

Australia's freight productivity, its effect on the national economy and opportunities for improvement¹

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Executive summary

Looking forward, a number of global developments are combining to shrink supply chains. New technologies, collectively called Industry 4.0, are making production more mobile as automation reduces the importance of large pools of cheap labour. This is facilitating a shift of production toward consumers, reducing inventory cost while allowing greater customization and consumer responsiveness. Some products are getting smaller (or flatter, like TVs) while others are becoming digitized (like books, newspapers, music). Urbanisation and the aging of the Australian population is tending to reduce per capita resource consumption. The net result of these trends is a weakening in container flows, creating downward pressure on freight rates. For the foreseeable future, excess capacity in the shipping industry will keep downward pressure on ocean shipping and port costs.

Technological advances under the headings of electrification, digitalisation and automation have the potential to dramatically improve freight productivity. Productivity relates to the efficiency with which inputs are converted into outputs. In national accounting, the primary

¹ This paper is a contribution to the enquiry into National Freight and Supply Chain Priorities and has been commissioned by the Department of Infrastructure and Regional Development (DIRD). The views expressed are the author's own and are intended to provoke reflection and debate.

inputs to any sector are capital (K), labour (L), energy (E), materials (M) and services (S). Electrification, digitalization and automation will in combination raise the input of capital at the expense of labour, decrease net energy consumption, and reduce the input of services. As the output of the logistics industry is a service, few materials (intermediate products) are consumed.

Electric vehicles (EVs) of all kinds, including the cranes used in ports, have the ability to regenerate electricity while braking and lowering loads, thereby reducing net energy consumption and emissions. Moreover, electric trucks can be tailored to a wide range of applications in support of urban supply chains. The move to EVs is lowering the barriers to entry to vehicle manufacture to the extent that Tesla, with no track record in the motor industry, has been able to establish itself as a leading supplier of luxury EVs. It is widely acknowledged in the motor industry that the key to future success lies in the batteries, as evidenced by the rapid rise of Chinese battery maker and now vehicle manufacturer BYD, creating a sense of panic among some established vehicle manufacturers who have so far neglected this technology. Australia possesses the main ingredients for batteries (lithium, nickel, copper, cobalt), so could make the production of batteries a central feature of an industrial strategy designed to resurrect a domestic vehicle manufacturing industry.

Digitalisation is facilitating the automation of data storage and handling in supply chains. In shipping, e-certificates for ships and seafarers are gradually gaining acceptance. The standards required for the secure electronic exchange of trade documents, like bills of lading, letters of credit, invoices, guarantees, insurance certificates etc, are emerging. Single window and port community systems, which collate documents and data in a single database then facilitate stakeholder access on a secure 'need to know' basis, are spreading to more ports worldwide but making slow progress in Australia. While digitalisation raises the need for new and better cyber security, it will undoubtedly facilitate major gains in productivity.

Automation is transforming cargo handling. The standard dimensions of shipping containers facilitate the automation of intermodal freight transport. Automated stacking cranes and automated guided vehicles (AGVs) were introduced in Rotterdam in the 1990s. More recently, Autostrads (automated straddle carriers) were pioneered in Brisbane and have now been introduced in Port Botany's Patrick terminal.

The technical development of autonomous ships is progressing steadily, although IMO regulations are yet to catch up. Calculations by the author (see formula on page 9) reveal that by reducing the fixed cost of shipping, the optimal size for an autonomous ship will be smaller than its conventional counterpart, making supply chains more continuous and increasing the number of accessible Australian ports. By also reducing the labour cost component of shipping, coastal shipping may once again become price competitive with road and rail, potentially obviating the need for expensive new interstate transport infrastructure. Given the importance of ocean shipping, and the potential benefit for coastal shipping, Australia has an interest in actively furthering the development of autonomous shipping.

Freight productivity

The first paper argued that the “tyranny of distance” does not apply to logistics, either for export chains or for import chains. However, there are still significant inefficiencies in Australian logistics which hamper economic growth.

There has been government concern recently about slowing productivity growth, reflected in the *Shifting the Dial* report published by the Productivity Commission this year. Slower productivity growth translates into slower income growth. Five categories of input in the process of production, referred to as factors, are distinguished in national accounts, namely labour, capital, energy, materials and services. We can look at either individual factor productivity or multi-factor productivity. Multi-factor productivity in the Transport, Postal and Warehousing sector has slowed since 2003 and declined since 2007². This has been attributed to capital deepening due to large capital investments in the sector rather than declines in labour productivity.

The causes of this downward trend in multi-factor productivity, which is afflicting other developed economies as well, are not entirely understood. Rapid technological advance in recent years (smartphones, the internet, cloud computing, apps of all kinds, 3D printing and other technologies associated with Industry 4.0) has yet to significantly raise multi-factor productivity. This may be because we have yet to learn how to take full advantage of these new technologies. It may also be that new technologies have indeed increased the quantity of services offered, but prices have fallen because demand has not kept pace with the supply. The ‘gig economy’ and the casualization of some employment in the transport and freight industries (Uber, Deliveroo, etc.) is evidence of new technology generating new but low paid jobs providing cheaper services, causing labour and multi-factor productivity to appear to decline on the back of falling wages and prices.

Historically the ports have constituted bottlenecks in supply chains, leading the Australian Productivity Commission to study port performance in 1998 and commence regular monitoring, reported in BITRE’s Waterline series. In the absence of effective competition between Australian ports, the landlord model has been successfully deployed in the capital city ports. By separating the landlord, who is responsible for the infrastructure (the quay, the breakwaters, and the yard), from the operators, who are responsible for the superstructure (the cranes, warehouses, and vehicles) as well as cargo handling, an element of intra-port competition can be generated. In the ports of Brisbane, Botany, Melbourne and Fremantle, three terminal operators compete with each other for the container handling business. In Adelaide, there is only one terminal operator, who periodically retenders for the contract to handle containers, also generating some competitive pressure.

Waterline has reported improving container port productivity, although it is still below levels achieved in larger container ports in the northern hemisphere, indicating that, while intra-port competition has improved efficiency, it is not as effective in raising efficiency as inter-port competition experienced in northern Europe, China and Malaysia/Singapore. Any

² Figure 5 in BITRE Information Sheet 55, 2014.

comparison of bulk ports is likely to show that Australia is relatively efficient, because of the high level of investment in railway, stockyard and ship loading equipment.

Industry 4.0

The first industrial revolution was steam, the second electricity, the third computers and the fourth a collection of new interconnecting technologies including the internet, smartphones, cloud computing, and 3D printing. Although their impact on freight productivity is yet to be great, it is expected that eventually these new technologies will prove transformative. For freight productivity, the key elements of Industry 4.0 are likely to be electrification, digitalization and automation. We look at each of these in turn.

Electrification

With advances in battery technology, electric vehicles (EVs) are gaining in capability. The internal combustion engine, with its emissions of Sulphur oxides (Sox), nitrus oxides (NOx), carbon dioxide (CO₂) and particulates, is becoming increasingly unacceptable because of its impact on human health and the urban environment. By contrast, EVs have zero emissions if the electricity is sourced renewably. The battery powered EV is well suited to urban logistics (Box 1) because of its acceleration, quietness and the limited range required for many urban delivery operations. Currently the range between charges is around 200km. Where longer ranges are required, overhead power lines are a possibility on motorways (Box 2) or, alternatively, compressed hydrogen and fuel cells offer around twice the range of batteries alone (Boxes 1 and 3). Trams in central Europe are offering a new way to move good in cities, but require off-network loading and unloading areas so as to not disrupt passenger services (Box 4). Additionally, drones (Box 5) will find a niche for just-in-time deliveries. It is important that Australia prepares its large coastal cities for a shift to EVs, which will transform not only personal mobility but also urban logistics.

Box 1: StreetScooter ramps up production as demand grows for e-vehicles

- Deutsche Post-DHL is ramping up production of its StreetScooter subsidiary as it looks to roll out more than 20,000 of the “e-vehicles” a year.
- StreetScooter’s latest model has a range of 200 km, and a top speed of 120 kph, with DHL noting that a number of customers are looking for increased range.
- The company has also begun a 2-year project to test a fuel cell model, with a range of 500 km.



Source: www.theloadstar.co.uk, 3/10/17

Box 2: Siemens to bring e-highway demonstration to California

- The e-highway has started a 2-year trial near Gävle in central Sweden.
- Hailed as innovative, economical, and environmentally friendly, the e-highway concept is being tested in California near the Los Angeles and Long Beach container ports, where truck traffic is intense.
- The new technology permits the trucks to operate as electric vehicles when on the e-highway, and as hybrid vehicles elsewhere.
- Source: www.Lloydsloadinglist.com, 15/8/16



Box 3: Toyota Motor North America tests hydrogen fuel cell trucks on drayage routes

- Local, frequent trips (around 320 km per day) will test the drayage capabilities of the fuel cell system.
- So far, the truck has successfully completed 6,400 km (320 km per fill).
- Toyota will introduce longer routes as the study progresses.
- The truck generates more than 670hp from two fuel cell stacks and a 12kWh battery, a relatively small battery to support US class 8 load operations.



Source: www.porttechnology.org, 15/10/17

Box 4: Electric trams shuttling groceries and car parts around European cities

- In Saint-Étienne, France, older trams are used to move produce from a warehouse on the outskirts to Casino stores in the city centre once a day.
- In Dresden, Germany, two blue freight trams, operated by city transport company DVB, run up to 3 times per day and take around 25 mins to cover the 5.5 km route between a VW logistics centre and the e-Golf assembly plant. The route is shared with passenger services.



Source: www.theguardian.com, 5/11/17

Box 5: Zurich drone delivery test the first in a major European city

- Mercedes-Benz, Swiss e-commerce platform Siroop and US drone developer Matternet embarked on a 3-week trial of a same-day delivery service in Zurich, Switzerland.
- Drones will deliver goods weighing up to 2 kg to a landing platform on courier van roofs, and the vehicles then make the final delivery to consumers.
- Source: www.theloadstar.co.uk, 3/10/17



Digitalization

An important manifestation of digitalization for Australian supply chains is the Single Window, which is the core of a Port Community System (PCS). The UN Centre for Trade Facilitation and Electronic Business (UN/CEFACT) defines a Single Window as “a facility that allows parties involved in trade and transport to lodge standardised information and documents with a single entry point to fulfil all import, export and transit-related regulatory requirements”. While the Single Window is limited to the regulatory requirements of international trade, a PCS serves all supply chain stakeholders. However, the concept is the same: Data should only be submitted once electronically, reducing errors, increasing transparency, improving security, reducing delays at ports, and cutting trade costs (Box 6).

A national PCS for Australia has been researched extensively by NICTA (now Data61) on behalf of the Western Australian Government and by the National Transport Commission (NTC). In 2016, the Department of Immigration and Border Protection, Australian Business Register Program and the Department of Foreign Affairs and Trade formed a partnership to undertake two research studies, the *Domestic Single Window Study* and the *International Single Window Study*, to assist the Australian Government determine the next steps for Australian trade. To date, there are some services such as 1-Stop (<https://www.1-stop.biz/>), but no fully integrated national PCS.

The introduction of e-certificates for ships and seafarers by ship registries and ship classification societies has the potential for reduce fraud and cut the cost of port state control inspections by the Australian Maritime Safety Agency (AMSA). Likewise, the move to electronic bills of lading, guarantees, letters of credit and other trade documents will eventually cut the cost of trading.

The first and last leg of supply chains is both a difficult challenge and an opportunity for creative thinking among app developers (Box 7). Although the result may be that freight moves more efficiently, the impact on freight productivity, as measured by BITRE (for example in Information Sheet 55, 2014), may ironically be small or negative as it may reduce prices for delivery services and generate casual, low paid jobs.

Box 6: Marseille upgrades its Port Community System (PCS)

- The previous PCS could not avoid the need for paper documents, but the upgraded system links all port activities together in one place electronically.
- The software communicates directly with external systems, such as the Port Authority Vessel Traffic System (VTS) and the Cargo Community System (AP+).
- At its core is a Single Window complying with EU Directive 2010/65, simplifying formalities between EU ports.



Source: www.portstrategy.com, 5/11/17

Box 7: The car boot as a lock box for delivery or pickup

- DHL is working with Volkswagen on a new method of delivery – leaving parcels in the boot (trunk) of cars.
- An app from the car manufacturer tells DHL delivery drivers where the car is, and gives them a code with which to open the boot.
- Once the boot has been closed, the access code no longer works.
- Couriers can pick up parcels, or drop them off.



Source: www.theloadstar.co.uk, 3/10/17

Automation

Perhaps the biggest improvement in freight productivity will be achieved by automation. One area of particular interest and relevance to Australia is the automation of shipping. Automation is proceeding as a number of steps leading to the progressive reduction of crew sizes. The first steps are already underway. Larger ships have autopilots, which will become smarter with the addition of 'intelligent awareness systems' (Box 8). Navigation and cargo

handling systems will benefit from the ‘internet of things’ technology (Box 9), enabling great supply chain integration.

Landside control is likely to be an early feature on the road to ship autonomy, with a shore-based operator taking the role of the pilot, thereby obviating the need to send out a pilot to the ship by boat or by helicopter. The responsibilities that currently reside with the master of the ship (the captain) could pass to the shore-based operator.

As ship autonomy develops, there will be a need for greater equipment reliability as onboard engineers are gradually removed. In aircraft, safety and reliability is achieved through duplication. For example, when one engine fails, the other(s) are sufficient for the aircraft to proceed safely. Similarly, autonomous ships will need duplication, for example at least two engines, so that, if one fails, it is possible for the ship to proceed safely to the next port of call.

The removal of the crew, crew quarters and crew safety equipment (like a lifeboat) saves a significant amount of space on board. It also reduces the optimal size of the ship because of the reduction in the fixed cost (the cost of operating the ship irrespective of the amount of cargo carried). Let v^* be the optimal size of the ship measured in deadweight tonnes (dwt), T be the total quantity to be shipped (in tonnes per day), c_f be the fixed cost per trip (for example, the trip charter cost), i be the inventory cost per tonne per day and w be the storage cost per tonne per day, then

$$v^* = \sqrt{\frac{c_f T}{(i + 2w)}}$$

Hence, everything else being equal, a halving of the fixed cost per trip would lead to a 30% reduction in the optimal size of the ship in terms of its carrying capacity.

A reduction in the size of an autonomous ship in comparison to its conventional counterpart would increase the number of ports that can be accessed, as narrower and shallower channels could be used and smaller cranes could be deployed. This in turn raises the interesting question as to whether this would be sufficient to revive the Australian coastal shipping industry for containerized cargo. In Scandinavia, autonomy is perceived as a huge opportunity for coastal shipping (Box 10). A consortium led by Wärtsilä, a Finnish designer and builder of marine engines, is aiming to introduce a fully autonomous cargo system to the Baltic by 2025 (Box 11).

While greater ship autonomy raises new cyber security threats, it also provides interesting security applications. Roll Royce has proposed an autonomous patrol ship equipped with drones for enhanced visibility, electric propulsion for greater reliability and stealth, and solar panels to keep the ship at sea for long periods (Box 12). Given the extent of the Australian coastline, this could be an attractive option for the Royal Australian Navy.

Perhaps the largest impediment to ship autonomy on the high seas will be the passing of the necessary conventions and convention changes through the International Maritime Organisation (IMO) and then the ratification of these for national jurisdictions (Box 13). In

the meantime, interest is focusing on trialing autonomous ships in coastal waters where national jurisdictions apply, such as the Norwegian coast and the Baltic. The Australian Maritime Safety Agency (AMSA) is reported to be open to the prospect of unmanned ships under certain conditions and permitted an unmanned hydrographic vessel to operate this year off the coast of WA by granting exemptions to a number of regulatory requirements (*Lloyd's List*, 8 August 2017).

Box 8: Rolls-Royce and Google Cloud team up to make autonomous ships a reality

- Rolls-Royce and Google are developing 'intelligent awareness systems', which are essential to making autonomous ships a reality.
- Rolls-Royce will use Google's Cloud Machine Learning Engine to train artificial intelligence (AI) to detect, identify, classify and track objects at sea.
- Intelligent awareness systems will also benefit shipping now by making vessels and their crews safer and more efficient.



Source: www.seatrade-maritime.com, 4/10/17

Box 9: Rolls-Royce and TCOMS develop smart ships

- UK-based engineering company Rolls-Royce and the Technology Centre for Offshore and Marine Singapore (TCOMS) have formed a strategic partnership for developing smart ship technologies.
- By developing demonstrator technology around sensors, data analytics and the Marine Internet of Things (MIoT), ships will become more reliable, efficient and integrated into global supply chains.



Source: www.worldmaritimenews.com,
18/04/17

Box 10: Autonomous vessels a 'huge opportunity' for shortsea shipping

- Yara Birkeland will be the first fully electric and autonomous container ship due for delivery in second half 2018.
- There is a huge opportunity for shortsea shipping, but it will take rather longer before fully autonomous ships are crossing the oceans.



- Source: www.seatrade-maritime.com, 1/6/17

- Image courtesy of YARA Birkeland

Box 11: Wärtsilä takes part in autonomous shipping project

- Wärtsilä Corporation (engine designer and builder) and marine information and communication technology (MICT) companies are part of a project to create the first autonomous marine transport system.
- The initial focus will be on a fully autonomous cargo system for the Baltic Sea by 2025.
- Wärtsilä believes that artificial intelligence, robotics, and remote connections will play an important role in the future shipping industry.



Source: www.worldmaritimenews.com, 18/04/17

Box 12: Rolls-Royce unveils plans for an autonomous patrol ship

- The ship will use a combination of artificial intelligence and sensors instead of a crew allowing it to perform a range of roles (for example, a drone launching pad).
- Electric power will assist stealth, reliability and the environment.
- Rolls-Royce plans to equip the boat with solar panels and 3,000kWh of energy storage to keep the ship loitering for as long as possible at sea.



Source: www.engadget.com, 14/9/17

Box 13: IMO scopes autonomous ship rules



- IMO's Maritime Safety Committee (MSC) has launched meetings to discuss a wide range of maritime safety rules, among them rules for autonomous ship safety.
- Such rules might be added to IMO conventions, and take account of the security and environmental impact of autonomous ships.
- "Technology moves quickly. Regulation moves slowly," says the International Group of P&I Clubs.

Source: www.porttechnology.org,
19/6/17

Shrinking supply chains

One consequence of automation is a greater mobility for production, which becomes less dependent on abundant supplies of cheap labour. As a consequence, production will tend to move toward the main markets, as being close to the consumer minimizes inventory and facilitates greater customization. This process, referred to as 'near shoring' or 'reshoring', has been observed in a number of developed countries. Industry 4.0 technologies are also facilitating smaller batch sizes, enabling production to be more distributed. Taken together, these developments are causing supply chains to shorten.

In addition to shorter supply chains, demand for manufactured products is facing a number of headwinds. As the populations of developed and developing countries age, the wealthier retiring generation is consuming less resources, while the younger millennial generation, saddled with student debts, high rents and competitive employment markets, cannot compensate for the falling consumption of the retiring generation. Developments associated with Industry 4.0, such as the 'gig economy', are creating new but relatively low paid jobs leading to low unemployment with low wage growth and low productivity. As a consequence, supply chains are exhibiting a tendency to shrink both in terms of length and width (or volume). Since the GFC, the rate of growth of container flows measured in TEUs through Australian ports (1.6% per annum in 2016, according to Waterline 60) has fallen below the rate of growth of GDP (2.8% per annum in 2016, according to the World Bank).

An industrial opportunity for Australia

The growing significance of EVs around the world, together with the growing need for batteries to smooth out fluctuations in electricity generated by intermittent sources (wind and solar), is driving the growth in demand for lithium. As Table 1 shows, Australia was the top lithium exporter in 2014 (in 2016 Australia accounted for a 41.5% share of world output,

ahead of Chile with 35.7%, according to the *Australian Financial Review* on 6/7/17). However, as Table 2 sadly reveals, Australia is not in the top 10 (or even the top 15) battery producing countries.

Table 1: Top 6 Lithium exporting countries 2014³

Rank	Country	Tonnes
1	Australia	13,000
2	Chile	12,900
3	China	5,000
4	Argentina	2,900
5	Zimbabwe	1,000
6	Portugal	570

Table 2: Top 10 producers of lithium batteries in 2016⁴

Rank	Country	US\$	Share
1	China	\$366.7 million	14.60%
2	United States	\$346.7 million	13.80%
3	Singapore	\$298.4 million	11.80%
4	Hong Kong	\$238.5 million	9.50%
5	Japan	\$197.5 million	7.80%
6	Indonesia	\$190.8 million	7.60%
7	Germany	\$147.1 million	5.80%
8	France	\$93.5 million	3.70%
9	Belgium	\$79.2 million	3.10%
10	South Korea	\$78.4 million	3.10%

The first lithium ion battery was produced by Sony of Japan in 1991 (Box 14), after which Japan and South Korea dominated the industry until recently. China now dominates with a 60% share of the global market, and also leads in the production of EVs (Box 15). It is received wisdom among vehicle manufacturers that to succeed in EV production it is necessary to lead in battery technology. Given Australia's access to the main ingredients for lithium ion batteries (principally lithium, but also cobalt), a good industrial strategy could be to promote the development and manufacture of batteries in Australia, and thereby potentially resurrect a domestic vehicle manufacturing industry focussed on EVs. In 1938 Australia considered itself so short of iron ore that it banned exports – a policy which remained until 1961. While banning the export of lithium may be neither feasible nor

³ Source: <http://www.worldatlas.com/articles/the-top-lithium-producing-countries-in-the-world.html>

⁴ Source: <http://www.worldstopexports.com/lithium-ion-batteries-exports-by-country/>

desirable, a policy that favours the export of lithium ion batteries rather than lithium would stimulate the development of employment and skills in the key lithium ion battery field.

Box 14: Chinese battery makers catch up

- Japan produced the first prototype lithium ion battery, with Sony starting production in 1991.
- Japanese and South Korean companies dominate the Japanese, American and European EV markets, with leads in operating distance and battery safety.
- Chinese companies have succeeded in breaking Japanese and South Korean dominance, with BMW opting for CATL's batteries.
- Solid-state batteries are seen as the holy grail of EVs.



Source: Nikkei Asian Review, 14/10/17

Box 15: Beijing's green car push helps Chinese EV makers

- With heavy state support, Chinese makers of lithium ion batteries for EVs have over 60% of the global market, squeezing technologically advanced Japan with over 20% and South Korea with under 10%.
- China leads with 51% of world EV sales, or 240,000 units, the majority fitted with Chinese batteries, creating a strong domestic demand.
- Access to battery technology is the key to success in the EV market.



Source: Nikkei Asian Review, 14/10/17

Conclusions

Pulling together the various arguments presented in this paper, the impacts of Industry 4.0 on freight productivity can be summarized using the KLEMS multi-factor productivity framework in Table 3, where a minus indicates a loss of factor productivity and a plus sign a gain in factor productivity. As freight is a service, the materials (or intermediate products) consumed are not considered.

Table 3: The impact of Industry 4.0 on freight productivity

Industry 4.0	Primary impacts	Freight productivity*				
		K	L	E	M	S
Digitalisation	PCS and single window systems; e-certification of ships and seafarers; e-bills of lading; e-letters of credit; apps for first/final leg; blockchain for transactions	+	+	+		–
Electrification	EVs in ports and urban areas; compressed hydrogen and fuel cells for greater range; e-bikes; freight trams; electric and hybrid cranes; drones	–	–	+		–
Automation	AVs; less drivers and crew; greater safety and reliability; more mobile production; shrinking supply chains; smaller, more autonomous ships	–	+	+		–
*	K=capital, L=labour, E=energy, M=material, S=services					

Digitalisation has the potential to improve freight productivity throughout the supply chain, particularly in ports, where port community and single window systems can reduce errors, improve transparency for carriers, cargo owners and authorities, reduce dwell times, improve security, and cut trade costs. Similarly, the gradual move to e-certificates for ships and seafarers and to electronic trade documents should with time reduce delays, cut the cost of trading, and therefore improve freight productivity. Blockchain technology has the potential to improve the security of trading significantly at some future time, but at the cost of encryption. Through digitalization, capital, labour and energy are expected become more productive, but at the cost of a higher input of services to support IT systems.

Electrification is making an immediate impact on freight productivity and, where electricity is sourced renewably, sustainability. As a result of rapid advances in battery technology, EVs in ports (Autostrads) and on urban road networks are able to save energy through the regeneration of electricity when braking or lowering of heavy loads like containers. Where batteries are insufficient on their own, hybrid systems or compressed hydrogen with fuel cells are offering greater ranges between refilling and/or recharging. In urban areas, EVs will be complemented by e-bikes for couriers and trams for end-to-end deliveries. Drones will

doubtless find a niche in the just-in-time segment. Through electrification, energy resources are expected to become more productive, but at the cost of greater labour, capital and service inputs. Eventually an increase in multi-factor productivity is anticipated.

Access to advanced battery technology is expected to be the key to success for EV manufacturers, as evidenced by the successful transition of BYD in China from battery maker to EV maker. Australia is currently the largest producer of lithium but does not rank among the top 15 lithium ion battery producers. Promoting battery manufacturing in Australia could be a way to grow the skills required for EV development and manufacture domestically.

Automation is also transforming supply chains inexorably. Automation is making production more mobile, freeing it from dependence on cheap labour and enabling it to gravitate to consumers, thereby reducing inventory cost and facilitating greater product customization. Simultaneously, digitalization and other Industry 4.0 technologies are facilitating smaller batch sizes, enabling production to be more distributed. Taken together, these trends are causing supply chains to shrink, so growth in GDP is no longer matched by growth in container flows. Through automation, labour and energy productivity is expected to increase, but at the cost of greater capital and service inputs.

In ports, automation is gradually leading to greater reliability and safety in container handling. After pioneering automated straddle carriers (Autostrads) in Brisbane they are now operating safely and reliably in Brisbane, Port Botany and shortly also in Los Angeles. Automation in shipping is under development, but initial indications are that autonomous ships will be smaller and cheaper to operate than their conventional counterparts, raising the prospect of a revival in the coastal shipping of containers. Given the potential importance of this for economic growth and sustainability, Australia has an interest in promoting the development of autonomous shipping.