Productivity and Innovation in the Mining Industry

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Foreword

Fundamentally there are two sources of economic growth: increasing the use of inputs such as labour (including embodied human capital), capital, land and other natural resources such as minerals; or increasing the productivity of those inputs. Over the past century a large share of economic growth has been derived from improvements in productivity, that is, improvements in output per unit of input, but of course more labour and capital have also been employed. The quality of capital has improved over time as have the overall skillsets of the workforce. The ongoing revolution in technology has been crucial in making these improvements possible not only directly in the workplace but also in improving communications and training.

Wealth is generated by the application of new ideas to solve existing problems or by creating new products and services that consumers' desire and in modern economies the service sector constitutes by far the largest share of economic activity. Fundamentally however humans will always require physical goods such as food and clothing and the minerals used to produce modern consumer and producer goods.

Humans have been mining for at least 40 000 years. Two thousand years ago the Romans developed large scale hydraulic mining methods for use in alluvial gold deposits in Spain. They also developed underground mining techniques. Despite the long human history in mining and the ongoing development of new techniques, mining has in the past typically involved much hard labour in often difficult and dangerous work environments.

Around 500 million years ago life on earth went through a period of rapid diversification known as the 'Cambrian Explosion'. It is not known why this occurred but one proposal is that the rapid changes resulted from the evolution of vision and the resulting ability to be able to hunt more efficiently. Some researchers in robotics and automation have suggested that we are about to witness a similar 'explosion' in the development of robotics, which could have profound implications for the way we work and for which firms are successful in mining and other sectors.

Today mining is not simply about hard hats, sweat and big machines – it is increasingly about the successful integration of new technology and ideas into an industry almost as old as human kind.

This report was commissioned by Rio Tinto to explore progress in mining innovation since the first report published on the topic by BAEconomics in 2012. Improvements in technology have the potential not only to extend the life and productivity of mines and thus increase returns both to miners and the community more broadly, but also to make mining safer for those who work in the industry. This report explores the realised and potential productivity impacts of automated technology deployment in Rio Tinto's Pilbara operations as well as the potential for systems integration and data analytics.

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April, 2016

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Executive summary and conclusions

Productivity and innovation are key items on the federal government's agenda. The government's agenda emphasises, among other things, the further need for collaboration between industry and research providers and the importance of ensuring that training is available in subjects that are necessary to be successful in the 'digital age'. Innovation and change are fundamental to wealth creation.

Success in innovation also requires a number of other factors. First, taking new ideas and converting them into useful processes or products usually relies on the ability to interact with groups undertaking similar research or producing similar products. These 'network' effects help to explain why activities tend to cluster in particular geographic locations where a critical mass of innovators, research scientists and venture capitalists come together. Second, government policy must take a long term view and not be inimical to product and process risk taking. For example, corporate or personal tax rates and other taxation arrangements that are internationally uncompetitive will ultimately lead to development of innovative ideas being undertaken elsewhere. Third, making advances in an industry where the country already has a comparative advantage will generally be more straightforward and successful than starting a new enterprise in a new sector. To this end building on the comparative advantage and global scale that Australia already has in mining provides a strong foundation for new innovation.

Rio Tinto has focussed efforts in its iron ore business around a range of productivity enhancing programs and technologies, including the automation of mine, rail and port equipment, with the ultimate aim of systems automation and integration. These technologies represent a class of innovations likely to profoundly change how minerals are brought to market in the future and they are applied in an industry where Australia has a natural comparative advantage. It follows that the program will add substantially to Australian wealth creation.

Rio Tinto's Western Australian iron ore business comprises much more than mining iron ore - it involves a range of sectors including infrastructure, domestic transport and logistics and international shipping, and it relies on world-class data analytics, computing and communications. Without seamless, integrated, and highly efficient infrastructure and logistics processes, the business cannot sustainably generate value. As such, Rio Tinto is undertaking significant investment in the development and deployment of innovative new technologies and processes across all aspects of the exploration, mining, processing, and transportation chain. In this sense Rio Tinto is as much a logistics and processing business as it is a mining business.

A central focus of Rio Tinto's innovation efforts is the increasing application of automated systems. These new technologies are delivering significant advances in safety, improved process and transport productivity and better utilisation of resources, labour and equipment. Results from existing iron ore sites using automated equipment show impressive improvements in productivity of up to 15 per cent stemming from higher utilisation rates, more precise equipment operation, reduced maintenance costs and longer useful asset life, with further efficiency improvements projected in future.

While direct benefits such as improved safety, operating cost reduction and environmental outcomes are hallmarks of automated mining operations, these systems also come at significant cost. Automated mining relies on an array of new technologies in the fields of computing, signalling and sensing technologies, as well as sophisticated communications systems. Developing these technologies is complex and requires collaboration between experts from different scientific fields, as well as between mining companies and equipment producers. The full-scale roll-out and commercial use of these technologies can only occur after extensive R&D and multiple intermediate testing stages.

Rio Tinto has been developing and implementing its world class 'Mine of the Future™' innovation program over many years. Many components contribute to the Mine of the Future™ vision and Rio Tinto has achieved remarkable performance improvements to date with further enhancements expected in future as the program continues to move from equipment automation to systems automation.

Systems automation utilising robotics requires significant advances in big data capture, analysis and utilisation, and will be driven in part by extensive R&D collaboration with academic institutions and industry partners. Incentives at the company wide and employee level will need to be right to drive the necessary behaviours and outcomes to best utilise the vast amounts of information that increased automation will bring. In addition, Rio Tinto will increasingly require people with greater skills in information technology and high level computing.

The payoffs both internal to Rio Tinto, and to the broader Australian economy are significant.

- For Rio Tinto, ongoing innovation and productivity enhancing programs will ensure that the company remains cost competitive, which in turns creates a margin buffer through the economic cycle, and places the company in a good position to deliver industry leading returns.
- For Australia such efforts place us at the forefront of global innovation in this field with attendant benefits for knowledge accumulation and exports of human capital to other countries and sectors. The rapid development of a significant mining services sector in Australia has also generated jobs and boosted growth.

Australia is a global leader in research into mining automation, and, coincident to the government's innovation agenda, Rio Tinto has funded for some time several Australian research centres, including the Rio Tinto Centre for Mine Automation, as well as centres located overseas. Rio Tinto has also developed long term strategic partnerships with key suppliers to implement new technologies and processes and drive optimal business performance.

The innovation and productivity programs being developed and run by Rio Tinto in its iron ore operations are reaping benefits to the company and also for the wider Australian economy. Rio Tinto is one of the lowest cost iron ore producers in the world as a result of its ongoing innovation efforts, which will ensure profitability in an extremely challenging market characterised by low commodity prices and uncertain exchange rates. External benefits to the wider economy include higher capital, labour and multifactor productivity, with the associated potential to increase GDP growth and living standards, which in turn stimulates consumption in other sectors.

1. Introduction

Over the past decade, Australia has benefited greatly from its natural resource endowments and the mining boom. In 2014-15 the mining sector represented 9 per cent of Australian GDP, up from 6 per cent in 2004-05 (Department of Industry, Innovation and Science 2015). The sector employed around 220,000 workers in November 2015 and contributed over $171 billion dollars in exports in 2014-15.

Since the early 2000s, mining capital stock has grown substantially. At its peak, mining investment was growing at 8.5 per cent per year resulting in mining's share of total capital stock growing from 5.3 per cent before the boom to its present 12.6 per cent. This massive growth of 230 per cent in new capital stock has provided a strong basis for an ongoing contribution from the mining industry to the Australian economy.

As little as three years ago, the general consensus was that demand for mineral resources would continue to grow strongly as developing countries industrialised and lifted the living standards of their populations. Strong demand, together with slowly responding supply was projected to result in continuing high real commodity prices. The current reality of much lower commodity prices and tightening margins is in stark contrast to this prior outlook, and the speed with which the market deteriorated was more rapid than many commentators expected.

However, there is no real surprise that the China-led boom has ended. Inevitably, given sufficiently high prices stimulated by strongly rising demand, supply will catch up and commodity prices will fall. This has been the pattern of commodity booms witnessed by Australia in the past and that pattern will continue. What is surprising is the gloom expressed by commentators and governments each time a boom ends, together with the seemingly inevitable call for the commodity industries to be replaced by industries that are currently more 'fashionable'. In the past this response led to calls for more Australian based manufacturing (and government subsidisation of industries that have subsequently failed) and more recently to calls for a move into the 'apps' industry.

The aim in this paper is to illustrate, by way of a case study of Rio Tinto's Pilbara iron ore operations, that mining is an evolving high innovation sector that will continue to be a mainstay of the Australian economy for many years to come by adding significant value to otherwise unusable rocks in remote locations, through use of some of the most sophisticated technology available. In the case of Pilbara iron ore mining, it has also developed one of the most sophisticated logistics operations in the world. This study is approached within the context of the current national conversation around productivity and innovation, and the ongoing contribution of mining to national income.

Perhaps the most important factor in ongoing wealth creation is that countries concentrate on the industries in which they have a comparative advantage. Australia definitely has a comparative advantage in mining not least because of the vast extent of our natural resources. Australians have demonstrated that they can compete in many other fields as well, including computing and manufacturing. But there is no reason to believe that the mining industry is a sunset industry simply because a price boom has ended. Nor is it a reason for governments to favour any one industry over another. What will be important is for governments to put in place policies that facilitate the adoption of world class technologies in all of our industries and allow them to compete on a level playing field. In that way, those industries that can contribute the most to growth will do so and those that are less internationally competitive will contract, thus freeing up resources for those with a comparative advantage.

Mining will continue to be a major export earner for Australia for decades to come. The significant ongoing demand for commodities coming from Asia represents an opportunity for Australia, as well as a challenge to ensure we remain competitive against other countries as alternative sources of supply. Unfortunately for Australians, there is no shortage of high grade mineral reserves elsewhere on the planet. If there were then Australia could control supply and dictate prices to buyers. Instead, Australian suppliers of minerals face strong competition from other commodity exporters and from domestic suppliers in customer countries such as China.

Productivity in mining fell globally during the boom years as companies moved to expand and produce as much ore as possible to capitalise on greatly elevated commodity prices. This fall in productivity may have contributed to a perception of mining as a low value adding activity that has little to contribute to a modern developed economy such as Australia's – an industry that is inherently less 'valuable' than modern manufacturing or services.

However, as we examine in this paper, the mining industry response to high prices was a completely rational economic response. Moreover, mining involves much more than the 'simple' extraction of minerals from the earth's crust, and requires sophisticated networks to ensure that products can be efficiently delivered to the market via extensive rail, road and port networks. Without these networks, mining products are simply stranded assets. Hence a major focus of the mining industry is the productivity of its logistics operations, and innovating to improve the efficiency, cost and reliability of the entire supply chain from mine to customer. That value adding consists not only of the value produced by processing rocks into crushed or concentrated minerals available at the mine gate but the 'place' value involved in transporting the product from where it is first produced to where it will be used by the customer, the 'time' value involved in storing that product as it moves along the supply chain and the 'ownership' value as product legally changes hands.

In late 2015 the Australian Government released its National Innovation and Science Agenda. Its focus is on facilitating a change in culture that encourages more entrepreneurial risk taking and supports greater private sector investment by co-investing to commercialise promising ideas through two government innovation funds. Much emphasis has been placed on developing skills more suited to the 'digital age' and on facilitating the development of start-ups and innovative small businesses together with increasing the collaboration between industry and research bodies, including universities. These are all laudable goals but more needs to be done to recognise the ongoing efforts in technological improvement and automation that is being undertaken continuously in the commodity sector, particularly in the mining sector and the ongoing research collaboration in which the sector is engaged.

Australia's mining innovation efforts to date have ensured we remain a low cost producer in iron ore, and have resulted in Rio Tinto becoming the world leader in mining automation. Over the past eight years, Rio Tinto has spent around A$1.5 billion on technology programs in iron ore, including its automation efforts and the Operations Centre in Perth. This is no small sum when placed in the context of the federal government's recent announcement to spend around A$1.1 billion over four years on economy-wide innovation efforts and highlights the central role that the private sector must play in developing and adopting new ideas and converting them into real productivity improvements.

This paper is organised as follows. Section 2 describes the mining industry and the broader economic and policy context in which it operates. Section 3 outlines productivity trends in Australian and international mining as reported in the literature and official statistics. Section 4 explores the various productivity programs and innovations underway and being developed by Rio Tinto across all aspects of its Australian iron ore mining and logistics business, while Section 5 describes the benefits from these programs in terms of overall productivity and competitiveness.

2. Global mining industry context

Over the past decade, the minerals industry initially saw a dramatic increase in demand for globally traded commodities with an associated but lagged supply response from existing and non-traditional producing countries. More recently, the industry has experienced rapidly declining commodity prices as demand has moderated and new supply continued to enter the global market.

2.1 Demand for resources

Over the past ten years, industrialisation and urbanisation in China and elsewhere in Asia significantly increased the global demand for resources, a trend from which Australia and other exporters of bulk commodities benefited greatly. However, the current experience, and the medium term consensus is that growth in the demand for minerals commodities will moderate as key economies address a number of challenges, including the need to undertake structural reforms and consolidate debt in an environment of tightening international financial conditions.

In particular, as Chinese growth slows from around 6.8 per cent in 2015 (WEO 2015) to a forecast 6.3 per cent in 2016 and 6.0 per cent in 2017 (IMF 2016) as the government consolidates moves toward a more consumption-driven economy, the reduction in fixed asset investment will reset growth in demand for commodities. The positive effects of ongoing structural reforms and lower commodity prices will however buffer the demand reduction to some extent. On the supply side, productivity enhancements will offset some of the impact of lower prices.

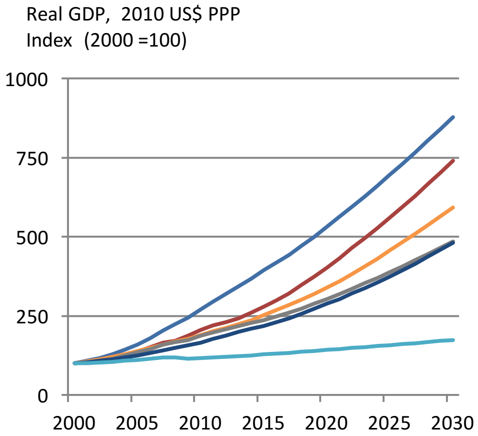
Over the longer term, commodities demand is expected to be more buoyant as India's population overtakes that of China and its economy gathers pace, and Africa's population nearly doubles leading to associated higher rates of urbanisation and industrial development.

The United Nations (2015) forecasts that the world's population will surpass 9.7 billion by 2050, an increase from around 7.4 billion at present. Furthermore, while the population of developed countries is expected to remain virtually unchanged, the populations of the 50 least developed countries (of which about half are in Africa) will likely more than double from 0.9 billion to 1.9 billion by 2050, while growth in the remainder of the developing countries, although somewhat slower, is also robust with populations projected to increase from 5 billion to 6.4 billion in 2050. Overall, between 2015 and 2050, just nine countries are expected to account for half of the world's projected population increase, namely India, Nigeria, Pakistan, DRC, Ethiopia, Tanzania, the United States, Indonesia and Uganda. Within seven years, the population of India is expected to surpass that of China.

By 2050, an additional 2.5 billion people will be urbanised, bringing the total urbanised population to 6.3 billion. This means that over the coming three decades, the world's population will grow by two-thirds and 90 per cent of the increase will take place in urban areas of Asia and Africa (UN 2014). Given around 80 per cent of global GDP growth is generated in cities, this suggests significant ongoing growth in demand for commodities that fuel urbanisation and industrialisation in these regions in particular.

Bloomberg (2015) projects that the Chinese economy will roughly double in size between now and 2030. However, this still represents a decline in the growth rate observed earlier this century. Meanwhile, India's economy will more than double in size over the same timeframe, with real GDP growth in excess of 8 per cent over the coming five years.

Figure 2-1. Economic growth projections for key regions



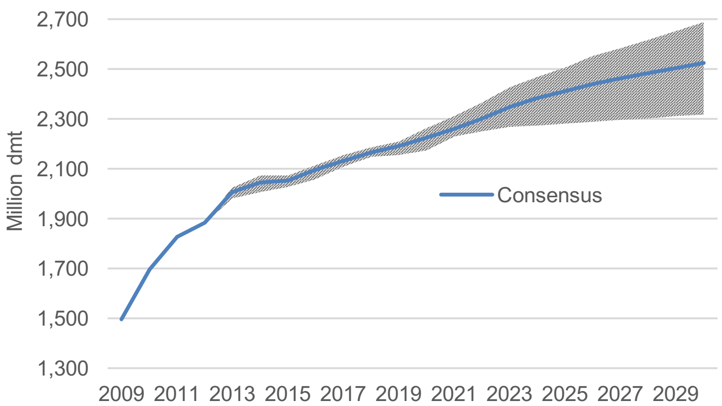
Average growth p.a

	\`00-05	\`05-10	\`10-15	\`15-20	\`20-25	\`25-30
China	9.8%	11.2%	7.8%	6.2%	5.5%	4.8%
India	6.7%	8.3%	6.2%	7.6%	6.9%	5.7%
Vietnam	6.9%	6.3%	5.9%	6.1%	6.1%	5.4%
Non-OECD	6.2%	6.8%	4.9%	5.1%	5.0%	4.6%
Indonesia	4.7%	5.7%	5.6%	5.7%	5.3%	5.2%
OECD	2.2%	1.1%	1.7%	2.2%	2.1%	1.9%

Source: IMF (2016), BAEconomics projections

In association with these economic growth projections, global iron ore demand is also set to continue growing, albeit at a slower rate than over the past ten years. By 2030, global iron ore demand on consensus estimates is projected to reach over 2.5 billion tonnes, an increase of 25 per cent on today. Analysts predict seaborne iron ore demand will grow from around 1.35 billion tonnes today to almost 1.6 billion tonnes in 2020. Contestable iron ore demand outside of China will grow at an annual cumulative rate of nearly 3.5 per cent per year to 2030. This 'rest of world' growth will primarily be driven by ASEAN nations and some other developing countries. Chinese contestable demand is expected to grow somewhat slower as scrap use increases, comprising up to 25 per cent of steelmaking inputs by 2030.

Figure 2-2. Global iron ore demand – still growing



Source: Analyst consensus, AME, Wood Mackenzie, CRU

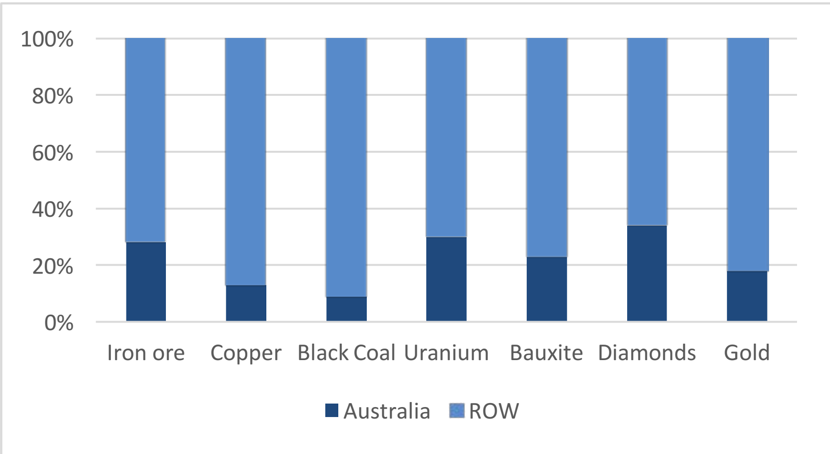
2.2 Global supply competition

Strong competition exists in the global market for traded commodities, and prices are highly transparent. Non-ferrous metals (copper, tin, aluminium and aluminium alloys, lead, nickel and zinc), minor metals (cobalt, molybdenum) and precious metals (gold, silver) are traded on commodity exchanges. Spot and contract prices for iron ore, coal and uranium are routinely published by industry publications such as Platts, The Tex Report and the McCloskey Group, as are spot freight rates and vessel fixtures.

It is necessary to produce at prices that are determined by international competition. Mining businesses competing in global markets must improve the efficiency of their operations to maintain their competitiveness over time, not just relative to other existing producers but also to emerging producers as new deposits are developed. In addition, the mining industry must effectively compete for scarce capital and labour with the non-mining sectors of the global economy.

While Australia and other traditional producers hold a significant proportion of world reserves of many important commodities (Fig 2.2), other countries also have large reserves of energy and mineral commodities. For example, China is a leading producer of aluminium, coal, copper, gold, iron ore and coal, magnesium, manganese, rare earths, tin, tungsten, zinc and many other commodities (USGS 2009).

Figure 2-2. Australia holds only a fraction of world commodity reserves



Notes: Economic Demonstrated Resources.
Uranium based on Reasonably Assured Resources (RAR) produced at less than US$ 130/kg uranium.
Source: Britt et al. 2014

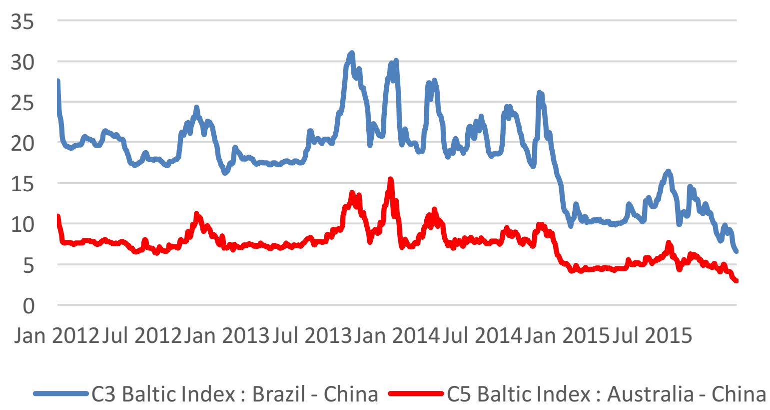
Outside Australia a number of significant expansions and new mining projects are under way (see Appendix 1), and will compete with Australia for market share:

- Iron ore: the expansion of the Carajás S11D Mine in Brazil, due to come online in 2016 and add 90Mt per year at full capacity, at a low cash cost of $US7/tonne which is well below that of Rio Tinto and BHPB. Vale's high grade expansions supported by Chinese investment will ultimately bring the group capacity up to 450 Mtpa.
- Coal: the Indomet expansion in Indonesia, and development of Elga mine in the Russian Federation.
- Copper: the Oyu Tolgoi expansion in Mongolia and Buenavista de Cobra expansion in Mexico.
- Uranium: the McArthur River expansion in Canada.

In addition to mining expansions, there are many new mining developments that will ultimately compete with Australian resources. While many mining projects must overcome significant obstacles before mineral products can be delivered to market, including key challenges around poorly developed infrastructure, many large mining businesses now offer to undertake significant development efforts to gain access to minerals in developing countries. Governments in developing countries also have strong incentives to attract foreign investment and know-how and will often contribute to development of such infrastructure and agree other facilitative arrangements.

Innovation in the mining and logistics space is becoming an essential part of remaining internationally competitive. Current low freight rates and projected low oil prices will benefit Brazilian competitors shipping into China, with Baltic freight rates between Brazil and China having significantly dropped relative to Australia-China rates over the recent past (Figure 2.3).

Figure 2-3. Baltic freight rates are narrowing

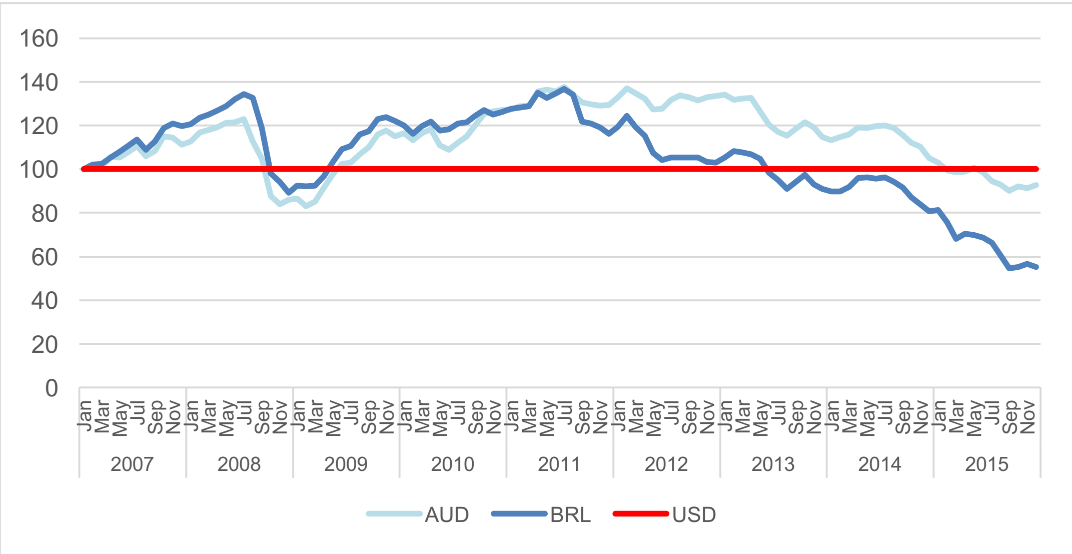


Furthermore, ten Chinese ports are expanding or have already expanded capacity to 400DWT to accommodate large Valemax ships. Following the 2014 ban on large vessels over 250DWT berthing at Chinese ports, Vale also established a transhipping hub in Lumut, Malaysia to receive Valemax vessels. This iron ore terminal now forms part of Vale's global iron ore supply chain, with capacity to handle and blend 200 Mt per year for re-shipping into various parts of

Asia (BMI 2014). The cost savings associated with this transhipping hub mean that Vale is achieving freight cost savings that further erode Australia's geographic advantage into Asia.

In a global industry with revenue denominated in US dollars, exchange rates also influence local supplier profitability and competitiveness. Competitive pressure from Brazil is also mounting because of the relative performance of the Australian dollar versus the Brazilian Real against the US dollar. Whilst Australia has experienced some depreciation against the US dollar over the past five years, the Real has depreciated significantly more. This has given Vale a competitive advantage against Australian producers since the currency spread developed in 2011.

Figure 2.3: AUD and BRL performance against USD



In respect of other factors that affect global competitiveness, Australia also has higher corporate tax rates than many other countries, at 30 per cent compared to a global average of 23.68 per cent in 2015 (KPMG 2015). Reform of Australia's tax system is a current topic of debate as several countries recently cut their corporate tax rates - including New Zealand by 5 percentage points, South Africa by 7 points, Canada by almost 10 points, and Britain by 9 points. Moreover, in the Asian region, the average corporate tax rate is around 21 per cent, suggesting Australia is well out of competitive step with our closest neighbours.

Although Australia is considered a jurisdiction with low sovereign risk, the regulatory burden placed on the mining industry is high. This is particularly the case with respect to project approvals where long delays can occur with approvals required by three levels of government (Fisher 2014). Excess regulatory burden together with a taxation regime that is out of alignment with major competitors is a disincentive to investment in Australia.

2.3 Lower price environment

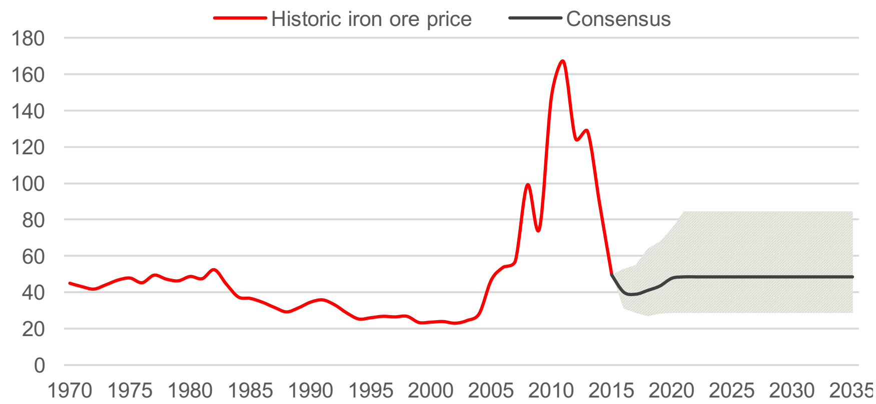
Prices for many commodities have fallen in recent months and dramatically when compared with market highs achieved in 2011. RBA (2016) estimated that over the past year alone, the commodity price index fell more than 23 per cent in SDR terms, and by 17.1 per cent in

Australian dollar terms. This was led primarily by declining bulk commodity prices, in particular iron ore, thermal coal and coking coal.

Iron ore spot prices also experienced significant volatility, falling to ten year lows of US$38/t in early December 2015, from over US$60/t in July 2015 before rising moderately to the middle US$50s in March 2016. These prices compare with record highs in excess of US$188/t in 2011.

It is interesting to note however that whilst iron ore prices have fallen over the past year, they have not fallen to record lows on an historic basis in real terms. Iron ore prices were for much of the 1980s and 1990s lower in real terms than even December's lacklustre prices. The long term consensus is that some strength will return to the commodity as markets normalise, with long term price expectations as high as US$84/t (Figure 2.4).

Figure 2-4. Iron ore price composite 2015$/dmt (excl. freight)



Source: Consensus estimates derived from CRU, AME, WoodMac, Macquarie, JPMorgan, Goldman Sachs, Morgan Stanley, Merrill Lynch, RBC, Citigroup, Credit Suisse, UBS, Barclays, Deutsche Bank.

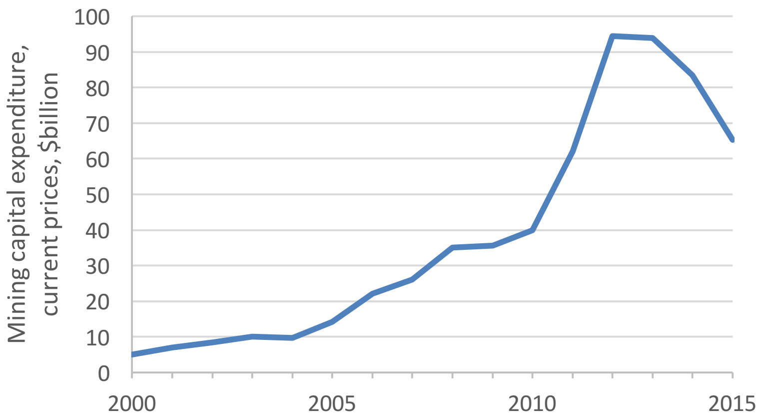
2.4 Constrained capital

Capital is required to sustain, grow, and fund shareholder returns. It is also necessary to fund development of innovative approaches and technologies to drive productivity. Ideally, companies invest in innovation throughout the cycle in order to benefit disproportionately when favourable conditions return. However, through cycle innovation and technology trials pose constant challenges. While innovation and technology programs may face competition during economic downturns due to capital scarcity, it is also a challenge to continue pursuing these programs in the midst of a boom. Since trialling technology is associated with opportunity costs as research and development takes place, many businesses also find this challenging amid a thriving market where maximising output is critical. To illustrate the point, a tonne of iron ore sales lost due to delays associated with the introduction of new systems at the height of the iron ore price boom would have cost an exporter $US188 (in nominal terms) whereas today the opportunity cost is around $US55. But, today the availability of capital is generally more constrained and thus a new challenge has arisen to the introduction of new innovations.

A current reality of corporate finance is that capital availability is typically insufficient to pursue all value-accretive projects. Strategic discussions are focussed heavily on the competitive uses of capital and optimisation of capital deployment. This has partly been driven by softening market conditions including lower commodity prices, but also by pressure to deliver greater shareholder returns via dividends and buybacks, as well as increasing finance costs and hurdles as lending institutions build in higher risk associated with forecast mining returns.

These pressures on capital budgets, along with completion of current projects, have been significant influences in driving the decline in mining investment in Australia, which has fallen almost 25 per cent year on year since December 2014 (Figure 2.5). Expectations for mining investment in 2015-16 are also 35 per cent lower than expectations for 2014-15 (ABS 2015). Barclays Research (2015) indicates that the pipeline of remaining mining-related construction projects continues to shrink, with private construction work yet to be completed falling from around 10 per cent of GDP in 2012 to 3.8 per cent in Q2 2015. Moreover, it is expected that mining engineering work will fall to pre- boom levels of 1 per cent by mid-2016 thereby completing the unwinding of the record mining capital expenditure boom.

Figure 2-5. Private capital expenditure, mining



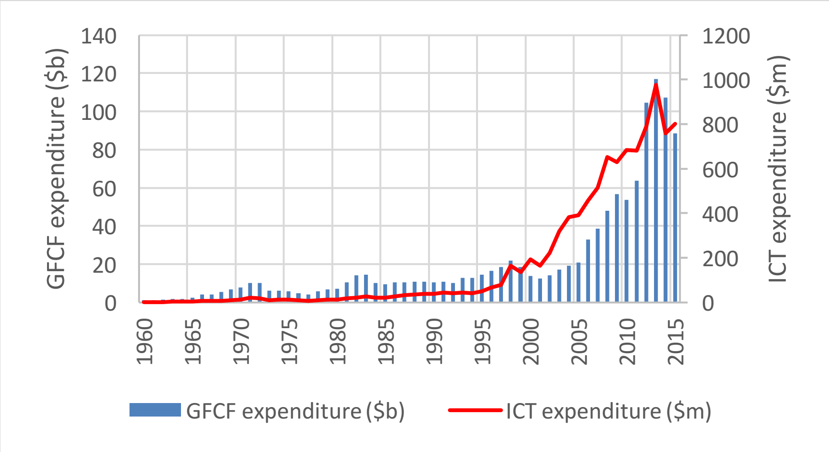
Source: ABS 2015a, 5625.0 Private New Capital Expenditure and Expected Expenditure, Australia.

Much of the improvement in processes and efficiency reported in this paper would not have been possible had it not been for the prodigious improvement in computing power since World War II and the advent of the world wide web as recently as 1989. Over the twentieth century, computer performance in constant dollar terms improved relative to manual calculations by a factor in the order of 2 trillion times with most of that performance occurring post the second world war (Nordhaus 2007). Ongoing improvements in both computer and sensor technology will enable continuing integration of automated processes into the mining industry. It is possible, as Pratt (2015) notes, that we are on the verge of explosive growth in automation leveraged by 'cloud robotics' and 'deep learning'.

While some mining businesses provide information about ongoing innovation efforts, most Australian businesses do not. It is therefore difficult to gauge overall trends in technology spending. What is clear however, is that information and communications technology (ICT) expenditure in the mining industry has increased rapidly in recent years. ICT is important in all stages of mining and associated logistics activity, especially in exploration, three-dimensional seismic surveys, and automation.

Whereas ICT expenditures have increased relatively slowly when investment has picked up in the past, ICT expenditures have grown rapidly over the past fifteen years but with a significant reduction coincident with falling mining construction over the past year (Figure 2.6). ICT expenditure is expected to continue to contribute a greater share of capital formation in the future with the increasing importance of automation in the mining industry together with other developments in telecommunications in the Australian economy.

Figure 2-6. Gross fixed capital formation in the Australian mining sector – Aggregate and ICT expenditure



Notes: Chain volume measures. ICT refers to expenditure on computers and peripherals, computer software, electronics and electrical equipment.

Source: ABS 2015b, 5204.0 Australian System of National Accounts

2.5 Grade decline and complexity of ore bodies

There is a general trend that deposits, at least in countries with long-established mining operations, are becoming more difficult to mine over time. This trend reflects the standard course of development that ordinarily occurs in mining projects.

High-grade minerals or those that can be extracted most cost-effectively are generally extracted first. Over time, as mineral reserves closer to the surface are depleted, the remaining deposits tend to be of a lower grade, in more remote locations, deeper in the ground, mixed with more impurities, or involve other factors that make extraction more difficult and costly:

- as the quality and accessibility of deposits decline, more capital and labour are generally needed to extract them;
- when deposits are deeper or below the water table, more development work is needed to access and mine the resources; and

- if there are more impurities, greater costs are incurred in extracting and processing the material into a saleable product or price discounts are imposed on the miner by downstream processors.

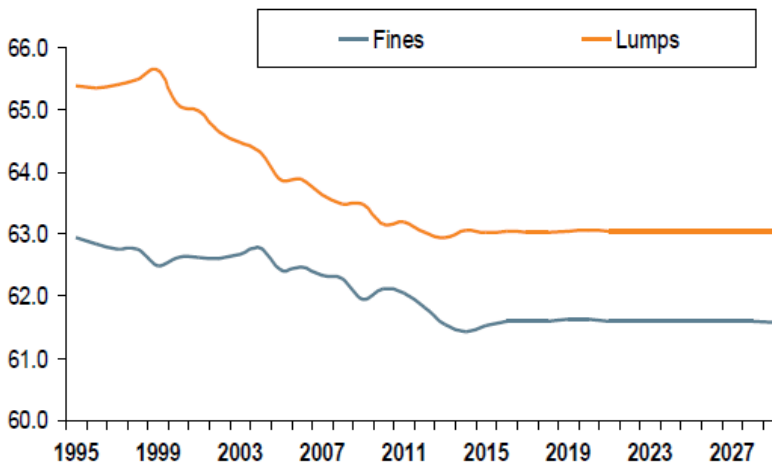
Overall, this means more effort is needed to produce a unit of output, thus having a negative impact on measured productivity. For example, Geoscience Australia (2008) reported that between 2002-03 and 2006-07 the depth of metres drilled increased by 64 per cent, reflecting the need for companies to drill deeper in their exploration efforts. Based on a detailed analysis of minerals production in Australia, Mudd (2009a) reports:

- long-term declines in average ore grades processed for copper, gold, lead, zinc, uranium, nickel and silver; and
- dramatic increases in the extent of overburden for coal, copper, gold and uranium since the mid twentieth century and especially since the 1980s.

The World Steel Association (2015) has also cited AME research indicating that global ore grades have been falling steadily over the past 10 years (Figure 2.7), with some stabilisation expected over the coming decade.

New product blends that stabilise total ore content at around 62 per cent Fe also assist to expand the mine life of lower grade deposits and those with greater impurity levels, by allowing blending with higher quality production from other deposits. This type of product blending is at the heart of Rio Tinto's Pilbara blend product and the recently announced proposed joint venture between FMG and Vale, which aims to blend high quality fines from Brazil with FMG's lower grade high sinter ore with the aim of increasing the two companies' combined market share in China.

Figure 2-7: Trends in global average Fe content



Notes: Fe content for fines and lumps 1995-2029 for producing, committed and probable projects
Source: AME cited in World Steel Association (2015)

2.6 Health and safety

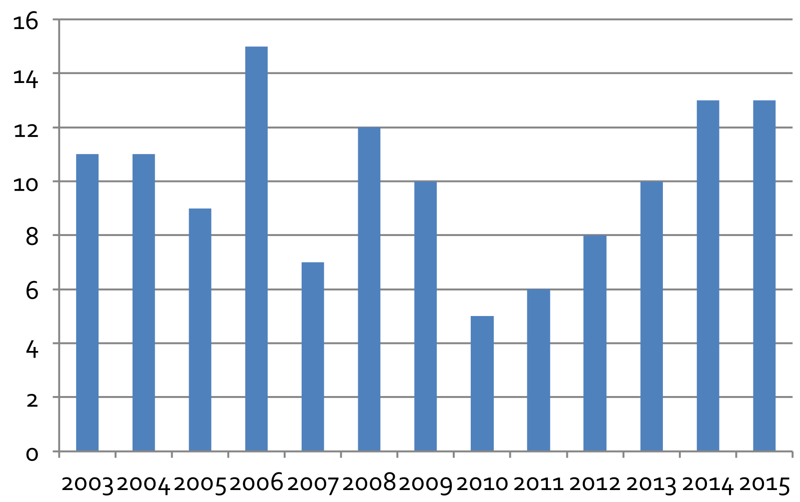
While there has been a process of continuous innovation and modernisation in the industry, mining typically takes place in harsh and often hostile environments. Miners work in conditions that are dirty, noisy, sometimes confined, and often in remote locations. All aspects of mining and related activities that take place around mining processes are hazardous (NRC 2002):

1. In open pit mines, rock falls and slope failures can create significant hazards. Large surface mines are effectively giant industrial sites in which humans interact with very large and moving equipment. Hazards to humans arise from:
   - limited visibility/blind spots of personnel from the vantage of very large haulage vehicles;
   - irregular road designs, blind intersections and obstructions;
   - factors such as fatigue, boredom and complacency; and/or
   - speed of moving equipment.
2. Dangers encountered in underground mines include massive failures of pillars, severe coal and rock bursts and roof and side falls, as well as explosions and fires. Additionally, large and moving industrial equipment in confined spaces are a significant hazard in underground mines.
3. Across all mining activities, hazards are posed by gases, dusts, chemicals and noise in the work environment, as well as from working in extreme temperatures. As processing technologies move toward finer and finer particle sizes, the health effects on workers of these particles (but also resulting environmental concerns) are becoming increasingly important. Additional health hazards arise from chemicals used in mining or processing of ores.

International Mining Fatality Review (2014) statistics report over 3000 mining fatalities for specific countries between 1995 and 2008. Whilst many of these mining related deaths occurred overseas, Australia has also recorded a number of mining fatalities (Figure 2.8). The number of deaths reported in developed countries pale in comparison to fatality estimates from China. It is estimated that between 2000 and 2009, more than 51,000 miners died in coal mining accidents alone (Wei 2011).

In Australia since 2000, the majority of mining fatalities have occurred in New South Wales, Queensland and West Australia. Most coal mining fatalities have occurred in New South Wales and Queensland; fatalities in other mining sectors have predominantly occurred in West Australia. Many more incidents (around 80 per cent) occurred in open-cut, non-coal mines than in underground mines. While many fatalities happened in the actual mining area, they also occurred in processing plant, workshops, on roads and roadways, and in yards. Most fatalities occurred during the operation of trucks and load-haul-dump vehicles (LHDs), with the leading identified causes of deaths being the unintended operation of equipment, contact with moving objects, falls from heights and tyre explosions.

Figure 2-8. Fatalities in the Australian mining sector



Note: Mining fatalities include fatalities occurring in the coal mining, oil and gas, metal ore mining, gravel and sand quarrying, and services to mining sectors.
Source: Safe Work Australia 2016

2.7 Environmental issues

The potentially adverse environmental impacts of many types of mining operations are well known and have led to significant changes in how the industry operates and is regulated. Depending on the type of mineral extracted and the size of the mine, mining often involves the production of large quantities of waste. These impacts are often more pronounced for open-pit than underground mines, and can potentially degrade aquatic ecosystems and water bodies as a result of sedimentation, acid drainage and metals deposition. Metals production processes, for instance, result in a range of emissions during mining and processing, and indirectly via the consumption of raw materials and utilities (Norgate et al. 2007). The beneficiation and chemical transformation of ores to extract metals and produce industrial materials requires significant amounts of energy, as well as reagents, water and fuel. Many factors influence the environmental impacts of such processes, including ore grade, electricity energy source, fuel type, material transport, and process technology.

In recent years, given significant public concern over the environmental impacts of mining, governments as well as the mining industry itself have made significant efforts to move toward a more sustainable approach (Azapagic 2004). In Australia, sustainability reporting has become the norm for large mining businesses, but individual corporate initiatives also play an important role. Examples include:

- the Rio Tinto Foundation set up with $35 million in funding to support research and technical development into sustainable solutions for environmental challenges for the mining industry (CSIRO, 2005);
- new technology initiatives aimed at waste minimisation, pollution prevention and cleaner production processes instituted by companies such as Newmont Australia, Alcoa and Tiwest (van Berkel 2007);

- the Woodside Energy Limited sponsorship of the study by the Australian Institute of Marine Science (AIMS, 2009) of ecosystem processes on the Scott Reef in the Indian Ocean; and
- Shell Australia and INPEX Operations Australia have contracted AIMS to assist with the establishment of environmental baselines for their oil and gas fields in the Browse Basin (AIMS 2015).

Significant challenges to the mining industry arise as a result of growing pressures to reduce greenhouse gas emissions. Mineral resource extraction and processing are energy intensive and a significant source of emissions. These vary greatly by type of mineral and even on a mine by mine basis. For instance:

- the production of bauxite and iron ore is estimated to produce around 4.9 kg of CO_2 per tonne and 11.9 kg CO_2 per tonne, respectively, about half of which occurs in the course of loading and hauling operations that are necessary to transport ores from deposits to mineral processing and export facilities;
- this compares to LNG production, which is estimated to produce between 320 and 630 kg of CO_2 per tonne of LNG from stationary energy and fugitive emissions (Grattan Institute, 2010); and
- fugitive emissions from coal mining as a result of methane trapped within coal seams are estimated to amount to between almost zero and 700 kg CO_2-e per tonne of coal (Commonwealth of Australia, 2008).

The imperative is therefore to improve the energy efficiency of mining and associated processes. This task is all the more pressing because of falling ore grades and the need to access deeper deposits. These trends will require larger volumes of material to be handled in more difficult environments to produce the same quantity of final output.

Another environmental challenge facing the mining industry is the requirement for water. CSIRO (2011) estimates that the Australian mining industry's use of water increased by around 29 per cent between 2000–01 and 2004–05. In other cases, water pumped out of some iron ore mines that are below the water table in the Pilbara actually provides a supply of irrigation water for the production of pasture for local agriculture and other uses.

In future, the challenges for the mining industry are likely to increase, reflecting expanding hydrometallurgical operations, declining ore grades, escalating production pressures and water scarcity.

2.8 The new normal: moving from growth to consolidation

The overall context for mining for the foreseeable future is one in which demand will increase less rapidly than over the past decade and commodity prices will be modest. This environment will reduce pressure on mining wages and other input costs relative to the recent past. However, many of the industry challenges described above point to an upward cost pressure environment that must be carefully managed if Australia is to remain internationally competitive.

Although cost management is always a priority for business, some cost escalation can be tolerated when commodity prices are very high and reliability and growth in output are the key imperatives. This was certainly the experience of many mining businesses through the boom.

For instance, when iron ore prices rose above US$180/tonne, the imperative was to extract and ship as many tonnes as possible while prices were high. Competition among miners for scarce inputs such as labour and materials also drove associated costs much higher than long term averages, but despite this, margins remained very healthy.

With a return to what must be considered from a long term perspective more normal commodity pricing, the imperative now is to drive costs out and ensure we secure the greatest possible returns from the mining investment boom in the face of significant competition from international expansions and new mining developments.

To a significant extent, cost reductions can be achieved through consolidation and careful management. However, to reduce costs in an environment framed by upward cost pressures, while simultaneously increasing output, requires step changes in innovation. Without such innovation, productivity in mining will stagnate or decline.

Step-change innovation implies a significant departure from business-as-usual processes. Such innovation typically takes place over relatively long time horizons and requires substantial upfront investments, with an uncertain outcome. Innovations of this type go through a number of stages:

- from an initial idea to the 'proof of concept' stage, to demonstrate the potential feasibility of the project;
- to the pilot project stage for an initial limited roll-out of a system as an initial test;
- to the demonstration stage where an innovation is trialled at a commercially significant scale; and
- full-scale roll-out and commercialisation of technology where it becomes an integrated part of a wider process.

Innovations that are unsuccessful at any point in the trial chain are discarded, and typically very few succeed to the commercialisation stage. Step-change innovations rely on significant technological advances and are therefore high-risk, both in terms of the financial investment they require and the fundamental uncertainty that remains about the success of the technology.

The task is made more complex where new technology needs to be incorporated into an existing fully functioning operation. For example, it is not possible to fully automate a currently functioning railroad that is running to capacity without some disruption to existing operations. This then leads to a choice being made to either bear the cost of the disruption or to construct a dedicated track that will be used solely for testing purposes – both options involve costs, one in terms of lost output and the other in capital expenditure that cannot be directly recovered.

Similarly, in an established operation such as the large iron ore mining systems in the Pilbara, capital equipment is not homogenous – it has been purchased over many years and, as a result, various makes and models of plant exist. Any system automation that is introduced must therefore be able to cope with equipment with a range of ages sourced from a range of manufacturers.

For these reasons, true step changes in innovation are difficult to achieve, and require long term commitment, risk tolerance, deep pockets and a degree of luck to accomplish. In addition, multiple external factors must align, including facilitative public policy at both State and Federal levels.

3. Productivity in Australian mining

3.1 What is involved in mining?

Mining is a diverse industry encapsulating exploration, production, beneficiation, logistics and transportation, and reclamation.

At a broad level, the mining process begins with minerals exploration, which in turn encompasses many different activities depending on the stage of exploration, the size of the area being explored and the type of information sought.

In many situations the production phase of mining involves breaking apart in-situ materials and hauling these out of a mine, but this definition hardly does justice to the multiplicity and range of distinct activities undertaken by the sector. Mining involves the extraction of a heterogeneous range of commodities, the deposits of which are distributed unevenly in terms of geographic location and qualities or grades, and a variety of extraction techniques (Topp et al. 2008). Although there are a number of common mining methods, the techniques applied within these broad groupings vary widely:[1]

1. Surface mining entails removing vegetation, top soil, and overburden materials above a mineral deposit, and drilling and blasting followed by removing the deposit. In open-pit mining, waste is transported to a disposal site, and ores are transported to a downstream processing site.[2] In area-strip mining used for mining coal and phosphate, a trench is dug through the overburden to expose and mine the deposit.
2. In underground mining the deposit is accessed from the surface via vertical shafts, horizontal adits, or inclines. The deposit itself is developed by traversing the orebody to enable human access, the extraction of blocks of ore, the transport of ore and waste and ventilation. For 'soft' deposits such as coal, potash or salt, mechanical means can be used to cut and load the deposit. In hard-rock mines drilling and blasting techniques are used.
3. Other mining methods rely on the use of high-pressure fluids such as water. Solution mining uses fluids to pump out the resource (and sometimes to re-inject other fluids), and is mainly used in the oil and gas sector, but also for potash or uranium production. Hydraulic mining (used for gold, tin and other metals) uses water power to fracture and transport earth or gravel for further processing.

The extraction process itself is typically only one of many steps that must be undertaken to produce a saleable product and meet broader environmental, social and other obligations placed on mining companies. In most cases, mined products require further processing (beneficiation) to improve product quality. Beneficiation encompasses a great variety of processes that depend on the specific characteristics of the resource. In the case of iron ore,

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[1] In this report the focus is on traded mineral resources, as distinct from industrial minerals. Industrial minerals comprise crushed stone, sand, and gravel (aggregate); limestone and other construction materials; phosphates and other materials used in agriculture; many compounds used in the chemical industries; and other products. For most industrial minerals, international competition is limited.

[2] Quarrying is similar to open-pit mining, but generally refers to the extraction of dimension stone and aggregates.

beneficiation activities may include crushing, milling, separation, screening, and sometimes flotation to improve ore concentration and remove impurities.

Mining operations also typically incorporate significant transportation facilities, including trucks, trains, conveyor belts or other means to deliver the finished product to port or customers.

Finally, mine reclamation activities take place throughout the life cycle of a mine and once a mine has reached the end of its economic life, to deal with disturbed land, mineral waste, water and other environmental impacts.

The mining sector thus encompasses a broad spectrum of activities. The ABS classification of the 'mining sector' also includes a range of products deriving from the minerals sector, oil and gas extraction, and exploration and other support services. As such, when commentators discuss 'mining productivity', we must be clear that this is a highly aggregated measure across various sub-sectors that are subject to a variety of influences and activities.

3.2 Productivity trends in Australian mining

Productivity is an economic measure of output per unit input. Inputs include labour and capital, while output is typically measured in revenues or volumes. Single factor productivity, such as labour productivity, is calculated as the average ratio of output per unit labour such as each hour worked. An increase in this ratio, assuming all other factors are held constant, suggests increasing productivity of labour, meaning that each unit of output requires less labour to produce.

However, given that other factors tend to constantly move, precise measurement and interpretation of single factor productivity measures is complex. For example, an increase in labour productivity could occur primarily as a result of an increase in the capital to labour ratio. Therefore, multifactor productivity (MFP) is used to measure output changes not directly linked to changes in individual inputs. Drivers of MFP are typically things that generate greater efficiencies in input use, such as capacity utilisation, technological change, economies of scale, and changes in the quality of inputs (BREE 2013). As such, declining MFP growth tends to suggest that resources are being used less technically efficiently.

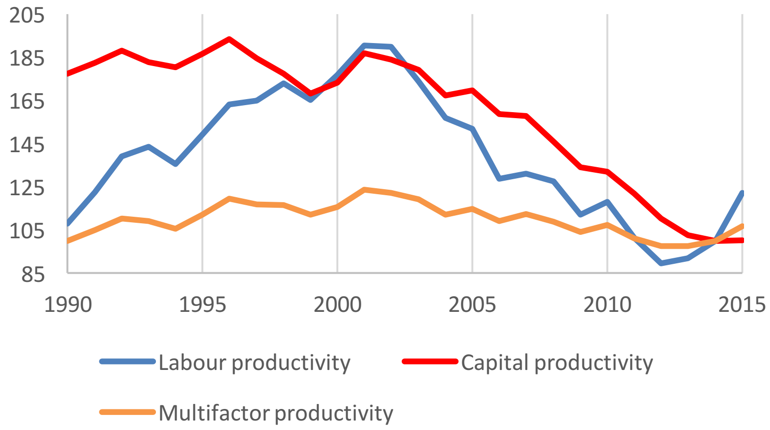
Productivity in Australian mining is analysed annually by the Australian Bureau of Statistics (ABS). The analysis conducted is quite involved and a significant amount of data are reported including metrics relating to income, expenditure, employment, and value added. However, owing to the methodological conventions employed by the ABS in calculating productivity, recent estimates for the mining industry may paint a more negative picture than is warranted.

The most recent industry productivity estimates published by the ABS (2015c) suggest that multifactor productivity in the mining sector has declined significantly in recent years. Since the mining sector makes up around 8 per cent of gross value added of the market sector, the ABS proposes that the decline in mining MFP also contributed substantially to a slowdown in productivity growth for the market sector as a whole.

Figure 3.1 charts the latest ABS data on labour productivity, capital productivity and (unadjusted) multifactor productivity. The labour and capital productivity indexes fell around 35 per cent and 45 per cent respectively from 2000-01 to 2014-15. Unadjusted multifactor productivity for the sector as a whole declined by around 14 per cent over this timeframe.

On the face of it, such degeneration in productivity metrics appear alarming. However, the story is perhaps less concerning when the reasons for the apparent decline in mining productivity are explored more deeply.

Figure 3.1. ABS indexes of productivity, mining



Notes: Multifactor and labour productivity estimates reported on a quality adjusted hours worked basis
Source: ABS 2015c, 5260.0.55.002 – Experimental estimates of industry multifactor productivity

Several studies have been conducted into mining productivity in Australia, and provide some insight into these apparently large declines in productivity.

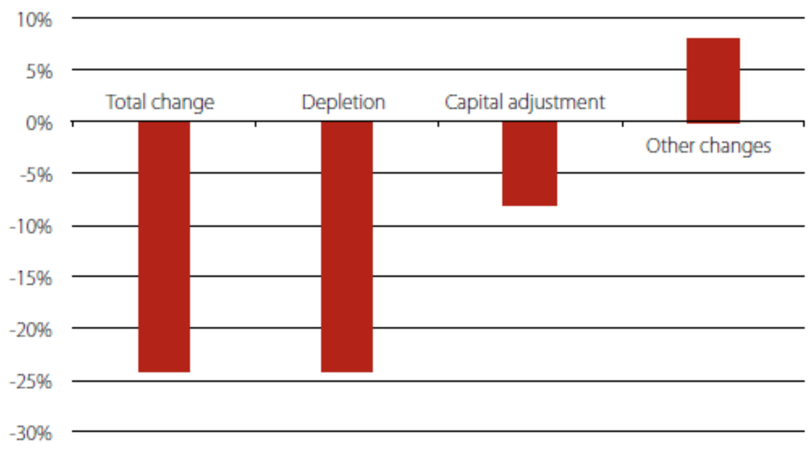
Topp et al. (2008) analysed mining productivity over a 30-year time horizon from 1974-75 to 2006-07. They found multifactor productivity stagnated over that timeframe, growing at only 0.01 per cent a year on average. Two key factors were cited in explanation of this decline, namely resource depletion, and output growth lagging behind capital investment.

In relation to resource depletion, Topp et al. (2008) showed that the increasing difficulty of mining and processing minerals, as represented by an index of mining 'yield', was a key explanatory factor in the observed decline in MFP between 2000-01 and 2007-08 (Figure 3.1). The index was defined to represent a composite of features that characterise the quality of natural resource inputs used in mining, such as ore grade (metal per tonne of ore), ore quality (impurities, milling characteristics), reservoir pressure (flow rates of crude oil or gas), overburden ratio (waste material to ore or coal production), mine or well depth, distance from markets or key inputs and complexity of terrain/mine geology.

Topp et al. (2008) also found that between 2000-01 to 2006-07, around one third of the decline in mining MFP could be attributed to production lags associated with long lead times between mining investment (which is both capital and labour intensive) and mining output. While production lags were found to be the dominant cause of mining MFP declines from 2004-05 to 2006-07, yield declines were more dominant in the earlier years of their study, as well as overall. Adjusting MFP measures for yield decline and production lags, Topp et al. (2008) found that MFP was 8 per cent higher than unadjusted MFP (Figure 3.3).

Loughton (2011) also examined cumulative resource extraction as an indicator of resource quality, and found that accounting for declining natural resource quality resulted in a 2 per cent growth in mining MFP from 1985-86 to 2009-10.

Figure 3-3. Drivers of mining MFP, 2000-01 to 2006-07



Source: Topp et al. (2008)

BREE (2013) studied productivity growth in the Australian mining sector at national, regional and sector levels. In particular, the report examines the influence of technological change and input use on MFP. The study finds that after adjusting for the influence of depletion in deposit quality and production lags, the MFP growth rate in Australian mining increases from an average annual rate of negative 0.65 to positive 2.5 per cent between 1985-86 and 2009-10.

BREE also decomposed MFP growth into the three components: technological change, technical efficiency and scale effects. Their analysis finds that Australian mining experienced no statistically significant technological change over the study period. The decomposition also shows that both technical efficiency and scale effects contributed positively and significantly to Australian mining MFP, after removing the effect of resource depletion.

To summarise the findings of these studies, in contrast to unadjusted MFP figures, adjusted Australian mining MFP was reported as having significant growth:

- BREE (2013): 2.3 per cent to 2.5 per cent (1985-86 to 2009-10);
- Topp et al. (2008): 2.3 per cent (1985-86 to 2006-07); and
- Loughton (2011): 2.2 per cent (1985-86 to 2009-10).

BREE (2013) further examined these mining MFP effects at the state level. For Western Australia, adjusted MFP was reported as significantly higher than unadjusted MFP particularly through the growth phase from 2005 onward as significant capital expansions were occurring in the West Australian iron ore industry.

Cumulatively, these studies indicate that declining resource grades and quality, or other factors resulting in higher work indexes, as well as capital lags involving time delays between investment in mining projects and commencement of production, may account for a substantial proportion of the reported mining productivity declines over the past decade.

However, these factors do not account for all of the productivity decline in the sector. PWC (2014) notes that the adoption of a volume strategy rather than a cost-conscious strategy during the commodity price boom resulted in growth in additional inputs that outstripped growth in output. Of course, as discussed above, the opportunity cost of failing to ship a tonne of product at the height of the commodity boom was substantial and thus it was rational in many instances to incur higher short term costs in order to meet booming demand.

3.2.1. International trends

Bradley and Sharpe (2009) undertook a comparative analysis of mining productivity in Canada, the United States and Australia, and found similar productivity trends occurring internationally as those observed in Australia. However, while mining MFP fell in all three jurisdictions, the rate of decline was greatest in Australia for labour productivity and MFP over the period 2000-2007.

The situation in Canada included a number of influencing factors including declining capital intensity, resource yield decline, production lagging investment, labour skills shortages and increasing regulation. The strongest effect was contributed by falling capital intensity growth rates which explained 42 per cent of Canada's decline in mining productivity. The authors focussed on continued innovation and investing in human capital as key to improving future mining productivity.

Declining ore yields have also been reported in other established mining countries. Mudd (2009b) identified long-term declines in ore grade for mined copper in Canada and the United States. In the United States, mining has depleted the best coal seams, with coal reserves, for instance in the Appalachian basin located in thinner, deeper coal beds than those currently being mined and a declining energy content of extracted coal (Höök and Aleklett, 2009). There is anecdotal evidence that exploration for many minerals is increasingly targeting zones for new deposits that are deeper than existing mines. Giurco et al. (2009) point to an increasing depth trend in copper, nickel and platinum metals mines, as well as in gold mines in South Africa and Canada.

These trends have significant implications for the mining industry. Quite apart from the technical and cost challenges of accessing deposits in more difficult ore bodies, they also raise new health and safety issues (Abrahamsson et al. 2009). More generally, difficult to access orebodies in established mining locations reduce the attractiveness of countries such as Australia as a location for future mining investment. Bellamy and Pravica (2011) cite evidence that at the height of the recent mining boom, resource companies saw Australia as a mature mining region, as evidenced by a fall in capital investment in the gold and metals sector in West Australia in 2008. There was a notable trend to direct more investment to other regions where better mineral deposits were available, and labour costs, taxes and administration expenses were lower.

4. Productivity at Rio Tinto

As the mining sector wrestles with a new global context of lower prices, increasing competitive pressures, greater regulation and declining ore grades, many companies have increasingly focused on innovation to stay competitive. Cost reduction and consolidation have also played key roles in driving productivity improvements coming out of the mining boom. Clearly a suite of factors will need to be brought to bear in returning Australian mining productivity to its former peaks of a decade ago.

In this section some of the challenges Rio Tinto's Pilbara operations face in continuing to drive ever-greater productivity are described. Rio Tinto's approach to meeting these challenges is then outlined by way of the innovation and productivity programs the business is implementing and planning.

4.1 Pilbara iron ore challenges

The environment in which Rio Tinto and other mining companies operate is forever changing. Unlike some other industries that operate in more static and predictable environments, mining and logistics is characterised by complex and often multitudinous unpredictable interactions. For example, volume, grade, and material type are changing variables that must continually be managed for. This fact alone makes it difficult to reliably drive planned performance improvements. Add to this that plant and equipment differs in age, design and capacity within and across multiple sites and it becomes clear that homogeneous improvement solutions have little relevance.

There are also a range of other factors warranting closer attention that ensure the starting point for productivity improvement and cost reduction in Rio Tinto's Pilbara operations is a moving feast, with the bar being raised year on year:

1. Work index is a key indicator of effort required to achieve SOP, which is a measure of total material moved and haul length. As ore bodies are becoming harder to reach in the Pilbara, work indexes are projected to rise. This is typical of maturing mining operations and was discussed in sections 2.5 and 3.2. Over the past decade, drill and blast activities, load and haul and processing activities in the Pilbara have been subject to cumulative cost-escalating factors that are to some extent outside the control of the business, and are expected to continue in the future.
2. Continual development and investment is required to ensure ongoing production capacity and risk mitigation. Without further investment, mine capacity would constantly fall as depletion rates from existing pits accelerate. As such, 2015 capital expenditure in the Pilbara stood at US$1.6B, and over US$580M of this was allocated to sustaining capital.
3. Drilling is essential not only to maintain production, specifications and yields but also for risk mitigation, optionality and long term sustainability. Pilbara reserves could decrease substantially over the next decade without increased drilling to improve orebody knowledge and resource to reserve conversion. Additional drilling also provides insights for evaluation of low capital development pathways, strategic planning and mine sequencing.

4. Community investment is a key requirement in maintaining engagement. As such, despite being cost focused, Rio Tinto continues to support the communities in which it works, including through the Pilbara Community Infrastructure and Services Partnership, the Dampier Community Hub and the Royal Flying Doctor Service.

All of these challenges mean that real productivity improvements are happening continually, but the observed output increments may not be reflective of how much real improvement is actually taking place.

4.2 Rio Tinto innovation and productivity programs

Rio Tinto has approached the productivity challenge from multiple fronts, including via high profile equipment and systems automation programs, by deploying product group productivity programs, and by funding partnerships with leading academic research centres, as well as developing long-term strategic partnerships with key suppliers. These innovations and productivity programs continue to be rolled out across Rio Tinto, delivering significant value with the promise of further applications and productivity enhancements in future. The approach to innovation is now culturally embedded within the company, and performance enhancement is an aspiration at all levels of the organisation.

Perhaps the most high-profile innovation program at Rio Tinto has been increased automation of its Pilbara iron ore operations, and the next section of the report is focused on these innovations. It is worth noting that many of these innovations have had long lead times, with the first Operations Centre trials commencing in 2007. This highlights the commitment required to investing in innovation through the cycle.

4.2.1 Autonomous and remote equipment

Most innovations developed over the past century were reliant on guidance by a human operator, but this is rapidly changing with the development of remotely operated and autonomous equipment. These technologies represent a broad class of innovations that involve a step-change in the R&D effort and are likely to profoundly change how minerals are mined, transported and processed in the future.

Automation can be broadly defined as the intelligent management of a system using appropriate technology so that its operation can occur without direct human involvement (Lynas et al. 2011). Automated and remote machines increase productivity as mining and logistics equipment becomes more reliable, moves faster and covers longer distances, removes shift change requirements and requires fewer operators.

Until recently, most automation effort has been concentrated on the component or subsystem level, and at a relatively small scale relative to the number of mines, transport infrastructure, processing plants and export facilities in Australia.

Rio Tinto has been involved in developing and trialling several automated technologies over the past decade. In many cases these trials are now complete and automated equipment is now permanently utilised across several of RTIO’s Pilbara mines, with plans to expand autonomous equipment utilisation in the future.

As discussed below, Rio Tinto also plans to take automation of its iron ore supply chain to the next level, by significantly extending the automation of its mining and logistics systems through its Mine of the Future™ program.

Drilling and blasting: autonomous drills and 'smart' explosives trucks

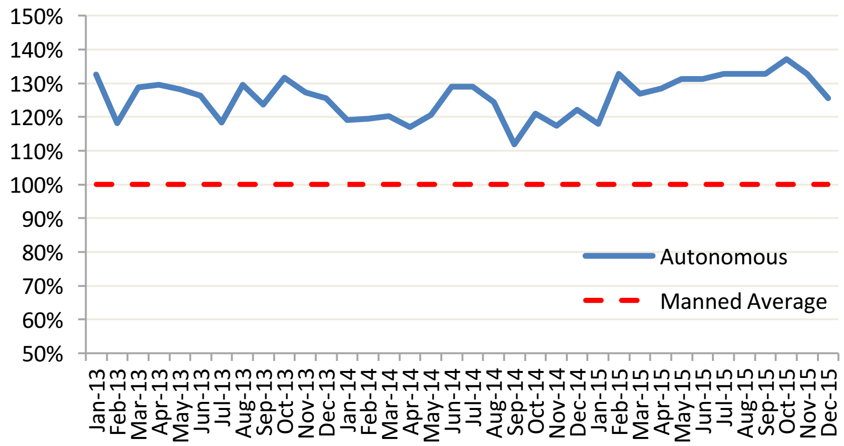
Rio Tinto commenced its Autonomous Drilling System (ADS) project in 2006 and progressed to deployment of autonomous drills at the West Angelas mine site in 2011. Around 20 per cent of drills across Rio Tinto's Pilbara operations are currently autonomous, and the West Angelas mine is the only mine in the world operating all of its large production drills autonomously (CEDA 2015).

Drills are placed on the bench site by operators, then switched into autonomous mode and operated from a remote location. Once operational, they drill the blast holes and collect real-time data to generate an enhanced map of the bench. These drills can accurately pinpoint each drill location, and use automated levelling technology to enable true vertical holes to be drilled. Optimised blasting is subsequently achieved using Rio Tinto's 'Smart' explosives loader. These technologies have realised many benefits for the business including improvements in safety, productivity and cost as follows:

- Improved safety outcomes associated with removing drill operators from hazardous areas, as well as a reduction in health risks associated with dust, noise and vibration. Since commencing operation, ADS has had zero injuries.
- Increased use of availability of automated drills over manned drills of approximately 15 per cent (see Figure 4.2).
- More efficient recovery of the orebody by reducing the amount of waste created and improved fragmentation of the blasted rock.
- More consistent and predictable outcomes from precision drilling and blasting, reduced requirement for re-drilling, and a reduction in consumables such as drill bits and explosives.
- A smaller, upskilled, more productive workforce operating multiple drills remotely, and new roles created in system engineering, communications and data analysis.

Figure 4-2. Comparison of manned and autonomous drills

Use of availability indexed to all manned sites



Source: Rio Tinto

Hauling: autonomous trucks

Rio Tinto currently operates 71 autonomous haul trucks across its Pilbara operations. The trucks have on-board navigation to inform them of the position of other vehicles and communicate with the computer systems at the OC. Trucks are fitted with radars, lasers, sensors and communication antennas and high precision GPS to operate communications, guidance and avoidance systems. These systems enable trucks to use pre-defined GPS courses to automatically:

- navigate haul roads and intersections;
- move within the loading and dumping areas;
- enter the tie-down area for refuelling; and
- interact with manned equipment such as excavators, graders, bulldozers and light vehicles.

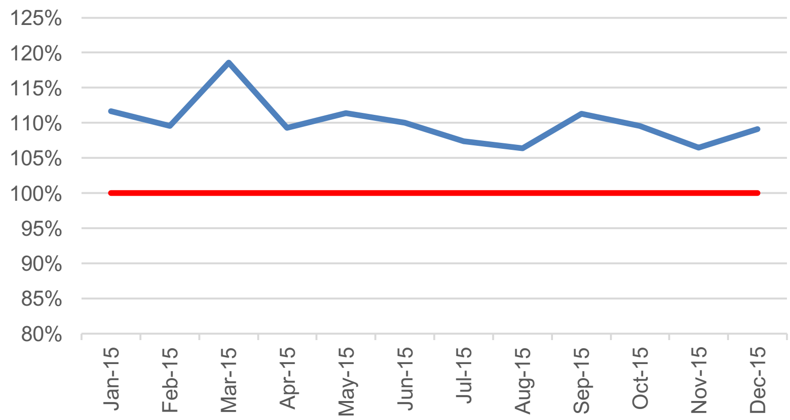
Autonomous haul trucks are demonstrating an average of 14 per cent higher effective utilisation than manned trucks indexed across all manned sites (Figure 4.3). The higher effective utilisation of autonomous trucks has generally resulted in significant cost savings for all sites using autonomous trucks. Utilisation improvements stem from autonomous trucks being able to operate for longer periods within each shift due to avoidance of breaks, absenteeism and shift changes.

There have been no significant safety incidents in haul truck operations, and incidents relating to property damage have also been reduced. Information derived from use of autonomous trucks has also assisted in improving the manned fleet performance. This result has stemmed partly from competition between manned and autonomous systems with manned fleets pushing to meet higher autonomous targets. The lessons learned from the deployment of autonomous haulage have led, among other things, to better pit design across company operations leading to spin-off benefits from the automation program.

Driverless trucks are also being tested by BHP Billiton in the Pilbara and at coal mines in Queensland and NSW, while FMG has installed driverless trucks at its Solomon mine.

Figure 4.3. Autonomous haul trucks performance

% Effective utilisation indexed to all manned sites



Source: Rio Tinto

Source: BAEconomics Pty Ltd

Processing: remote controlled rock breaker and run-of-mine bin

Remote rock breakers are used to smash oversized rocks that are prevented from entering the crusher because of their size and otherwise dumped into the ore receptacle or 'run-of-mine bin'. In conventional operations, an on-site operator identifies an oversize rock with the naked eye and uses a wireless remote-control pack to determine the most effective way to break the rock.

The new remotely controlled technology enables the operator to be based at Rio Tinto's OC in Perth. The remote rock breaker system combines virtual reality and actual reality images, which the operator can access as required to direct the operations of the machine. The choice of interface was determined by conducting a number of human factor studies to find the most acceptable and productive approach. Remote operation of this process has a number of advantages:

- relocating operators to the OC and away from the mine site enables them to perform their work in a safer and cleaner environment;
- instead of requiring a dedicated operator per rock breaker, operators can operate one or more rock breakers simultaneously;
- the technology reduces the number of workers on site and thereby the number of fly-in fly-out personnel and associated pressures on site accommodation; and
- reduced crusher downtime resulting from delays in deploying plant operators to the rock breaker area.

Transport: AutoHaul

Rio Tinto's newest innovation AutoHaul will deliver the world's first fully-autonomous heavy haul, long-distance railway system, designed to improve productivity and enhance safety. It will eliminate the need for around 70,000 kilometres of remote area driving each week (and the associated risks) to get train drivers in place to start or finish their shift, as well as provide flexibility in scheduling and eliminate driver changeovers.

Rio Tinto has invested substantial capital in autonomous trains for the Pilbara rail network, and AutoHaul is expected to facilitate significant additional capacity availability through the planned output expansions without the requirement for large investments in additional trains. AutoHaul is also expected to deliver substantial cost reductions in addition to tonnage benefits. Steady progress has been made in the testing and verification of AutoHaul, including 70,000 kilometres of mainline trials being completed as at the end of December 2015.

Source: BAEconomics Pty Ltd

Product handling: remote ship loading

For Rio Tinto's Pilbara mining operations, the end of the supply chain is marked by a loaded vessel. A key determinant of the safe passage of the vessel to its destination is dependent on how it has been loaded. Timely and efficient loading of the vessel is critical to the production capacity of the Pilbara operations. Thus getting the ship-loading process right is critical for vessel safety, customers and operations.

Source: Rio Tinto Innovation Development Group

A significant information gap in the loading process is that the loading operation is conducted without detailed information on how the vessel is responding to the load and its position in the water. The current practice to keep the vessel upright during loading relies on ship-loader operator visual observation, list indicator lights on the vessel's bridge, and frequent radio instructions from the vessel's Chief Officer. The ship-loader operator needs regular feedback to avoid consistently loading off-centre and causing excessive and unsafe list. List indicator lights on the bridge give a measure of list, however it is very coarse and frequent radio communications are still required, and sometimes complicated by language issues and simultaneous task requirements.

The ship-loader operator also has to deal with the changing position of the vessel relative to the ship-loader as tide and vessel load states vary. This affects collision separation distances and restricts ship-loader movements.

The portion of the ship-loader typically in close proximity to the vessel is well below and behind the ship-loader operator. Direct visual observation of clearance is impossible and the ship-loader operator has to rely on a spotter or CCTV, which is subject to dust and lighting issues and makes separation perception difficult.

The Remote Draft Survey (RDS) platform closes current information gaps by providing real time measurement of the vessel position - before, during and after loading. RDS monitors air draft and ship-loader to deck clearance, thereby assisting the ship-loader operator to avoid collision with the vessel. RDS also monitors list, assisting the ship-loader operator to keep the vessel upright within safety limits whilst loading. The additional information provided by RDS also allows the ship-loader operator to load more efficiently during difficult viewing conditions and to ensure that the vessel has 0° list during the critical final portion of the loading process. Currently RDS is in early deployment at four Pilbara berths.

4.2.2 Systems automation

In the wake of successes with implementing various types of autonomous mining equipment, Rio Tinto's focus has now firmly shifted to developing the autonomous systems that can carry out tasks automatically or with a minimum of external control. The goal is for automation to allow collection, analysis and use of large amounts of disparate information to deliver unified end-to-end interlinked processes from mine to port.

Fully automating mining and logistics processes remains a formidable task, however. While robots used in other industrial processes generally remain stationary and perform tasks on products or components conveyed to them, mining and logistics robots must move around, often in complex environments. Automated technologies are therefore only made possible by increased computing power; new algorithms for signal processing, perception and control; and new sensing technology for monitoring landscape geometry, including GPS, radar and laser systems. The requirements to develop and operate these technologies are correspondingly complex and rely on high-level interdisciplinary skills. Additionally, automation technologies are difficult to retrofit to existing equipment, and significant practical problems remain in making all the pieces of equipment and software fit together and work with each other.

Despite these challenges, Rio Tinto is making progress with its Mine of the Future™ vision and an associated goal to automate an integrated mine and logistics system.

Operations Centre and enabling technologies

The Operations Centre is a state of the art facility in use since 2009-10 that enables operation of all of Rio Tinto's Pilbara mines, ports and rail systems from a single location in Perth. The Operations Centre facilitates the operation of RTIO's assets as an integrated system, and acts as a point for central decision making, dynamic scheduling and planning, and condition based monitoring.

It utilises visualisation and collaboration tools to provide real time information across mining, maintenance and logistic activities. The centre currently undertakes the remote monitoring of a number of significant assets and oversees full-scale trials of autonomous trucks, drills and ship and train loading operations. It operates 24 hours a day, 365 days a year and is staffed with more than 400 controllers, schedulers, technical, planning and support staff (Rio Tinto, n.d.). The centre has been designed to control and monitor on a real-time basis Rio Tinto's entire operations across the Pilbara, including (currently) 15 mines, 1,700 km of rail, four port terminals, and power generation facilities at Dampier, West Angelas and Paraburdoo, and ultimately all trucks, drills and trains. The removal of human intervention from site to the Operations Centre is important in that it not only improves safety, but has the potential to significantly boost productivity, reliability and repeatability.

A number of advanced technologies enable the many monitoring, operational and planning processes undertaken by the centre, not least of which is the RTVis™ visualisation software. This three-dimensional visualisation software analyses in-ground data for the next phase of the Mine of the Future™ program. RTVis™ software is linked to Rio Tinto's Mine Automation System (MAS), providing a 3D representation of mine activities in real-time.

The MAS retrieves data from all the available production systems operating in the mine, including autonomous trucks and drills, and creates 3D images of mine pit activities to reveal information about the mining operation that could not previously be measured, including ore bodies, equipment usage and pre-blast optimisation.

RTVis™ has led to greater ore recovery through improved boundary identification, more accurate drill blasting and reduced costs in explosives, and improved waste classification, dig rates and field task planning. The new technology is deployed at several of Rio Tinto's iron ore mines in the Pilbara, and is being used to accurately identify material boundaries. Trials are also underway in other Rio Tinto product groups including Copper and Energy, and Diamonds and Minerals.

RTVis™ has also been able to detect the differences between clay pods and clay channels to safely and efficiently access ore-rich zones when mining below the water table. This is a low-cost application that complements existing Group-wide data technology in a way never previously available to enhance mining operations.

This visualisation software allows novel analysis of in-ground data, improving understanding of the orebody at an operation. Application of RTVis™ at the Yandicoogina mine has resulted in a reclassification of more than one million tonnes of material to a high silica ore product for blending. At West Angelas, the high-grade recovery program enabled by RTVis™ created a two per cent increase in high-grade ore recovery.

Mine of the Future™

The Mine of the Future™ project represents a concerted effort to automate all aspects of a fully integrated mine, logistics and port system from a remote location, and is the result of a long process of collaboration between Rio Tinto, research centres around the world and key equipment suppliers. The application of the Mine of the Future™ stable of technologies will enable a holistic view of all operations from mine to port and provide near real-time information as a basis for improved decision-making.

In Rio Tinto Iron Ore, Mine of the Future™ has focussed on the following areas:

- automated blast-hole drill rigs that will perfectly position every hole, conduct analysis during drilling, and dictate to the explosives delivery vehicle the explosives load and blend to be charged for each hole;
- an excavator that can 'see' the difference between ore and waste in the muckpile, can separate the two, and will automatically load a driverless haul truck before dispatching it;
- driverless haul trucks that safely navigate around the mine landscape to move waste and ore in a precisely optimised manner without human intervention, and that automatically report to workshops when re-fuelling or maintenance is due;
- remotely operated rock-breakers;
- the use of advanced sorting machines that are capable of upgrading low grade ores and significantly extending mine life;
- the incorporation of autonomous sensing equipment to fine-tune beneficiation and other processes so as to maximise recovery and save on energy and water use;
- the operation of driverless trains that seamlessly and reliably deliver product to automated train load-outs;
- ongoing coordination of all mine operations from mine to port so that quality controlled, correctly-blended product is available at port ready for shipment to customers;
- on-site employees that undertake essential service and maintenance and are assisted remotely by experts situated long distances away; and
- a remote operations centre that oversees the entire integrated operation of the mine while experts constantly analyse and fine-tune processes that enable the ongoing real-time update of knowledge about the full set of orebodies being mined.

The key goals of Mine of the Future™ are two-fold and involve achieving productivity gains in large scale surface mining, and extracting more ore from complex orebodies. In doing this, the program also aims to improve employee safety and reduce energy use and environmental impacts.

4.2.3 Excellence centres

In March 2014, Rio Tinto opened its first Excellence Centre in Brisbane bringing together subject matter experts from across the resources sector. These teams work in conjunction with process engineers, analytics teams and external partners to improve operating efficiencies at coal and copper sites around the world using real-time data analysed by world-class subject matter experts.

In the first centre of its kind in the industry, the Excellence Centre incorporates a state-of-the art collaborative workspace where personnel use interactive screens to analyse processing data and interact with site based personnel in real time.

The Excellence Centre differs from the Operations Centre in Perth in that it focuses on optimising a specific part of the value chain across unlimited sites anywhere in the world, and does not have control functionality.

The Excellence Centre team is extended through an in-house Analytics Excellence Centre (AEC) in Pune, India, where Rio Tinto has partnered with the US based global business group IGATE, who provide analytical capabilities to identify opportunities for enhancing efficiency and productivity across managed operations.

Rio Tinto's AEC was opened in March 2015. The centre assesses massive volumes of data captured by the array of sensors attached to Rio Tinto’s fixed and mobile equipment and enables experts to predict and prevent engine breakdowns and other downtime events, thereby significantly boosting productivity and safety. Using predictive mathematics, machine learning and advanced modelling, data scientists in the AEC will be working to identify a range of problems before they occur. This analysis will reduce maintenance costs and production losses from unplanned breakdowns. The AEC is designed to allow extraction of maximum value from data capture on the performance of equipment, thereby making operations more predictable, efficient and safer.

4.2.4 Current and prior collaborative programs in research and development

Automated technologies are only made possible by increased computing power, new algorithms for signal processing, perception and control and new sensing technology for monitoring mine geometry. Developing and operating such technologies is a complex task requiring high level inter-disciplinary skills, which are often learned through research and development and lead to new job opportunities in commercial implementation and operation.

Australia is a global leader in research into mining automation (Durrant-Whyte 2010). Innovative and productivity enhancing partnerships have been fundamental to Rio Tinto’s operating model for decades. Long term collaborative partnerships between Rio Tinto, research centres and key business partners have been run over many years, focused on specific strategic supplier relationships and academic initiatives aiming to drive to commercialisation.

The Rio Tinto Centre for Mine Automation (RTCMA) is one of a few key research centres in mining automation and focuses on machine learning, sensing technologies, data fusion and systems engineering. RTCMA was established at the University of Sydney in 2007 and funded by Rio Tinto with $21 million for an initial period of five years, resulting in the world’s biggest commercial privately funded external robotics initiative. The centre’s work has so far resulted in a number of major research advances targeted at improving the safety and productivity of autonomous operated mining sites. The research agreement with Rio Tinto has now been extended for an additional five years to support the next phase of research into step-change improvements in safety, predictability, precision, and efficiency.

The RTCMA is one of a number of research centres funded by Rio Tinto with links to universities:

1. The Rio Tinto Centre for Materials & Sensing, based at Curtin University in West Australia.

2. Collaborative efforts at UWA are focused on pooling knowledge in the development of an Airborne Gravity Gradiometer, which is advanced exploration technology designed to detect buried, otherwise invisible orebodies. Operating from an aircraft, it is the next generation airborne survey system and will become essential in discovering the next generation of mineral resources as ore bodies become harder to find.
3. The Perth USAsia Centre also situated at UWA is an international policy think tank, with which Rio Tinto has announced a four-year partnership to support policy, research, education and network building programs to increase industry participation, technology development and strategic community and stakeholder engagement to foster future opportunities in North America, Australia and Asia.
4. The Rio Tinto Centre for Advanced Mineral Sorting at the University of Queensland, which undertakes research in the areas of mineral excitation, non-destructive sensing, mineral sorting classification and orebody classification;
5. The Rio Tinto Centre for Underground Mine Construction in Canada, which focuses on rock mechanics, geotechnical rock mass modelling, mechanical excavation and underground construction techniques; and
6. The Rio Tinto Centre for Advanced Mineral Recovery at Imperial College (London), where research focuses on the fundamentals of rock fracture and processes to improve the efficiency of mineral extraction.

Rio Tinto also has long-standing industrial partnerships both within and external to the resources industry. For example, the autonomous trucks program was developed in collaboration with Komatsu, under an agreement of unprecedented scale that has been in place since 2008. Between 2008 and 2011 Rio Tinto trialled Komatsu's AHS trucks and began deploying them in 2011. Komatsu allocated people to work with Rio Tinto's autonomous team co-located in Perth to underpin the collaborative efforts.

Ansaldo Australia is also a strategic partner with RTIO, having signed a $A467 million five-year contract in 2010 for the provision of signalling, communications, train control and automation systems to support Rio Tinto's expansion and operational efficiency projects in the Pilbara. The partnership was refreshed in 2012 as the two entities agreed to collaborate on developing AutoHaul to enable complete automation of train operations.

In addition to project partnerships, Rio Tinto places critical importance on the role of government and industry in fostering STEM (science, technology, engineering and mathematics) education. As such, Rio Tinto has partnered with Scitech to promote STEM subjects in primary and secondary schools through interactive learning programs.

4.2.5 Continuous improvement

Rio Tinto runs core programs in continuous improvement including system wide high value initiatives, and site specific value chain improvements to constantly drive higher productivity.

High Value Initiatives (HVIs) are system wide projects with dedicated cross-functional teams that deliver significant cost and productivity improvements via improved process planning. Several achievements have been reported by RTIO:

- reduced rehandling of product by 16Mt in 2014 and a further 25Mt in 2015;

- reduced yard to yard cycle times for the rail fleet by 13 per cent;
- reduced Cape Lambert B hatch changes by 1 hour per ship; and
- conveyor belt life increased by 30 per cent and belt up-time improved 30 per cent at the ports, with further benefits expected via roll-out to inland equipment.

Site specific value chain improvements are assisted improvement projects targeting value chain bottlenecks at specific sites. RTIO reported significant increases in stacker capacity, truck wait times and truck productivity as a result of these targeted initiatives (Rio Tinto 2015a).

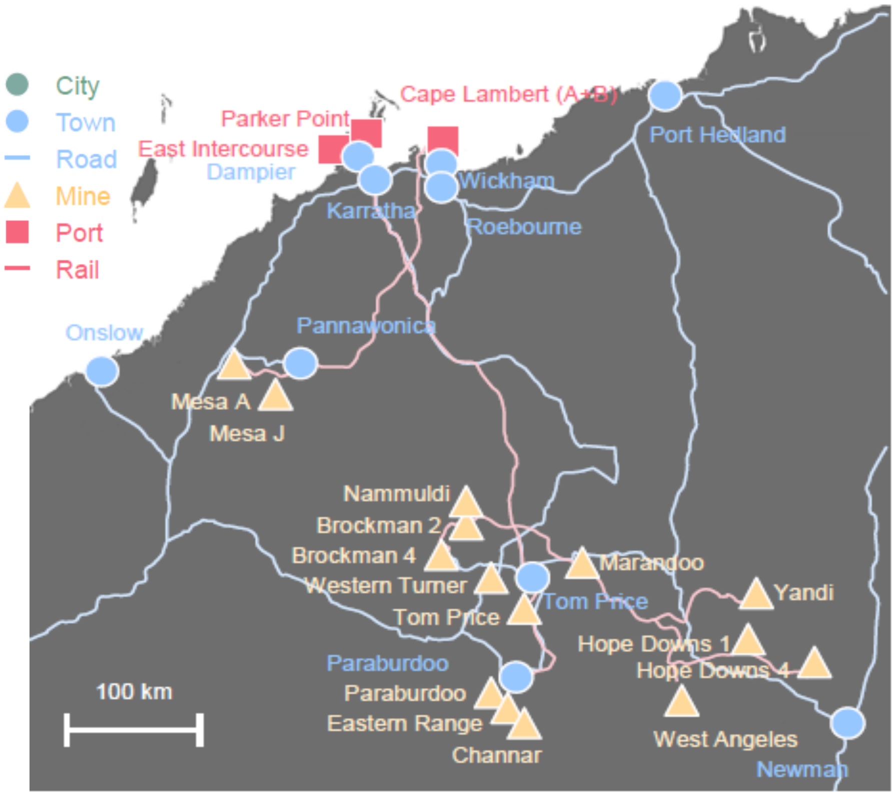
Ingrained in RTIO's culture is also the notion that small everyday changes to improve efficiency and eliminate waste can significantly lower total costs. In 2014, staff-led initiatives reduced costs by tens of millions, and identified hundreds of potential safety hazards for pro-active management.

5. Rio Tinto innovation – Making a difference

5.1 Pilbara network

Rio Tinto Iron Ore (RTIO) is the world's second largest producer of iron ore and a sophisticated logistics business. Rio Tinto's Pilbara iron ore operations network spans a vast area in northern West Australia and is fully integrated via an Operations Centre in Perth. The integrated network includes fifteen iron ore mines, four independent port terminals, three power stations, a privately owned 1,700km rail system including 190 locomotives and related infrastructure.

Figure 5.1. Pilbara operations



While the company mines iron ore, its extensive rail, port and utilities networks that are required to get the product to market mean Rio Tinto is also a major infrastructure and logistics player. The scale of operations, both in terms of size and distance is striking. Each year, RTIO drills a distance equivalent to the diameter of the Earth, and ships the same amount of cargo as passes through the Panama Canal. Every day, RTIO moves enough rock to fill the Melbourne Cricket Ground, its trains cover a distance equivalent to a return trip on the Trans-Siberian railway, and the enterprise uses the same amount of electricity as the city of Newcastle (Rio Tinto 2015a).

The product ultimately sold is iron ore, however the business is also heavily reliant on logistics. Without seamless, integrated, and highly efficient logistics processes, the business cannot sustainably generate value. Iron ore is sold in a highly competitive global market and commodity prices are set by prevailing market factors outside the control of individual producers. To generate value, companies must seek ongoing cost and productivity enhancements through continual incremental improvements throughout the supply chain, as well as step change innovations.

Rio Tinto's Pilbara operations commence with exploration and assessment activities and end with loaded ships arriving at international ports (Figure 5.2), and every activity in between requires careful planning and execution to ensure maximum productivity of the supply chain as a whole. A bottle neck or failure of any one element along the chain can have significant detrimental impacts on the output of the entire system.

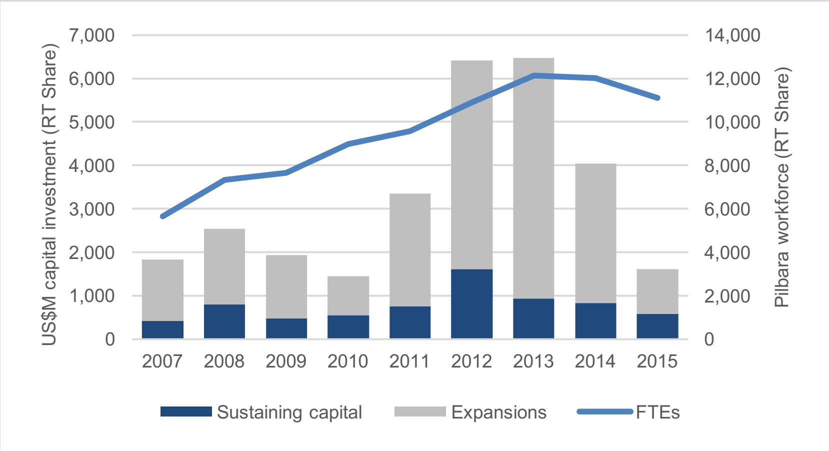
The high quality, fully owned and operated assets in the Pilbara provide Rio Tinto with high optionality and control over the entire supply chain, from exploration phase through to customer delivery. This is key to many of the programs designed to drive productivity gains from the system as the operations move from expansion mode to full capacity utilisation. This is also key to the ability to automate and optimise the system as a whole.

Figure 5.2. Integrated logistics business

Rio Tinto has invested many tens of billions of dollars in the Pilbara region since the 1960s. In addition, the company has been a key employer over several decades, and as of December 2015 directly employed over 12 000 people across its Pilbara operations (Figure 5.3) including around 1 000 indigenous employees, about 1 000 regional FIFO employees and around 1 000 relief contractors.

Capital outlay in the Pilbara peaked during 2012-13, with annual expenditures of around US$6.5 billion as Rio Tinto commenced building its 290 Mtpa mine expansions and 360 Mtpa infrastructure expansion. While capital investment has fallen as these expansions have approached completion, 2015 capital outlay in the Pilbara still exceeded US$1.5 billion, primarily owing to 40Mtpa of brownfield expansions and finalisation of the infrastructure program.

Figure 5.3. Pilbara capital and labour deployment



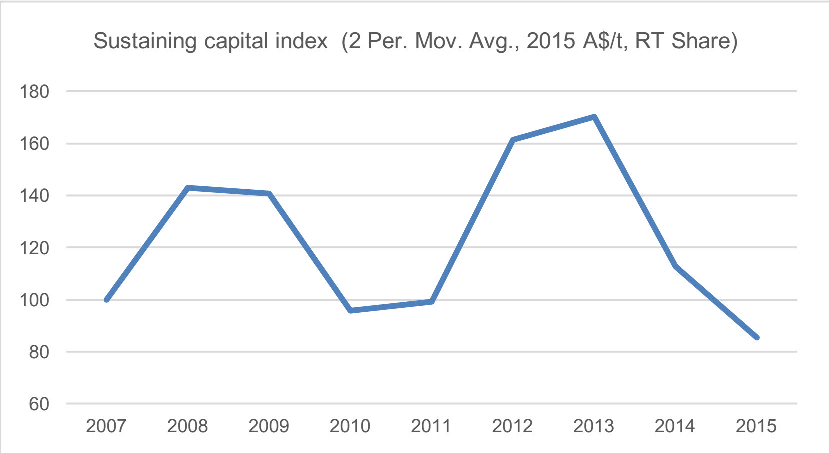
Note: Sustaining mines not separately identified prior to 2011.

Source: Rio Tinto, Rio Tinto annual reports per year of production

As discussed in section 2, mining productivity has been publicised in the media and some official statistics as having fallen dramatically during the boom years. Several authors examining this issue determined that various external factors were at play, including the lag between capital investment and increased output. This observation certainly holds true for Rio Tinto's Pilbara operations, where capital productivity normalised for growth projects displays significantly better results than aggregate capital productivity.

Figure 5.4 shows the A$ per tonne Pilbara sustaining capital productivity index based on ore shipments excluding capital deployed to sustaining mines and expansions. The chart indicates that whilst capital productivity declined in 2007-09 and from 2010-12, capital costs per shipped tonne have been falling since 2013, and are now substantially lower than in 2007. In other words, true capital productivity, excluding capital projects not yet operational and capital deployed to replace existing mines, is significantly better than some headline figures might represent. Moreover, the trend in capital productivity is now improving relative to the entire period of the mining boom, as evidenced by the downward-sloping trend line showing unit capital costs from 2012.

Figure 5.4. Pilbara capital requirement per shipped tonne



Source: Rio Tinto

It is important to note that whilst capital productivity fell during the mining boom years, this was an expected outcome given high competition for capital resources globally. Continuing to add capital to the production mix to drive higher output was also rational for mining companies given the opportunity cost (represented by the iron ore price) of lower tonnes.

While capital expenditure on automation has a high initial outlay, the investment proposition is based on value and return on investment. Overall, automated technologies in Rio Tinto's Pilbara operations have demonstrated significant productivity, reliability and safety benefits over and above standard equipment in multiple applications.

Of course, as with all new technologies, ramp up takes time and system failures are part of the learning process. Ultimately however, capital productivity is enhanced using automated equipment because it operates in a more predictable, controlled and precise manner. The various technical efficiencies that can be achieved are multifaceted and interrelated, and arise both at the process level and at the wider system level if processes are better integrated.

Automation extends the life of assets and eliminates a range of inefficiencies, as well as underpinning product performance including by:

- automated trucks and LHDs reducing or eliminating unnecessary wear and tear and fuel consumption;
- increasing the effective utilisation of equipment by not having to cease operations due to human factors including rest breaks;
- reducing or eliminating the need to repeat tasks such as re-drilling blast holes that do not meet specifications;
- placing equipment in precisely the right position to reduce unnecessary movements, for instance in the manual operation of ship loaders;
- reducing the use of energy and consumables, for instance because automated processes measure and adjust input requirements in real time; and

- technology programs consistently producing the right number and quality of tonnes, at the right location and time, which is key to product performance and optimising output and blending requirements.

The application of 'Big data' techniques is another potentially significant benefit attached to automation. The term typically refers to the use of large datasets for predictive analytics or other advanced means of extracting value from data, including improved accuracy, greater operational efficiency, cost reduction, better decision making, and lower risk. As computing power has progressed, and access to information-sensing mobile devices, aerial remote sensing, software logs and wireless sensor network technology has grown, access to vast amounts of information has correspondingly ballooned. Hilbert et al. (2011) estimate that since the 1980s, the per person capacity to store information has roughly doubled every 40 months.

IQPC (2014) estimated that mining investment in IT is due to multiply 5 times by 2017, partly due to the vast amounts of data produced on a daily basis by every phase of a mining company's value chain. A particular area of focus is real-time data acquisition and analytics to improve day-to-day operations. This is the type of data collection and analysis that Rio Tinto's Analytical Excellence Centre in India has been established to undertake.

Automated equipment designed to capture this type of information has the additional benefit that it can be better maintained, with less risk of catastrophic failure as the data can be effectively utilised for maintenance monitoring purposes. Traditional equipment maintenance takes place in fixed cycles or once an asset has failed. With greater automation that includes the use of sensors and other remotely transmitted data, equipment comes in for maintenance when a part is reliably observed to be approaching failure. Diagnostic tools that are incorporated in automated equipment allow faults to be identified more quickly, and also reduce equipment downtime. Maintenance costs are thereby brought down, since planned maintenance costs around six times less than unplanned maintenance.

The counterpart to efficiency improvements at the individual process level is improvements at the system level. Taking a holistic view of the operations using integrated real-time information, the Rio Tinto Operations Centre can analyse and coordinate operations across multiple sites and at all points in the value chain. More informed decisions are therefore made on the basis of real time data, for instance about the geology of the mine.

As sensor and data analysis capabilities have advanced, mine planning has become considerably more sophisticated with multiple efficiency, cost and safety benefits. However, the use of big data remains in its infancy, and the mining industry still has plenty of opportunity to fully leverage the capabilities of big data. There is a real competitive advantage to be obtained through optimising the use of big data systems that by definition are tailored to individual operations and therefore not easily replicated by competitors in an innovator-imitator paradigm.

Another mode by which automation improves performance and reduces cost is by essentially substituting labour and other inputs for capital to achieve the same or better production outcomes. Automation achieves this by significantly improving performance consistency and reducing variability, reducing equipment downtime and thereby increasing utilisation rates, lowering maintenance costs and enhancing safety. Automation also reduces the cost of transporting and housing employees at remote sites by moving workers to a safer environment, and assists in promoting social wellbeing by increasing the proportion of metropolitan versus remote workers, which in some instances has social benefits.

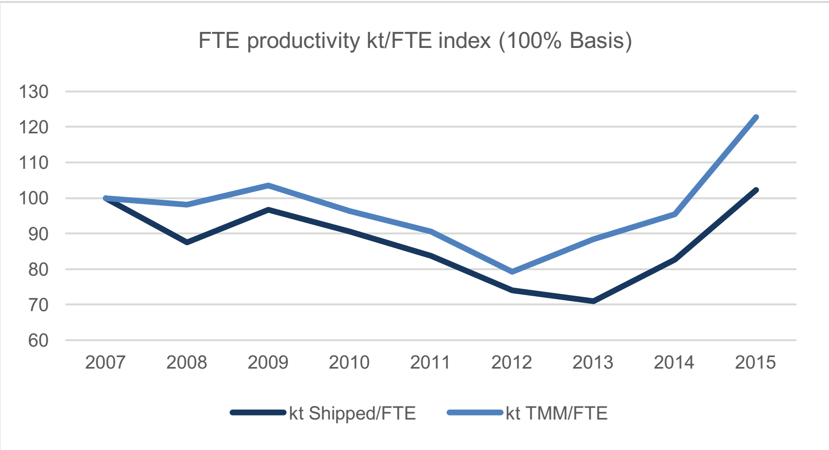
While automation can reduce overall employee numbers as operators undertake multiple tasks at the same time, where automation results in a reduction in workforce, oftentimes employees are re-trained for roles in other areas of the business. In such cases, employees benefit from upskilling and higher quality jobs, with attendant benefits of greater workplace interaction. For example, the Rio Tinto Operations Centre provides a highly interactive workplace with a high level of internal communications. This creates consistency and improves performance because maintenance, production and shift plans are all devised and executed centrally, which improves the efficiency with which decisions are made.

Importantly, retaining old labour practices that resulted in a decline in labour productivity would serve only to reduce Australia's international competitiveness, and ultimately put jobs at risk.

Labour productivity in the Pilbara has followed a somewhat similar pattern to capital. Rio Tinto has made significant reductions in its labour force in an effort to return headcount to more normalised levels, and reported labour productivity in its iron ore division has improved 20 per cent over the past year (Rio Tinto 2015b).

Figure 5.5 charts Pilbara labour productivity on both a total material moved (TMM), and shipments basis. Between 2009 and 2013, labour productivity declined on a shipped tonnes basis but is now back to pre–boom levels. Labour productivity measured against TMM is around 20 per cent higher than in 2007. The difference in productivity between shipped tonnes and TMM reflects the higher work index as ore grades have declined in some mines.

Figure 5.5. Pilbara labour productivity



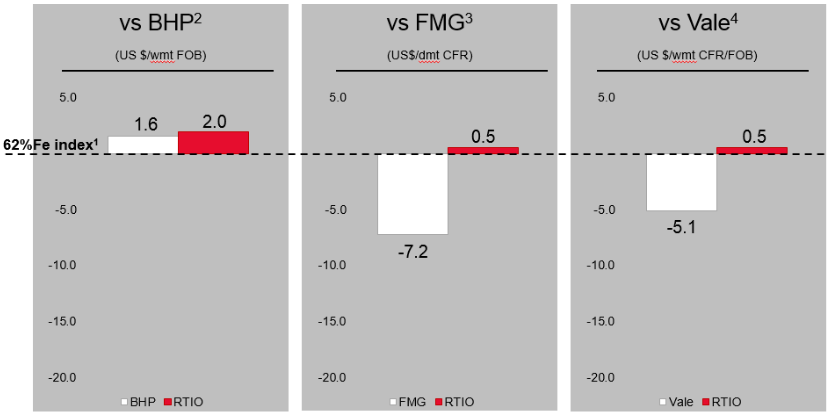
Source: Rio Tinto

Key to Rio Tinto's iron ore marketing strategy is its high quality suite of products, including the flagship Pilbara Blend. Rio Tinto began producing Pilbara Blend in 2007 to allow mixing of different grade and purity ores across most of its Pilbara mines. The product assists RTIO to deliver high quality, low variability iron ore reliably to customers, whilst optimising business performance by simplifying handling and aligning the total product mix with the resource base to maximise output. Pilbara Blend fines is now the most traded iron ore product in the world. The automated technologies adopted by Rio Tinto along with Operations Centre oversight are important components of maintaining Pilbara Blend product performance as they improve the ability to consistently produce the right quality tonnes, at the right locations, and at the right time to optimise output and value.

Rio Tinto's iron ore products are higher quality and perform better on pricing against both the iron ore price index and against local and international competitors (Figure 5.6), meaning State and Federal governments are collecting higher revenues.

Figure 5.6: RTIO products capture full value

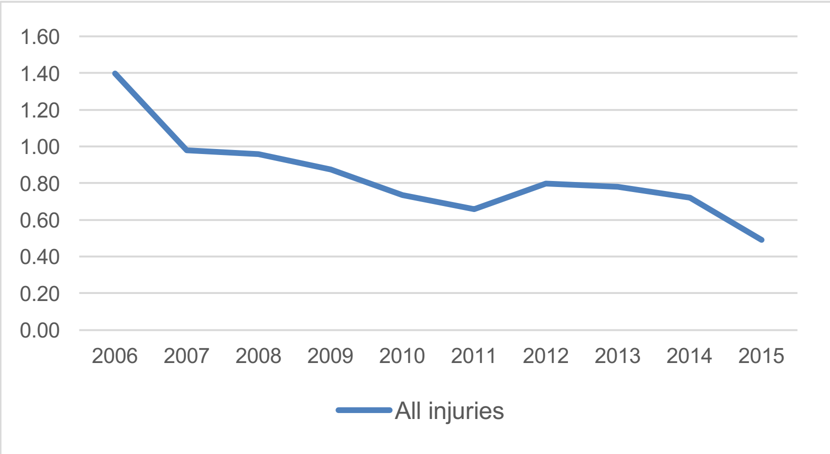
H2 2015 absolute price comparison:



Source: Platts, The Baltic Exchange.
1 For the BHP comparison, the index has been adjusted to FOB basis by assuming BCI C5 (WA-Qingdao) and 8% free moisture.
2 BHP Billiton Half Year Results for the year ended June 30 2016, page 3.
3 FMG Half Year Results for the Year ended June 30 2016, Media Release, page 2.
4 Weighted average of Vale Quarterly Financial Results. Iron Ore fines CFR/FOB realised price (ex-RoM & Pellets). Vale 2015 Earnings Release, page 35, 37.

Health and safety is an ongoing priority across Rio Tinto. Mining and associated heavy machinery operation, as well as rail and port activities and extensive long distance driving all place people in situations where safety must be rigorously managed at all times. Across Rio Tinto's operations, the frequency rate for all injuries has fallen around 65 per cent since 2006 (Figure 5.7), owing to a strident focus on safety and cultural change. The introduction of automated technologies within some parts of Rio Tinto's operations have also assisted in lowering the injury rate.

Figure 5.7. Iron ore all injury frequency rate (per 200 000 hours worked)



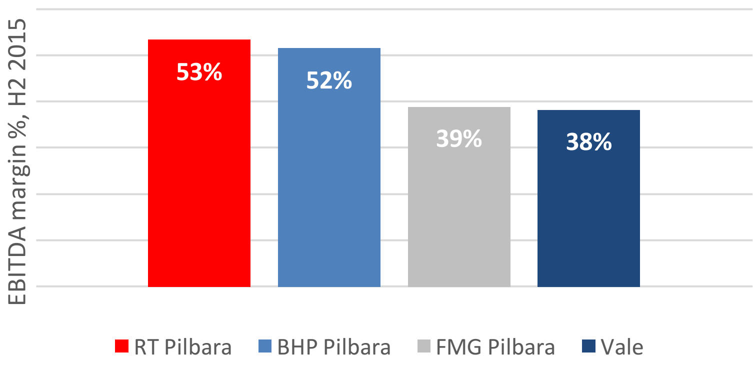
Source: Rio Tinto

5.2 Rio Tinto competitive position

Innovation and productivity programs implemented by Rio Tinto in recent years have paid real dividends. In 2015, Rio Tinto Iron Ore delivered $1.1 billion in cumulative cost savings against the 2012 base. This is reflected in Pilbara cash unit costs which fell to US$18.70/tonne in H2 2015, down from US$20.40/tonne at the same time the previous year (Rio Tinto). These improvements mean that Rio Tinto occupies a leading cost position amongst global iron ore suppliers, which is critical as the industry appears set to remain in a low price environment for some time. Rio Tinto will need to continue to work hard to retain a competitive low cost position as Vale's new iron ore mine S11D comes online with extremely low cash costs, and the added advantage of low oil prices reducing freight differentials into Asia.

The EBITDA (Earnings Before Interest Taxes Depreciation and Amortisation) margin of Rio Tinto's Pilbara iron ore operations outperforms its competitors, owing to top quality assets, low cash costs and rigorous focus on productivity enhancement (Figure 5.8). However, this position could easily be eroded without continuing enhancements in Rio Tinto's innovation and technology leadership programs and associated performance improvements.

Figure 5.8. Earnings comparison: major iron ore producers



Source: Rio Tinto, BHP, Vale, FMG Annual reports

Rio Tinto has a first mover advantage when it comes to automation of its operations. However, some Pilbara competitors such as BHP Billiton have also commenced the process of automating some parts of their operations. FMG, as a newer operation, has indicated fewer benefits to full equipment automation and as such this is not currently on their agenda.

While Rio Tinto profits directly from the innovation and technology programs it has established over many years, given the importance of the mining sector to the Australian economy, the broader economy-wide knock-on effects from automation are likely to be substantial. The range of external benefits to the wider economy may include the following:

1. Innovation is likely to be critical in supporting the ongoing wealth creation of the sector given intense international competition and other structural challenges facing the Australian mining sector today.
2. Increasing demand for mining technology services and equipment (MTSE)[3], with potential application in other sectors. As technologies have progressed, the range of applications has widened and a number of companies now supply industries beyond mining. This sector is set to become a major export earner as a spin-off from the mining industry, which in turn creates jobs, services and products.

[3] The MTSE sector mainly consists of small to medium sized businesses employing 50 or fewer people and specialising in:

1. technology applications for exploration, mine development, mining, minerals processing, minerals handling and transport, and mining maintenance technologies; they include remote sensing, airborne and ground exploration technologies, exploration and mine planning software, remote control systems, protection systems and communications systems;
2. equipment and machinery manufacture and supply, including of scientific and electronic equipment, but also heavy plant, machinery and equipment;
3. consulting services, such as surveying, geological, mining, geotechnical engineering, scientific research, laboratory and testing, environmental management, training and other services; and
4. contract services, including specialist on- and off-site service contractors.

3. Successful partnerships and funding of academic and research institutions, and promotion of STEM education.
4. Capital, labour and multifactor productivity enhancements resulting in improved allocative efficiency, and potential increases in GDP growth and living standards.
5. Health and safety benefits to employees, with reduced travel time for workers no longer required to fly-in and fly-out to/from remote locations, as well as reported improvements in working environment, and family stability.
6. Enhanced labour productivity, including from lower worker attrition rates and increased female participation, and resulting higher wages.
7. Second round effects, for example those resulting from higher consumption of goods and services associated with increased wages. Stimulating consumption drives production in other industries with associated increases in employment and incomes in those sectors.
8. Potential to transfer knowledge and skills built in the Pilbara to other countries, thereby driving technology and education exports.

Exploration of the broader economic effects of Rio Tinto's innovation and productivity programs merits consideration but is beyond the scope of the current paper. However, it is worth posing the counterfactual in concluding this paper; namely how would Australia's mining industry evolve if operations were not increasingly automated and driven to higher levels of productivity and innovation, and how significant the implications for the Australian economy if the minerals sector gradually declined in competitiveness relative to the rest of the world.

Appendix 1

Table A-1. Significant international mining expansions

Country	Mine	Minerals	Reserves	Status
Brazil	Carajás Serra Sul S11D	Iron ore	4.2Bt at 66.7% Fe Proven and Probable Reserves	$19.6 billion expansion underway to commence 2016, ramping to 90Mt by 2018, production to 2065
Guinea	Simandou	Iron ore	1.8Bt Reserves at 65.5%Fe 2.7Bt at 65.3%Fe Indicated and Inferred Resources (inclusive of reserve)	Development announced, expected to produce 95 Mtpa over 30 years
Cameroon / DR Congo	Mbalam	Iron ore	Probable Reserves 517Mt at 62.2%Fe LG Resources of 5.6Bt at 34%Fe	Development to produce 40 Mtpa over 13 years then additional 20+ yrs concentrate production
Brazil	Minas Rio expansion	Iron ore	Reserves 2.8Bt at 34.4%Fe Total Resource 6.35Bt at 34%Fe	Planning ~11-14Mt of concentrate in 2015 24 – 26Mtpa in 2016 26.6 Mtpa in 2017
Indonesia	Indomet	Coking and thermal coal	1.27Bt Proven and Probable Resources	Planned expansion to 5Mtpa by 2017
Mongolia	Tavan Tolgoi	Coking coal	Reserves estimated at 7.4Bt	Development potentially large, currently constrained by location, logistics and regulatory uncertainty
Republic of Sakha, Russian Federation	Elga	Thermal and coking coal	Reserves estimated at 2.2Bt	Mine being developed to produce 9Mtpa ROM
Mongolia	Oyu Tolgoi – Hugo North	Copper and gold	Reserves 28.38B lb copper, 14.97 M oz gold Measured & Indicated Resources 15.39B lb Cu, 8.51M oz Au	Underground mine to be expanded in two phases to operate from 2019-2055. Average 421,000tpa Cu and 245,000 oz pa Au from 2029-2038.
Mexico	Buenavista de Cobra	Copper	Proven and Probable Reserves 8.1Bt at 0.33% Cu	Expansion to 488,000 tpa Cu in 2015
Peru	Cerro Verde	Copper, molybdenum, silver	Proven and Probable Reserves 3,785Mt at 0.37% Cu, 0.02% Mo &	Expansion to 450,000tpa average production from 2016-2040

Country	Mine	Minerals	Reserves	Status
			1.54g/t Ag (milling) and 168Mt at 0.38% Cu (leach)	
DRC	Kamoa	Copper	53.3B lb Indicated and Inferred Resources	7.8 Mt copper over 30 years, with first production from 2021
Canada	McArthur River	Uranium	Proven Resources 498Mt at 18.7% U_3O_8 Probable 555Mt at 11.4% U_3O_8. 345Mlb (156.5kt) contained U_3O_8	Annual capacity 25 M lbs to 2023, with potential to increase beyond this rate

Source: http://www.mining-technology.com; Rio Tinto Exploration.

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