach human level general intelligence by 2029 and that the singularity will occur in 2045.A survey of four groups of ICT and AI experts (n=550) found the median estimate of respondents was for a one in two chance that high level machine intelligence will be developed around 2040-2050, rising to a nine in ten chance by 2075 (Müller and Bostrom, 2014).

Several very prominent scientists, technologists and philosophers are so convinced by the possibility of super intelligent machines that they have issued warnings to the world about their potential existential threat to humanity (Bostrom, 2014; Hawking et al., 2014; Joy, 2000,). Elon Musk, Steve Wozniak and Bill Gates have also expressed similar concerns (Sainato, 2015). For the purpose of this paper it is not necessary to speculate whether super intelligent machines will possess consciousness or sentience, as these attributes are not necessary for machine learning and intelligence or even super intelligent understanding of a system.

Computers are already capable of many apparently intelligent activities such as language translation which requires natural language processing (knowledge of at least two languages), reasoning to following the content or argument, knowledge to know what is being talked about and social smarts in order to understand the author or speaker's intent. Smart phones already have 'somewhat' intelligent personal assistant programs that can respond to voice commands and answer questions e.g., Apple's Siri, Microsoft's Cortana, Google Now, and Amazon's Echo. Such systems continue to grow in both power and usefulness to humans. Self-driving cars are another example and current application of AI.

As AI converges with progress in robotics, cloud computing and precision manufacturing, tipping points will arise at which significant technological changes are likely to occur very quickly. Crucially, advances in robot vision and hearing, combined with AI, are allowing robots to better perceive their environments. This could lead to an explosion of intelligent robot applications — including those in which robots will work closely with humans. (Nature editorial, 2016, p.413)

Continued progress in AI is dependent upon increasing performance from both hardware and software. Although some question how much longer Moore's Law can continue to be true, computational power is still increasing rapidly and developing technologies such as multifunctional chip circuits, grapheme based microchips and quantum computers still potentially offer vast improvements in hardware performance. Regarding the software, learning algorithms are continuing to accelerate in power and performance (Kurzweil, 2005; Bostrom, 2014). Artificial Intelligence is developing at an exponential rate, machines are becoming smarter and capable of doing more human like activities and this fact will have a very large impact on jobs and employment including rural enterprises and rural lifestyles. Wireless sensor networks will provide mega quantities of data, which in combination with information from other sources, scientific models and the learning algorithms of cloud based AI, will be able to 'understand and model' the data, transforming it into useful information and predictions, helping farming enterprises with decision support and farm automation.

There are many major businesses, as well as innovative start-ups, developing farm management technologies which integrate remote or embedded sensors with cloud computing and artificial intelligence to provide tools for improving farmer decision-making and increasing farm efficiency. Amongst others, this includes: The Climate Corporation, John Deere, Monsanto, Dupont, NuFarm, WinField, SST Software, Mapshots, Raven, Trimble, Ag Gateway, Agsolver, Ag Link, Delta Agribusiness, Precision Ag, Hortus Technical Services, Conservis and Ag Leader (Buckmaster, 2016; Clifford, 2016; Pawsey, 2016). It seems highly likely, given this drive towards digital agriculture by these major players and innovators combined with the need to increase the efficiency and sustainability of agriculture, that it is only a matter of time before these digital technologies are adopted across the agricultural sector.

AI, cloud computing, sensor technologies, the IoT and ubiquitous broadband will also enable new forms of recreation, collaboration, and socialisation, especially in combination with virtual, augmented and mixed reality technologies. They will provide new mediums for delivery of remote healthcare, innovative education services, and political deliberation and governance. These technologies will open new opportunities for rural work and rural lifestyles. On the other hand, it has been estimated that AI and robotics will automate 47% of current jobs in the US, 35% in Britain and 49% in Japan. Automation will occur not only in unskilled jobs but also in the professions. For example, Ross, is the world's first artificially intelligent attorney, based on IBM's Watson computer.

The law firm, Baker & Hostetler, announced that they will be employing Ross for their bankruptcy practice, currently comprised of almost 50 lawyers (de Jesus, 2016). Whether new jobs will arise to replace those that disappear (as has happened in the past) is an open question (The Economist, 2016).

3.1.2 Sustainable Energy Generation and Storage Technologies

Fossil based fuels are a significant cause of global climate change necessitating the need for a massive move to renewable and sustainable energy generation to keep atmospheric CO_2 within a safe operating space for humanity (Rockström et al., 2009). It is clear now that solar photovoltaic (PV) offer the potential to largely solve humanities energy requirements renewably and sustainably. Crystalline silicon PV cells have been declining exponentially in cost per unit of energy generated. In 1976 the cost was $US76 per watt. By 2000 it was $US5 per watt. In 2015 the cost had reduced to $US0.30. Sustainable PV electricity generation is now commercially competitive with fossil fuels; it has already reached cost parity with grid electricity in 40 countries and is projected to reach grid parity in over 50% of nations by 2017(Kalkman et al., 2015). As the cost of crystalline silicon PV has declined exponentially, adoption has increased exponentially since 2007, doubling every year, amounting to a tenfold increase in 7 years (Green, 2014). Currently, over 90% of installed PV capacity is crystalline silicon PV (Kalkman et al., 2015).

However, there are a large number of new PV technologies currently being developed and tested in laboratories around the world that may revolutionise solar energy production, making it even more efficient, affordable and practical. Six of the most promising and potentially disruptive (to crystalline silicon PV) new PV technologies are: 1) cadmium telluride thin film, 2) Copper indium gallium selenide (CIGS) thin film, 3) concentrated photovoltaic (CPV) and multi-junction solar cells, 4) organic photovoltaic (OPV), 5) quantum dots photovoltaics, 6) Perovskite PV and, 7) graphene PV (Kalkman et al., 2015). Current estimates are that solar PV could supply a quarter of total global energy capacity by 2035 (Green, 2014).

Other futurists are even more optimistic. Because of solar PV's exponential technological development and exponential cost reduction, Kurzweil considers that the technology will be truly disruptive, that over 50% of the world's electric generation capacity will be provided by solar by 2030(cited in Green, 2014). Seba (2014)is even more optimistic, projecting that by 2030, oil, coal, nuclear, natural gas, electric utilities and conventional fossil fuel cars will all be obsolete, that nearly all new cars manufactured in 2030 will be electric and self-driving and nearly all electric generation will be solar.

Battery technology, the ability to store energy for later use, has been a major impediment to the development of sustainable and renewable energy generation through solar and wind technologies. Solar only provides power during daylight and wind generation can be erratic. Energy dense batteries could help facilitate the use of solar and wind generation by storing power in battery banks in the grid or by storing power at people's homes, for use when wind or sun are not available (Seba, 2014).

Battery technology is a major focus of research with a large number of different and new and potentially more efficient battery technologies being developed and tested(Science Daily, 2016). The need for better batteries to power electric cars has driven development in battery technology with the spin-off being that it is now possible to make affordable battery storage units for homes and for grid energy storage. Tesla is currently marketing the Tesla Powerpack (Tesla, 2016a) which is a commercial and utility energy storage battery and the Tesla Power wall (Tesla, 2016b) which is a home battery.

The Power wall makes off the grid living for rural residents feasible and economic. It can also be used with a grid connection to draw energy in low demand periods when power is cheaper, to be used during peak demand periods. Recent research by the father of the lithium ion battery, John Good enough, and colleagues looks positive for the development of a safe, solid state lithium or sodium glass battery with a long cycle life and up to 3x the energy density of lithium ion batteries (Anderson, 2017; Braga et al, 2017).

When integrated together, solar PV and new battery technologies are potentially disruptive to the centralised grid based electricity generation system. It is becoming cheaper (over the lifetime of the equipment)for houses to generate and store their own electricity than to receive power from the grid. Although PV and batteries could also be used to complement and enhance grid based energy services by feeding power back into the grid at peak demand. Essentially, the future of electricity generation will be distributed. Distributed generation will make electricity use more efficient (less loss of power in transmission) and also enhance an energy system's resilience to catastrophic failure (e.g., Chernobyl), shocks of nature (e.g., Fukushima) and acts of terror.

Rural enterprises and residents need no longer rely on the grid, thus enhancing their resilience to nature's threats. However, when connected to the grid, solar PV, wind generation, and batteries are enabling the creation of new rural enterprises, such as energy farming.

3.1.3 Nanotechnology and material science

As mentioned in the section on miniaturisation, the field of nanotechnology is undergoing rapid development and generating a wide range of new materials with exotic properties and a range of new machines and devices. For example, in the field of solar PV, both quantum dot technology and grapheme technology are nanotech based. Nanotechnology is finding applications in fields as diverse as energy generation and storage, computing, communications, cosmetics, new foods, food safety, medicine, environmental science, transportation, sensors of all kinds, material science, and more efficient and greener industrial processes (National Nanotechnology Initiative, nd).

A range of applications for nanotechnologies in agriculture have been proposed. These include, 1) nanopesticides and nanofertilisers to improve productivity, 2) nanozeolites, hydrogels and nanoclay to improve soil quality, 3) nonmaterial (SiO_2, TiO_2 and carbon nanotubes) to stimulate plant growth and, 4) wireless nanosensors to provide smart monitoring(Fraceto et al., 2016). Wireless nanosensors are particularly relevant to digital agriculture, not only on the farm but all along the agricultural value chain. On-farm and in the field nanosensors can be used to control quality, monitor bio security and biodiversity, measure soil parameters such as pH, nutrients, residual pesticides in soils and crops, soil temperate and humidity, detect pathogens and pests, predict nitrogen uptake, and manage irrigation(Bellingham, 2011).

Nanosensors will help farmers manage their farms with precise knowledge and control, minimising inputs, maximising productivity, and reducing environmental impacts and waste (Fraceto et al., 2016). Nanosensors have the potential to play a pivotal role in making agriculture sustainable. Post-farm nanosensors will play a role in transportation, food processing, packaging, and distribution (Scognamiglio et al., 2014). Through their ability to detect a wide range of target molecules, nanosensors will play an important role ensuring "food quality, safety, freshness, authenticity, and traceability along the entire food supply chain" (Fraceto et al., 2016, p. 3).

In the most visionary and utopian projections, it is claimed that nanotechnology will herald an age of plenty sometimes referred to as the post-scarcity economy; small, even home based, manufactories or molecular assemblers will produce any item anyone wants, building them molecule by molecule (Dexler, 1986). Although manufactories and molecular assemblers do not as yet exist, nonetheless they may be important factors to consider in a more distal future (Nano factory Collaboration, 2016).

3.1.4 Block chains – Digital Security

Blockchain technology is touted as having the potential to revolutionise banking and financial systems by reducing the cost and complexity of transactions and improving transparency and regulation. However, its potential uses extend far beyond the financial sector. The Harvard Business Review defined blockchain as "a vast, global distributed ledger or database running on millions of devices and open to anyone, where not just information but anything of value – money, titles, deeds, music, art, scientific discoveries, intellectual property, and even votes – can be moved and stored securely and privately (Tapscott and Tapscott, 2016, Para 2).

Blockchain will help to manage and secure the Internet of Things, the devices connected to it and the data they produce. Block chain enables trust less transaction – transactions which ensure integrity and trust between strangers, thus opening up new mechanism for trade over the Internet. Transactions can be securely made between two parties without the need for a financial institution. Block chain is the technology that underlies crypto currencies such as Bitcoin (Nakamoto, 2008) and Ether (Finley, 2014). For the agricultural producer block chain enables a secure and transparent means of trading with consumers eliminating financial institutions and shortcutting the supply chain. Further developments and applications in block chain technology may be relevant to the future of agriculture and agricultural value chains. A number of banking institutions and Governments are currently considering the introduction of block chain technology and crypto currencies, while two of the major crypto currencies, Bit coin and Ether have seen their value surge in 2017 (Lant, 2017).

3.2 Emerging technologies relevant to rural enterprise and rural lifestyles

Below, I list a range of emerging technologies, developed already in proof of concept or early commercial versions, with potential implications for rural enterprises, livelihoods and lifestyles. The implications of these technologies are not fully developed below, and indeed they might not be fully foreseeable yet. Rather, brief comments are made about some potential applications or effects of these technologies.

- **SmartPhone/SmartWatch/SmartGlasses,** augmented reality (AR) devices–are the devices which interface between humans and the Internet and the Internet of Things. Wireless sensor networks on farms will transmit information to the farmer's phone. Digital agriculture will be accessible and manageable by mobile devices such as smart phones and tablets (Barcelo-Ordinas et al., 2013)or byAR devices such as Microsoft's Holo Lens.

- **Apps**– a wide range of applications will help rural enterprise and rural residents in their lives and businesses. These include, communication and networking apps, farm systems apps, animal data, welfare and traceability records, economic and environmental performance analysis, market information and trading apps, biodiversity apps, bio security apps, and weather warning apps (Barcelo-Ordinas et al., 2013). Rural living maybe enhanced by social media apps, health and wellbeing apps, teaching and learning apps and game and entertainment apps.

- **Smart House** -the integration of digital devices (IoT) into the home allowing automation of a range of processes controlling the home environment, allowing remote access by the owners, and interfacing the house with services and goods providers.

- **Smart farm**– a similar concept to the Smart house, but for the whole farm system (Henry, 2016). Smart farms, assisted by AI, will see the gradual atomisation of various aspects of farm systems. Robots will gradually improve inefficiency and use and, in the longer term, become cost effective as human labour replacement on farm.

- **Smart irrigation** – the use of sensor technology to deliver irrigation where and when it is required in the appropriate amounts has the potential to vastly reduce water use in agriculture and horticulture (Fraceto et al., 2016). Smart irrigation offers the potential to efficiently utilise scarce water resources.

- **Internet of health** (i.e., remote medical technologies and services) – Universal broadband will enable medical services to be delivered and managed across the Internet to remote locations(Broadbent, 2016; Hamons, 2014; Milner, 2016).Virtual medical centres, medical and elder companion robots, with AI capacity, will provide assistance and care for people in rural and remote locations. Smart wearable will contain sensors that monitor an individual's vital signs enabling AI doctor bots to make health and lifestyle recommendations, automatically update patient medical records and notify authorities in medical emergencies.

- **E-Fences** (new fencing animal containment technologies) – electronic or geo-fencing enables animals to be kept in geographically defined locations and moved about remotely by computer - potentially eliminating the need for fencing of paddocks on farms (Henry, 2016).

- **Sensors and wireless sensor networks-** sensor technologies, as discussed above, will enable the monitoring of a large range of environmental and plant and animal factors providing information for analytics and decision support and sending data wirelessly to the appropriate platforms for processing by AIs. Sensors may be used, located and embedded in a number of different ways including terrestrial, farm machinery, drones, balloons, planes, satellites, on humans, on animals, on plants, and in fields and soil. Some of their agricultural applications include providing information regarding plant and animal health and growth, weed control monitoring, field fertility, soil salivation, soil pH, irrigation needs, temperature, humidity, solar radiation, high resolution land and water mapping, animal tracking and management, bio security surveillance, biodiversity monitoring, and deployment of agricultural robots (Barcelo-Ordinas et al., 2013).

- **Plant and insect recognition technology/software**, DNA testing and identification - machine identification of plants and insects will facilitate decision support and provide a basis for farm activity automation such as robotic weeding and pest management (Li, 2014). These technologies have the potential to vastly reduce herbicide and pesticide use.

- **Electronic traceability** – will provide a mechanism to verify product provenance, ethical and environmental credentials (Sugahara, 2009). Block chain technology and "smart contracts" as proposed by Vitalik Buterin, the creator of the Ether crypto currency, will help enhance security and traceability across the web (Finley, 2014).

Electronic traceability also opens up market opportunities through product storytelling to inform interested high-end consumers.

- **Decision support software** – will be an integration of science models with big data and unstructured data analysis by artificial intelligence enabling better and more efficient on-farm decisions delivered to the farmer's mobile device in the field (Buckmaster, 2016; Clifford, 2016).
- **Farm automation** – progressively more elements of the farm system will become automated as sensor technology, science models, AI, decision support software, and robotics become part of the farm management system (Sukkarieh, 2016).
- **Drones**– drones offer the potential for farmers to remotely observe any part of their farm from within their home or some other remote location. A range of different sensors can be fitted to drones and these can provide information to digital agriculture systems. Drones could be controlled using VR helmets providing a mixed reality experience, with information and farm advice provided by AI software superimposed using augmented reality technology.
- **Robots**– robots are increasingly becoming more mobile, flexible in function and able to work alongside human beings. There is a large amount of research going into agricultural robotics with some very promising results. Some applications include milking machines, mechanical weeding, precision pesticide use, precision fertiliser distribution, horticultural harvesting, and human labour replacement – including managerial decisions (Sukkarieh, 2016). Social and medical robotics are also burgeoning fields, with robotic companions, robot home help and medical robots, which have the potential to enhance rural lifestyles, already under trial in remote New Zealand locations(Broadbent, 2016).
- **Human ability enhancement tools** (e.g., exoskeletons) – exoskeleton technology enables humans to do hard physical work, lifting heavy loads etc. without physical strain. This technology could find practical applications on farm enabling a single man to effortlessly lift large weights and do the work of several men (Lockheed Martin, 2016).
- **Autonomous vehicles** – already many tractors are GPS controlled and do not require drivers. Detailed digital mapping of properties along with GPS will enable fleets of small solar powered robotic vehicles to monitor and work the land. Self-driving vehicles (land, air, and sea) will allow driverless transport of products to processors or markets (Seba, 2014). They may also make rural roads safer for rural residents, eventually perhaps enabling rural social activities to include alcohol without concern about transport home.
- **New transportation technologies** (pods, hyper loop etc) – Hyper loop technology, currently under development, may create new, cheap, high speed avenues for freight transportation around the globe. Timeframes for such technologies and revision of transportation systems is uncertain (Mazza, 2016).
- **Personal flight technologies** (transport drones) – Personal flying devices (which may also be autonomous) are looking highly probable. These could have a range of uses for both rural enterprises and rural living – collapsing the remoteness of rurality (McGoogan, 2016).
- **New trading venues** -Internet market places and crypto currencies (e.g., bitcoin) based on block chain technology have the potential to radically reorganise value chain structures, cutting out the middlemen (Tapscot and Tap scott, 2016; Whitehead, 2016). Producers may use these technologies to communicate and market products directly to consumers, thus by-passing traditional value chains and marketing venues.
- **Energy farming** – renewable energy generation as a farm-based product; solar, wind, methane (UCS, nd).Climate change is driving the need to produce carbon neutral energy sustainably and renewably. Energy production either as electricity to be fed directly into the grid, or biogas generation, could become feasible revenue streams for landowners as the technologies for production become cheaper, more efficient and more reliable.
- **Virtual reality, augmented reality**, **mixed reality**– virtual, augmented and mixed reality devices are enabled by ultrafast broadband. Much hyped for many years, VR, AR and MR technologies have finally reached a sufficiently sophisticated form for early user trial and acceptance. Growth in commercialisation of these technologies is poised to explode in 2017-8. VR and AR will have a range of applications including farm management,

communication, education, recreation, entertainment, tourism, medical care, modelling and visualisation. The potential is to interact with anyone anywhere in a virtual space or even a distal real space (c|net, nd). Virtual school rooms will co-locate distal pupils in augmented and mixed reality learning spaces limited only by human imagination. AI teacher bots will enable individualised teaching instruction based on analysis of a student's capacity and current knowledge and skill levels.

Virtual offices will similarly enable co-location of distal workers and collaborators who will be able to interact with one another, control machines, manipulate objects on the macroscopic, microscopic and nanoscopic levels, and be tele-present in robots, controlling their function – eventually just by thought (Galeon, 2017b). Entertainment and recreation will similarly be revolutionised. Already the computer gaming industry dwarfs Hollywood and the movie industry. People already play on-line games in virtual spaces with other people from across the globe. The potential for virtual and mixed reality worlds is only just beginning. Virtual reality may help to mitigate the isolation that many people in rural areas feel. The social media giant, Facebook, recently purchased Occulus Rift, a virtual reality company for SUS2.3 billion (Day, 2015).Augmented reality devices, such as Microsoft's HoloLens (Alderman, 2015) may provide a useful tool for farmers to receive information about their farming operations and for the delivery of decision support from cloud based AI.

- **3D printers**–3D printing, or additive manufacturing, is a rapidly developing area of research and technology – many items that are used on farm on in the home may be able to be printed on-demand when needed by downloading the appropriate software from the Internet. A wide range of different things are currently being manufactured with 3D printing including orthotics, pharmaceutical pills, houses, artificial bones, skin and organs, components for jet planes, guns, guitars, electronic circuits and vinyl records to give a sample of the diversity possible). 3D printing of food is also a developing technology for example the ChefJet 3D printer use sugar and cocoa butter to create various sweet treats (Dredge, 2014).

3.3 Potential New Farm Products, Rural Jobs and Rural Businesses

New technologies will also create new job opportunities in rural industries and food production. Farming Futures, a joint initiative between IBERS at the University of Aberystwyth, NIAB, Harper Adams University, East Malling Research, Agri-Food and Biosciences Institute (AFBI) and SRUC, identified six potential new farming roles they believe may be common by 2030. The six new roles are geoengineer (carbon capture biotechnologies), energy farmer (wind and solar electric generation and biofuels), web 3.0 farm host (host to provide customer information about the farm and it products –provenance and sustainability storytelling – both digital and real), animal psychologist (holistic animal management using psychology and animal behaviour principles to farm "freedom food"), pharmer (pharmaceutical farmer), and insect farmer (insects are much more efficient producers of protein than the animals we currently farm). These new positions will require a range of new skill sets for future farm workers. New jobs will also arise in rural communities for the installation, maintenance and repair of digital technologies, robotics and precision agriculture farm equipment.

The new and emerging technologies discussed above may also enhance the suitability of rural areas for entrepreneurship in non-agricultural enterprises by providing mechanisms for reaching and trading on markets anywhere in the world. Thus, for example, people with careers as diverse as writers, software developers, inventors, artists, musicians, cheese makers and other crafts people could live and work from rural locations, mix with their peers in virtual spaces, sell their products in virtual market places, using secure crypto currencies (Tapscott and Tapscott, 2016). Technological advances that digitally collapse space and time, bringing rural communities closer to everywhere, are removing the isolation of rural life and may create conditions to attract new residents, refugees from unaffordable priced urban housing markets, who may now find meaningful occupation and lifestyles in rural areas.

4. Conclusions

The purpose of this paper has been to consider what new digital technologies are on the horizon and how they might impact on the development of rural enterprises and rural lifestyles over the next 10-20 years and beyond. While prediction is difficult and fraught with unknowns, utilising Gibson's concept that "the future is already here, just not evenly distributed" my approach has been to consider the most recent technological developments and advances at the edges of, or just beginning to enter, the mainstream of technology and business. My underlying assumption is that, due to a range of factors discussed in Section 2, the future will see many of these technologies exponentially improve in function and performance, reduce in price, and move into the mainstream.

Before considering emerging technologies, I first identified some important factors influencing the development of technology in general, and the probability of mainstream adoption of particular technologies.

These factors include technological co-evolution, technological convergence, technological integration, miniaturization, cost reduction, the Law of Accelerating Returns, the sigmoidal adoption pathway, disruptive and sustaining innovations, human collaboration and trust, and responsible technological development. Next some key enabling digital (and related) technologies, necessary for the development or application of many new and emerging technologies, were identified and their relevance to rural enterprises and communities and the downstream technologies which they enable were discussed. The enabling technologies identified were universal mobile broadband, wireless sensors and the internet of things (IoT) or Internet of Everything (IoE), cloud computing, artificial intelligence, sustainable energy generation and storage, nanotechnology and material science, and block chain technology.

Then a range of emerging technologies, mostly rapidly developing digital technologies and their potential implications for rural enterprises and communities were briefly considered. Many of these technologies, although creating change and the need for new skills and knowledge, will largely sustain current on-farm agricultural production, making agriculture more efficient. Their disruptive potential is primarily related to agricultural supply chains in the immediate future and, in the more distant future, as automation really takes hold, to human labour on-farm and throughout the agricultural supply chain. Given the current state and progress of technological development, the major companies and innovative start-ups involved, and the potential efficiency, production and environmental benefits, the wide scale first world adoption of digital agriculture in the near to medium future seems inevitable.

Many of these emerging technologies will also have significant impacts on rural communities and the lives of people living there. Digital technologies collapse space and time enabling instant worldwide communication, bringing rural communities closer to the rest of the world. A whole range of new activities and services will be opened up to rural residents: health services, recreation and entertainment, education, and social and political participation. This may work to reinvigorate rural enterprises and rural lifestyles, as an Australian report states "As the new utility helps overcome the tyranny of distance, it will reinvigorate regional centres and some rural communities, with teleporting enabling some jobs centred in capital cities to be relocated to the bush. Skilled workers will be able to live anywhere if they so choose and businesses will be able to source skilled employees across international boundaries" (Ruthven, 2012, p.14).

Digital technologies are rapidly transforming the efficiency, effectiveness and transparency of agricultural production, the nature and labour requirements of agricultural work, the structure of agricultural value chains, the range of agricultural business models, and rural living and lifestyle opportunities. There is a wide range of new and developing technologies, already demonstrated in concept, and clearly visible on the agricultural horizon. Which ones will dominate and which will die remains to be seen. Thus, rural communities and agricultural enterprises need to prepare for a degree of uncertainty. They need to be open to new ways of working and living so that they can harness the opportunities and benefits opened up by the digital paradigm shift and proactively anticipate and prepare for evolving consumer requirements.

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