Foundation of a framework for evaluating the impact of mining technological innovation on a company's market value

Mugebe, P.; Kizil, M. S.; Yahyaei, M.; Low, R.

Published in:
Resources Policy

DOI:
10.1016/j.resourpol.2023.103913

Resources Policy 85 (2023) 103913

Contents lists available at ScienceDirect

Resources Policy

journal homepage: www.elsevier.com/locate/resourpol

Foundation of a framework for evaluating the impact of mining technological innovation on a company's market value

P. Mugebe [a,*], M.S. Kizil [a], M. Yahyaei [b], R. Low [c,d]

[a] The University of Queensland, School of Mechanical and Mining, St Lucia, QLD, 4067, Australia
[b] The University of Queensland, Julius Kruttschnitt Mineral Research Centre, Indooroopilly, QLD, 4067, Australia
[c] The University of Queensland, School of Business, St Lucia, QLD, 4067, Australia
[d] Bond University, Bond Business School, Robina, QLD, 4225, Australia

ARTICLE INFO

Keywords:
Mining technological innovation
Autonomous haulage system
Productivity
Mining costs
Stock market value

ABSTRACT

Technological innovation development plays a pivotal role in mineral economics. History shows that the difference between a mineral deposit's economic status and its uneconomic status lies in the mining technological innovation most prevalent in each phase of technological development. The significance of mining technology is that it curbs the negative impact of mineral deposit depletion by improving productivity, thereby keeping mineral exploitation profitable. This relationship makes it imperative to develop a framework that utilises this concept to sustain mining in the future. The framework will incorporate the benefits of technological innovation implementation to demonstrate its impact on a company's share price. It will help public investors understand share price performance while serving as an additional internal new technology investment approval tool.

This paper demonstrates how applying technological development and innovation affects mining processes and its economics. This relationship is evident throughout the four historical mining technological stages, which started in the 18th Century with mechanisation, then remote control, automation, and currently, autonomous technology systems. At each stage, the need for a more productive technology arose as the effects of mineral resources depletion threatened mining's profitability. Thus, it can be judged that the future of mining profitability lies in the current advanced technologies that leverage artificial intelligence and machine learning systems. Nonetheless, while mineral commodity miners profit and firm market values grow, the growth is not empirically linked to the technological innovation development that drives it. Conversely, in other industries, the firm's technological development innovation resultant economic metrics, along with macroeconomic factors, are captured and empirically linked to stock market value. This exposes a gap in the financial impact evaluation of mining technology innovation implementation. Therefore, this paper explores the possibility of developing that framework for the mining industry by identifying improved productivity and cost metrics, profit margin growth, and the resultant share price performance.

1. Introduction

The mining industry is faced with many challenges which threaten its continued viability. Firstly, the depletion of high-grade mineral deposits, at the backdrop of global mineral demand for industrial growth and socio-economic welfare (Brundrett, 2014; Mitra, 2019; Ren et al., 2019), is a problem. For industry sustainability, methods to increase productivity must be found to combat the effects of resource depletion (Coulson, 2012; Hartwick et al., 1986; Humphreys, 2019b; Nebot, 2007; Tilton, 2018). The rising costs of labour, equipment maintenance, safety, and environmental stewardship (Brundrett, 2014; Humphreys, 2019a) are another challenge. For all these challenges, the rescue can be found in a cost-saving mining technological innovation which comes as a capital cost but with operating cost trade-offs in incremental "benefits in safety, productivity, tyre life, maintenance, personnel management and environmental stewardship" (Price, 2017). Such trade-off benefits ensure that the mining industry remains profitable and hence sustainable.

This study aims to address a research question from the standpoint that the difference between the economic status of a mineral deposit and

* Corresponding author.
E-mail addresses: p.mugebe@uq.edu.au (P. Mugebe), m.kizil@uq.edu.au (M.S. Kizil), m.yahyaei@uq.edu.au (M. Yahyaei), r.low@business.uq.edu.au, rlow@bond.edu.au (R. Low).

https://doi.org/10.1016/j.resourpol.2023.103913
Received 1 February 2022; Received in revised form 1 June 2023; Accepted 5 July 2023
Available online 21 July 2023

its uneconomic status lies in the level of mining technological innovation most prevalent in each time (Hartwick et al., 1986; Wellmer and Scholz, 2017; Wright and Czelusta, 2003). Some writers such as (O'Faircheallaigh and Corbett, 2005; Jenkins and Yakovleva, 2005; Von Benda-Beckmann, 2001) have presented other factors such as legislation, political, social, and environmental management as strong determinants for economic viability. Agreeably the relevance of these factors cannot be ignored but they can be negotiated through once there is adequate technology to exploit the minerals profitably. Several studies show that mining technological innovation improves the profitability of mineral deposit exploitation by improving mining productivity (Accenture, 2010; Bartos, 2007; Humphreys, 2019a, 2019b; Mitra, 2019; Sánchez and Hartlieb, 2020; Tilton, 1989, 2014; Topp, 2008). Thus, based on a direct relationship between technological innovation and firm market value in other industries (Koellinger, 2008; Nicolau and Santa-María, 2013; Schroeder et al., 1989; Sood and Tellis, 2009), it is expected that share price performance of mineral commodities conforms to the same relationship. Therefore, the research question is whether mining technological innovation has ultimately been linked to share price performance for mineral commodities. If so, could that relationship be used by both mineral commodity operators and the public investors for investment decision making?

Interestingly, the literature shows no evidence of an empirically defined impact of mining technological innovation on a mineral commodity's share price performance. Most literature concentrates on cost benefits, improved productivity, and safety (Brown, 2012; Fan et al., 2017; Mitra, 2019; Tilton, 2014). More benefits are realised with the introduction of Autonomous Haulage System (AHS) technology implementation in open pit mining. However, mining technological innovation impact on share price performance has not been described. This void presents a loss of opportunity to have an empirical relationship between mining technological innovation and share price performance. This study sets the foundation for building that scientific framework.

The framework serves as a common tool that mineral commodity operators and other investors can use to make investment decisions. It will be an additional tool for mining technology projects investment approval process for the mineral commodity operators. The public investors will use it to decide whether to invest in a mineral commodity company that is implementing a radical mining technological innovation. As indicated by Sorescu et al. (2018), many investors follow developments and news about certain organisations. Their investment into or divestment from the organisations is informed by what they find. This two-pronged usefulness of the framework makes this study a worthy exercise.

To develop the foundation of the framework, Fortescue Metals Group (FMG) implementation of AHS was considered for a case study. The study investigated the potential impact of AHS implementation on FMG's stock price. FMG commenced the implementation of AHS in 2012 and realised significant mining productivity and cost improvement (FMG, 2020; Gölbaşı and Dagdelen, 2017; Leonida, 2019), profit margin growth, and a subsequent skyrocketing of share price performance (ASX, 2021). The share price response demonstrated a relationship with mining technological innovation being implemented. This relationship lays the foundation for the development of a framework for evaluating mining technological innovation impact on a company's market value.

2. Mining technology impact

2.1. Mining technological stages and the industrial revolutions

Historically, all step-change increments in mining production are associated with technological innovation development stages at the time. The literature describes four distinct stages in mining technological innovation which are mechanisation, automation, remote control, semi-autonomous and autonomous systems (Brown, 2012; Brundrett, 2014; Coulson, 2012; Da Costa et al., 2019; Flynn, 2000; Garcia et al., 2016; Guerado, 2017; Hovis and Mouat, 1996; Humphreys, 2019a; Igor et al., 2017; Kenett et al., 2020; Marovelli and Karhnak, 1982; Montagna, 1981; Parreira, 2013; Samavati et al., 2019; Vellingiri et al., 2013; Wang, 2014). As such, these set the cardinal points to which the campus of mining development history refers. To gain a broader understanding, context, and impact of the mining technological innovation stages, it is important to look at it with reference to the bigger technological development phases in history, the Industrial Revolutions. The Industrial Revolutions have been segmented into four phases: The First Industrial Revolution, Second Industrial Revolution, Third Industrial Revolution, and Fourth Industrial Revolution. The mining technological development stages overlapped the Industrial Revolutions, as shown in Fig. 1.

As in other industries during the Industrial Revolution phases, mining technological changes and development have been extensively documented, and their benefits explained in terms of increasing productivity (Mitra, 2019; Matysek and Fisher, 2016; Upstill and Hall, 2006; Agarwal and Agarwal, 2017; Brundrett, 2014). Lately, the technological contribution to improving safety also has been documented (GMG, 2020; Price, 2017; Walker, 2014). Naturally, the mineral commodity operators who embrace such technological innovation invariably increase their market value and growth. Leveraging on the Industrial Revolution developments, new and more productive mining technology arose, improving productivity, despite the threats of mineral resources depletion. As shown in the copper and iron ore productivity graphs in Figs. 2 and 3, the steep positive gradient sections align very closely with the technological development stages.

One would then expect that the financial impact of these remarkable productivity boosts would make headlines in how firms' market value grew because of it. Unfortunately, that information is not available in the domain where mining technology and productivity is explored. Therefore, there is a need to provide a complete evaluation that covers market value growth.

2.2. Current extent of mining technology impact

The literature shows the absence of an empirically defined impact of mining technological innovation implementation on a mineral commodity's share price performance. Most literature on mining technological impact concentrates on cost benefits, improved productivity and safety. Authors such as Coulson (2012) and Humphreys (2019b) gave a detailed account of the early implementation of mining technological innovations dating from the 1800s to the mid-1900s. Absent from their work is the impact of technology on financial performance of the companies. From the mid-1900s to the present, the account of technological innovation implementation extended the list to reduce costs in production and maintenance and improve production efficiency (Tilton, 2014; Mitra, 2019; Brown, 2012; Fan et al., 2017). However, it is important to note that more benefits are covered with the introduction of AHS technology implementation, but not share price performance.

The impact of AHS includes improvements in the following: safety and health performance, fuel consumption, tyre wear, cycle times, labour costs reduction, breakdown frequency reduction, overcoming shortages of skilled personnel, and mining profitability. It has the potential to make some previously uneconomic mines profitable, sustain the competitiveness of mining companies and the industry, enhance a positive national economic outlook, and bring positive environmental impact (Parreira and Meech, 2011; Brown, 2020; Bellamy and Pravica, 2011; McNab and Garcia-Vasquez, 2011; Fisher and Schnittger, 2012; CoalAge, 2018; Walker, 2014). Nonetheless, absent from the work of many writers on AHS technology such as (Redwood, 2018; Price, 2017; Matysek and Fisher, 2016; Harris, 2019; Gölbaşı and Dagdelen, 2017), is the impact of implementation on share price performance on the respective organisations. This is despite the evidence that a firm's stock market value responds significantly to radical technological change (Mary, 2007; Sorescu and Spanjol, 2008; Lee et al., 2000; Doukas and

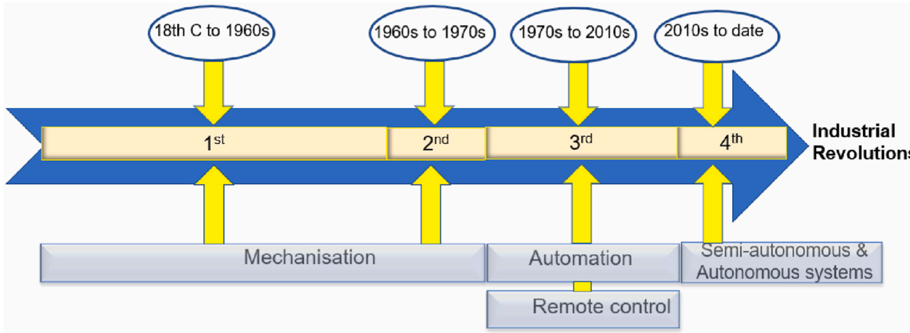

Fig. 1. Mining technology development stages.

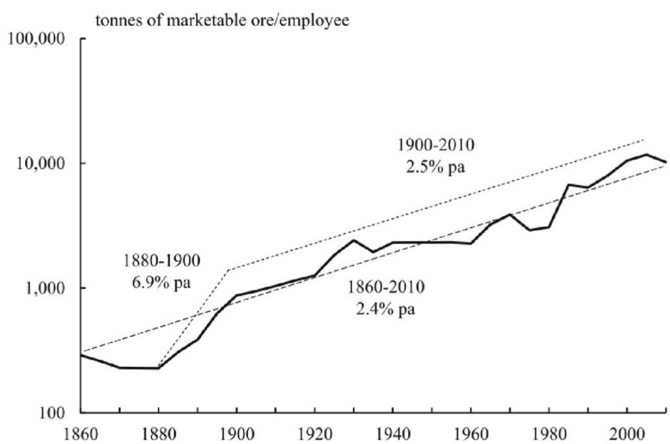

Fig. 2. Productivity growth in US iron ore mining (Humphreys, 2019b).

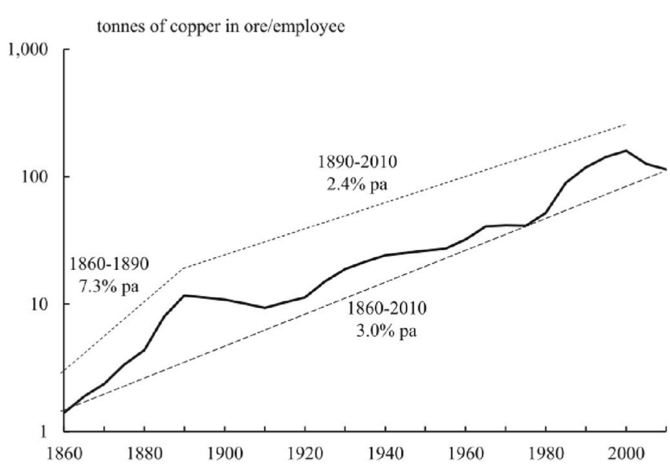

Fig. 3. Productivity growth in US copper ore mining (Humphreys, 2019b).

Switzer, 1992) as demonstrated in many industries. AHS is a radical mining technological innovation which impact on stock price performance can be similarly explored. However, that work is still outstanding.

It is noted that mining companies' decision framework to invest in new mining technology does not regard the firm's resultant stock market value. Flynn (2000) examines "Management's discussion and analysis of results of operations and financial condition" sections of many mining companies' periodic financial reports. He finds that introducing new technology focuses on improving productivity and safety, reducing costs, and increasing market share. However, he adds that companies should also consider generating sufficient revenues and earnings to meet targets for return on investment. Evidently, this still excludes stock market value from the decision matrix for new mining technology investments.

The existing void indicates that the technological innovation implementation's financial impact has not been taken through the whole value chain. The absence of a full appraisal which includes implications on share price performance creates a problem. The problem is the loss of opportunity to have a share price predictive model centred on a technological innovation implementation. This gap between mining technological innovation implementation and firm stock market value has considerable research scope.

2.3. Research contribution

Several studies have shown that mining technological innovation improves the profitability of mineral deposit exploitation by improving mining productivity (Tilton, 1989, 2014; Mitra, 2019; Humphreys, 2019a, 2019b; Topp, 2008; Bartos, 2007; Accenture, 2010; Sánchez and Hartlieb, 2020). In other industries, a direct relationship between technological innovation and firm market value based on productivity improvement is established (Sood and Tellis, 2009; Nicolau and Santa-María, 2013; Schroeder et al., 1989; Koellinger, 2008). Therefore, it is expected that share price performance of mineral commodities conforms to the same relationship. This value chain flow is portrayed in Fig. 4 by depicting the interplay of mining technology, mining sustainability, and investment attractiveness.

The question mark is the link that needs to be completed. Mining technology intervention as a solution to sustainability challenges is proven through productivity improvement. Because of technology, mining sustainability equates to mineral commodities profitability, which enhances investment attractiveness. This is proven too. To complete the picture, mining technology direct impact on investment attractiveness (share price) needs to be explored. Therefore, the aim of the study is to explore the possibility of establishing a framework that relates technological innovation implementation to share price performance. This exploration triggers the following research questions about the missing link.

- Is there any basis to suggest a relationship?
- What are the metrics which can be used to test the relationship?
- If the relationship exists, could the metrics be used to build an empirical framework?

Answering these questions brings closer the understanding of how mining technological innovation potentially impacts share price performance. Hence, the objectives of the study are addressed by undertaking the following tasks.

- Select a mining technological innovation and the mineral commodity producer(s) for the research.

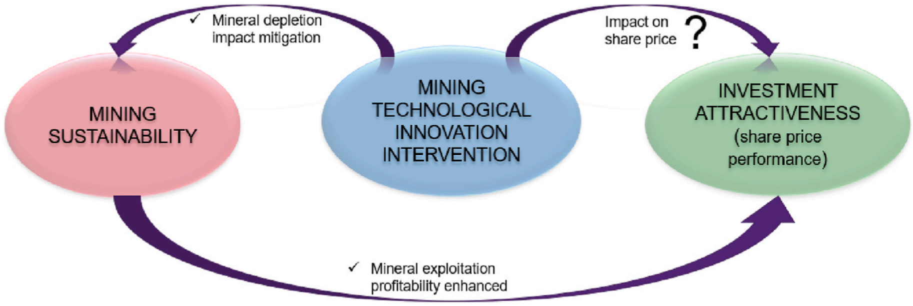

Fig. 4. Mining technology value flow.

- Use Event Studies technique to investigate the impact of technological innovation implementation milestones on share price performance.
- Track the performance of the metrics impacted by the technology during the implementation period against the share price performance. The same is performed on the macroeconomic factors.
- Explore literature to identify a suitable tool to build the empirical framework using the metrics.

The relationship would find support in that share price performance is a function of productivity and cost, mineral commodity price (as a function of supply and demand), and other macroeconomic factors (Bhattacharyya and Williamson, 2016; Demir, 2019; Isidore and Christie, 2019; Mullins, 1990). As such, understanding how mining technology affects productivity and cost (and hence profitability) under the watch of macroeconomic factors lays the foundation for the framework.

The developed framework will be a common tool that mineral commodity operators and other investors in mineral commodities can use to make investment decisions. For the mineral commodity operators, it will be an additional tool for approving step-change mining technology projects. This will be similar to how Njike and Kumral (2019) applied a company's operational performance level in their newly developed mining corporate portfolio optimisation model. The public investors will use it to decide whether to invest in a mineral commodity company that is implementing a radical mining technological innovation. As indicated by Sorescu et al. (2018), many investors follow developments and news about certain organisations, and their decisions to invest in or divest from the organisations are informed by what they find. Consequently, the pathway for this work to creating value is shown in Fig. 5.

3. Stock market performance factors

Share price or stock market performance is driven by several factors which exert varying weights to influence the ultimate behaviour or trending patterns. Different factors affect stock markets of different firms in varying degrees, to such an extent that one factor may positively influence stock market values in one industry while negatively influences in another. Understanding these factors helps to determine how share prices are likely to behave in the short, medium, and long-term periods. Considering that share price movement of a firm is an important indicator and drives investors' market future expectations, it is equally important to know the factors that send signals of how share prices are likely to trend (Wong, 2020). The share performance factors are classified into firm-specific factors and macroeconomic factors.

Fig. 5. Workflow to value creation.

The firm-specific are those which are within the control of the firm, while the macroeconomic are external factors which the firm does not have capacity to influence (Lee and Chen, 2009; Wong, 2020; Demir, 2019; Isidore and Christie, 2019; Ponikvar and Tajnikar, 2012). The macroeconomic factors can further be split into industry-specific and general prevailing economic conditions locally and globally (Lee and Chen, 2009; Isidore and Christie, 2019; Astakhov et al., 2019). By thoroughly analysing the fundamentals, (which is the economic conditions, the industry outlook, and the firm-specifics) through evaluation of publicly available information, the stock price of a company can be determined (Isidore and Christie, 2019). As these factors affect stock markets differently, this research starts by identifying factors that affect stock markets in general. The analysis will then narrow down to those factors that are most significant to stock markets responding to implementation of a radical technological innovation.

3.1. Firm-specific factors

The fundamental analysis of firm-specific factors upholds that the stock market prices, current and future, rely on the intrinsic value of the stock and the expected return. Firm-specific factors derive from company's market power, its cost and productivity efficiency of production factors, and the technological characteristics of its production processes. Essentially, they are a product of strategies employed and pursued by the company (Ponikvar and Tajnikar, 2012). In a broader view, firm-specific fundamental analysis includes factors that reflect on corporate financials, future prospects of the firm, quality of senior executives, firm's competitive edge, labour relations policies, as well as firm size and market share (Lee and Chen, 2009; Wong, 2020; Isidore and Christie, 2019). Which means as new information is made available about the company's performance, its stock market value is re-evaluated and updated to reflect the expected return changes. This makes it possible to predict stock market prices before changes happen (Isidore and Christie, 2019).

The respective factors that are mainly evaluated comprise a long list which includes, but not limited to, revenue, earnings before interest depreciation and amortisation (EBITDA), net debt to EBITDA ratio, return on capital employed (ROCE), earnings per share(EPS), price per earnings ratio (P/E ratio), return on assets (ROA), return on equity (ROE), net asset value (NAV), market capitalization (MC), dividend yield (DV), dividend per share (DPS), dividend policy (DP), dividend payout ratio (DPR), stock split policy, merger and acquisition policy, bonus payment policy, debt to asset ratio (D/A ratio), debt to equity ratio (D/E ratio), debt to capital ratio (D/C ratio), firm size, and firm's past performance in the area under consideration (Idawati and Wahyudi, 2015; Lee and Chen, 2009; Wong, 2020; Benkovskis and Wörz, 2013; Demir, 2019; Isidore and Christie, 2019; Kodithuwakku, 2016; Aveh and Awuyo-Victor, 2017; Avdalovic, 2018; Astakhov et al., 2019). Public investors scrutinise preferred selections of these factors to make investment decisions depending on which set they deem more applicable to the firm under consideration, also with respect to prevailing macroeconomic conditions. For technological innovation impact evaluation, the factors that directly reflect on productivity and profitability are given more weight.

3.2. Macroeconomic factors

The macroeconomic factors make another set of fundamentals which impact either positively or negatively on stock market returns. Since these are external factors, the company has no means to control how they play out as they are driven by industry and general economic conditions. The daily stock markets fluctuations are in part influenced by economic and political affairs as they are not immune to independent domestic and global macroeconomic effects. In that regard, investors are impacted by these effects and hence their decisions on shares must consider the overall prevailing economic conditions in the market (Demir, 2019). The domestic economic factors include governmental policies, the actions of workers' and employers' organisations, adding to the general global economic factors. These are time-varying, and they affect firms of the same industries equally (Ponikvar and Tajnikar, 2012). The factors arising from national and global economic systems are complex and they affect stock markets at an aggregate level (Wong, 2020). This shows that the economy plays a vital role influencing stock market investment process because when some stocks are trending upwards, others are trending downwards and vice versa during both the bull and bear phases.

Economic systems generally trigger minimum volatility in stock market behaviour. When they cause high volatility, it is a problem because stock market price movements play a major role in stock market investment decision process (Isidore and Christie, 2019). The assumption behind analysing the economy prior to buying a firm's stock is that if the economy is growing and is stable, then it should follow that the firm would also prosper along with it, thus causing the share price to appreciate its value (Isidore and Christie, 2019). It is therefore important to carefully consider how economic factors are behaving when evaluating the impact of technological innovation on stock market performance.

The other category of external factors is industry-specific factors. These include the characteristics of specific industries in terms of product differentiation, concentration of firms, market entry barriers, technological profile of the industry's means of production, and general demand and supply dynamics. Effectively, these determine the average weight which companies within a specific industry exert on share prices. As a result, the average industry markup is determined by these factors, while firm-specific factors pull a firm's markup from the trending industry average (Wong, 2020) In evaluating the effects of industry related factors, Isidore and Christie (2019) and Ponikvar and Tajnikar (2012) outline that stock market price trending is determined by the industry to which it belongs. This means that even when a firm's share price is doing well, it can be brought down by credentials of its industry. As such, the industry trends affect the share prices.

The list of external share market performance factors, both industry-specific and economic in general includes the following: real effective exchange rate (ER), foreign exchange reserve (FER), relative value of the domestic currency, domestic portfolio investments, foreign direct investments, global market share, gross domestic product (GDP), market entry barriers, growth rate, interest rate (IR), inflation rate (IFR), money supply (M2), commodity prices, crude oil price, industrial production, government bond rate, unemployment rate, government antitrust policy, workers' and employers' organisations actions, level of competition, foreign entrants regulations, government attitude, and threats from potential entrants (Bhattacharyya and Williamson, 2016; Wong, 2020; Benkovskis and Wörz, 2013; Demir, 2019; Isidore and Christie, 2019; Ponikvar and Tajnikar, 2012; Khan and Zaman, 2012; Astakhov et al., 2019; Kiymaz, 2011). The firm-specific and macroeconomic factors affect share price performance differently because of their varying nature (Wong, 2020). Consequently, macroeconomic factors must not be ignored when assessing the impact of technological innovation implementation on stock price.

4. Methodology

Having established that there is an empirical relationship between technological innovation implementation and share price performance in other industries through literature search, the next task was to investigate the same for mining technology and mineral commodity stock price. Hence, the mining technological innovation and the mineral commodity producer(s) needed to be identified for the study.

4.1. Mining technological innovation selection criteria

The research to investigate the impact of mining technological innovation started by identifying the suitable technology whose implementation results provided adequate information to answer critical research questions. A mining technological innovation needed to be of a scale extensive enough to significantly improve productivity. This brought the need to identify the mining process which drives the mining cost and focus on the technological innovation that could improve its performance metrics. The impact of the technological innovation had to be quantifiable. Its performance metrics had to be directly translatable into key financial performance indicators of the company. This was necessary because the financial performance of a company directly relates to its share price performance. These were the first major requirements that needed to be satisfied while searching for a technological innovation that fitted to be a case study.

The second set of requirements was of sustainability and environmental settings considerations. The technological implementation duration had to be long enough to produce sufficient data to sustain extensive research. It had to be applied to a mineral commodity whose stock price had been traded long enough to produce sufficient data to sustain elaborate research. For authenticity of research findings, the technological innovation needed to cover a considerable cross-section of the mining industry. While looking at the cross-sectional application of the technology, it had to be in similar geographical and economic environmental settings. This would bring standardization to the research findings as the operating companies would be affected by the same physical and economic factors. This would make the results authentic because they would be repeatable in other settings where prevailing conditions affected the operating companies equally.

4.2. Selection of AHS

Surface mining was the preferred selection of mining method for the investigation of technological innovation impact on share price. A wide range of technological innovations that are extensively applied in surface mining were considered. These included drones for survey purposes, advanced information technology for monitoring and management systems, advanced mine design software applications, autonomous drilling technology, and autonomous haulage system (AHS), among others. In consideration of the selection parameters, autonomous haulage system was selected as a viable option for the study.

AHS application in open pit mining was suitable for many reasons. It is applied to material haulage which is the biggest cost driver in open pit mining, making up to 50% of the total mining cost (Nebot, 2007; Bellamy and Pravica, 2011; Munirathinam and Yingling, 1994; Subtil, Silva and Alves, 2011; Samavati et al., 2019; Gölbaşı and Dagdelen, 2017). On this basis, its impact directly affects the financial key performance indicators of the company, and consequently affects the share price performance too. AHS has been in operation in iron ore production for close to 13 years to date and hence its sustainability was proven. Iron ore stocks have been traded for decades with known trends. Hence, the introduction of a technological innovation to the mining process that significantly drives the mineral production should reflect in the stock price behaviour. AHS has been adopted by major mining iron ore mining companies operating in Australia, which are Rio Tinto, BHP Billiton, and Fortescue Metals Group. As such, the companies are always exposed to the same geographical and economic impacts. Therefore, these factors made AHS a credible technological innovation to research on its impact on iron ore stock price.

4.3. Case study selection

The three companies considered for case studies for this research were FMG, BHP Billiton, and Rio Tinto. The extent of the mineral commodities diversification profile of a company played a role in its selection as a suitable case study. The reason was that the more minerals the company operates in, the less impact of one technological innovation implementation in one mineral has over the overall share price performance of the company. This is due to dilution effect from the performance of the other minerals the company operates in. As such, the role of each company, if any, in this research was evaluated accordingly.

4.3.1. BHP billiton

BHP Billiton mines and processes, and sometimes even refines, a wide variety of minerals in Australia and overseas. The list of minerals they operate in includes iron ore, copper, zinc, gold, silver, uranium, potash, and coal (BHP-Billiton, 2023). All these commodities together impact on the share price performance of BHP Billiton at once. In addition to the varied mineral profile, the company operates in many different countries across the globe and hence it is exposed to multiple macroeconomic, political, and environmental factors at once as opposed to a company that operates in one country. For this reason, any technological innovation implementation taking place in the mining of one mineral in one country will not significantly reflect in the overall performance of BHP Billiton share price. It was therefore judged that a detailed study of the implementation of AHS at Jimblebar Iron Ore operation in Western Australia would not give much information to the objectives of this research.

4.3.2. Rio Tinto

Rio Tinto has a wide variety of businesses. They mine, smelt and refine minerals. They are further diversified into sales offices, data centres, research and development laboratories (Rio-Tinto, 2023). The list of minerals they operate in includes iron ore, copper, zinc, gold, silver, uranium, potash, and coal. Rio Tinto has presence in Australia, Africa, Central America, Europe, Asia, Africa, North America, and South America. The company is therefore exposed to multiple macroeconomic, political, and environmental factors at once just like BHP Billiton. Similarly, it was judged that a detailed study of their AHS implementation in the Iron Ore operation in Western Australia would not adequately address the objectives of this research.

4.3.3. FMG

During the period of AHS implementation, FMG was operating only in iron ore business and only in Australia. The company started embarking on diversification ventures after the completion of AHS implementation. This company profile made FMG an ideal entity to explore the objectives of the study to achieve the aim of the research.

4.4. Data collection

To explore the possible existence of a foundation for the development of a framework, the impact of AHS implementation on iron ore stock price was investigated in a case study on FMG which commenced implementation of AHS in 2012 (Gölbaşı and Dagdelen, 2017). The performance indicator metrics were obtained from the quarterly and annual reports. The selected mining productivity improvement metric was mining and processing cost per wet metric tonne (US$/wet metric tonne). Mining cost was not examined as a stand-alone parameter because FMG reported it together with processing cost in the period under review. The financial performance indicators impacted by AHS implementation selected were profit margin, ROA, ROE, net gearing ratio, and current ratio. The macroeconomic factors known to strongly impact iron ore stock price, that is, iron ore price and AUD/USD exchange rate, were selected. The iron ore prices were collected from Market Index website (Index, 2021), while foreign currency exchange rates were sourced from The Reserve Bank of Australia database (RBA, 2021).

4.5. Event Studies technique for abnormal stock returns evaluation

Event Studies technique was used to investigate the impact of technological innovation implementation milestones on share price performance. This was carried out by determining the type of sentiment the implementation of AHS created in the investors and quantified the same by calculating the corresponding change in stock price. In an efficient market, stock price reflects all the known information about the company. When new information is received in the market it is incorporated into the stock price immediately. In such a market, a change in stock price is a true reflection of changes in the expected future cash flows of the company. Hence, by checking the company's stock price response when new information that potentially impacts on the company's cash flow reaches the market, one is actually testing the underlying change in the true market forecast of the company's future income (Chaney et al., 1991; Koku et al., 1997). Event Studies techniques are commonly used in economics, business, and finance to carry out this type of investigation when new products are introduced into the market.

When Event Studies techniques are used, the impact of the events is observed on the stock market performance. The impact is mostly recorded in the form of abnormal stock returns following the event being investigated. Many researchers attest to the relevance of this methodology as results obtained from the calculations have been relied upon in many studies (William et al., 2017; Cable and Holland, 1999; Koch and Fenili, 2013; Saens, 2006). In this research, the corresponding abnormal stock returns are calculated following the AHS implementation milestones publication, either by announcements or by periodic reports.

The following generic equation is employed to calculate abnormal stock returns using Event Studies (Koch and Fenili, 2013):

$$R_t = \alpha + \beta R_{mt} + \epsilon_t \tag{1}$$

Where.

R_t = rate of return of a company's stock on a given day of the event t $(t = 1, 2, \ldots, n)$;
R_{mt} = Rate of return on day t of a market portfolio of stock;
αintercept;
βsystematic risk associated with the stock i;
ϵ_t = error term resulting from random shocks (announcements), such that $\sum(\epsilon t) = 0$ if the announcement is of no impact.

Hence, using equation (1), the daily abnormal returns (DARs) in the event period are:

$$DAR_t = R_t - (\alpha + \beta R_{mt}) \tag{2}$$

The cumulative abnormal returns (CAR) are therefore calculated as:

$$CAR_t = \sum DAR_t \text{ for } (t = 1, 2, \ldots, m) \tag{3}$$

4.6. Abnormal returns quantification

These abnormal stock returns were investigated by tracking the share price response to the announcements of the milestones. The announcements were in the form of company and ASX periodical reports, and open sources such as news media, journals, and conference presentations. To determine the abnormal returns, a prediction of what the stock price would have been without the events must be carried out. Firstly, to estimate the FMG stock return when there was no milestone announcement made, the values of α and β in equation (1) needed to be determined when ϵ_t was zero. To achieve this, the S&P/ASX200 Material Stock Index was used as a measure of how the market portfolio was performing in the 30 days period before the announcement date. The 30 days period was used because it was long enough to get an accurate read of what the market was doing, but not too long to include contaminating events which would otherwise occur.

The first AHS announcement of July 5, 2011 was used as an example to demonstrate how the cumulative abnormal returns were calculated. The quantification was achieved by calculating the stock price return from 2 days prior to announcement to 3 days after announcement. The reason for considering 2 days prior to announcement was that news leakage prior to the day of announcement is common (Lee and Chen, 2009), and this impacts on the stock price performance. At the same time, brief daily stock price "event windows" after the announcement are preferred to minimise the noise of other influences that may distort the impact of the announcement (Koch and Fenili, 2013). To this end, the 30-day period data is shown in Table 1 and the corresponding Regression Analysis output is in Table 2.

Secondly, using equation (1) above, and noting that there were no shocks arising from AHS announcements in this period, $\epsilon t = 0$, hence,

$R_t = \alpha + \beta R_{mt}$

$R_t = -3.575 \text{ x } 10–5 + (-3.596 \text{ x } 10–1)R_{mt}$ (Using results from Regression Analysis output)

Thirdly, for the 2 days before announcement and 3 days after (Day 1 to Day 5), including announcement day, the DAR and CAR were calculated from equations (2) and (3) as follows:

Day 1

$DAR_1 = R_1 - (-3.575 \text{ x } 10–5 + (-3.596 \text{ x } 10–1)R_{m1})$

$= 0.006 – (-3.575 \text{ x } 10–5 + (-3.596 \text{ x } 10–1) \text{ x } 0.003) = 0.0074$

A similar calculation was performed for Day 2 to Day 5. Therefore, the cumulative abnormal return for the first announcement was obtained using the formula:

$CAR_t = \sum DAR_t$ for $(t = 1, 2, \ldots,5)$

$= 0.0074 + 0.0132–0.0002 – 0.0047–0.0108$

$= 0.0049$

The results are shown in Table 3.

Fourth, the predicted share price of FMG on July 5, 2011 was obtained by dividing the actual share price of that day by the antilog of natural logarithmic value of CAR (Koch and Fenili, 2013). Hence, for July 5, 2011, the predicted FMG share price was $6.438. This predicted share price was what the share price would have been if there was no AHS announcement made. The above steps were repeated for all the announcements recorded. There was a total of 31 AHS announcements recorded over the period under consideration. The differences between the actual share price and what it would have been (the predicted share price), are shown in Fig. 6.

Table 1
AHS announcement 1 on July 5, 2011.

Date	FMG Share Price(AU$)	FMG Share Price Return	Market Index Price	Market Index Price Return (AU $)
23/05/2011	6.33	−0.017	10,163.89	0.017
24/05/2011	6.29	−0.006	9,923.10	−0.024
25/05/2011	6.24	−0.008	9,950.80	0.003
26/05/2011	6.33	0.014	9,903.74	−0.005
27/05/2011	6.40	0.011	9,972.80	0.007
30/05/2011	6.40	0.000	9,952.77	−0.002
31/05/2011	6.52	0.019	9,751.01	−0.020
1/06/2011	6.69	0.026	9,856.71	0.011
2/06/2011	6.46	−0.034	9,903.80	0.005
3/06/2011	6.46	0.000	9,893.71	−0.001
6/06/2011	6.36	−0.015	9,886.42	−0.001
7/06/2011	6.23	−0.020	10,020.88	0.014
8/06/2011	6.35	0.019	9,907.68	−0.011
9/06/2011	6.35	0.000	9,945.88	0.004
10/06/2011	6.32	−0.005	10,030.10	0.008
14/06/2011	6.26	−0.009	10,026.06	0.000
15/06/2011	6.30	0.006	10,102.77	0.008
16/06/2011	6.02	−0.044	10,176.05	0.007
17/06/2011	6.06	0.007	10,174.92	0.000
20/06/2011	6.02	−0.007	10,220.25	0.004
21/06/2011	6.08	0.010	10,225.80	0.001
22/06/2011	6.10	0.003	10,276.45	0.005
23/06/2011	6.06	−0.007	10,393.01	0.011
24/06/2011	6.17	0.018	10,335.20	−0.006
27/06/2011	6.04	−0.021	10,235.14	−0.010
28/06/2011	5.99	−0.008	10,142.24	−0.009
29/06/2011	6.20	0.035	10,198.58	0.006
30/06/2011	6.35	0.024	10,220.46	0.002
1/07/2011	6.39	0.006	10,251.59	0.003
4/07/2011	6.48	0.014	10,224.30	−0.003
5/07/2011	**6.47**	**−0.002**	**10,260.31**	**0.004**
6/07/2011	6.43	−0.006	10,302.47	0.004
7/07/2011	6.38	−0.008	10,216.21	−0.008

4.7. AHS milestone announcements impact assessment

The AHS milestones were tracked from AHS trial period in 2011 to full implementation in mid-2020. They were classified according to their potential impact on iron ore stock price as described in Table 4. The respective stock abnormal returns were matched by colour codes to the type of announcement they responded to. Each colour coded box along the x-axis represents an announcement type. The stock price abnormal returns were plotted against the announcements of the milestones as shown in Fig. 7. It is evident that the milestone announcements created positive sentiments in the investors as two thirds of the announcements

Table 2
Regression Analysis output.

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	18.57%
R Square	3.45%
Adjusted R Square	−0.26%
Standard Error	0.018
Observations	28
ANOVA	
	df
Regression	1
Residual	26
Total	27
	Coefficients
Intercept	−3.575E-05
Market Index Price Return (AU$)	−3.596E-01

Table 3
Daily abnormal returns calculation.

Count	Date	FMG Share Price (AU$)	FMG Share Price Return	Market Index Price	Market Index Price Return (AU$)	DAR
Day 1	1/07/2011	6.39	0.006	10,251.59	0.003	0.0074
Day 2	4/07/2011	6.48	0.014	10,224.30	−0.003	0.0132
Day 3	**5/07/2011**	**6.47**	**−0.002**	**10,260.31**	**0.004**	**−0.0002**
Day 4	6/07/2011	6.43	−0.006	10,302.47	0.004	−0.0047
Day 5	7/07/2011	6.38	−0.008	10,216.21	−0.008	−0.0108
CAR						**0.0049**
Predicted share price (AU$)						**6.438**
Share price difference (AU$)						**0.032**

resulted in an increase of share price. The stock price trend was similarly plotted over the AHS implementation period as depicted in Fig. 8 to confirm any correlation. It is shown that even in the period when the stock price was in a bear trend between January 2017 to June 2018, the milestone announcements still gave hope to the investors as most

Table 4
AHS announcements and potential impact on iron ore stock price.

Type of announcement	Description	Likelihood to affect stock price	Count	Colour code
ASX – Technology change	Release containing high technology change content. Very popular source where important company announcements are collated and viewed by investors and corporate decision makers. Mostly the first point of call for checking for important company announcements.	Extremely likely	3	
Technology change	Literature in which AHS message is prominent.	Very likely	8	
ASX	Very popular source where important company announcements are collated and viewed by investors and corporate decision makers. Mostly the first point of call for checking for important company announcements.	Extremely likely	7	
Media release	Mainstream media publications with notable AHS coverage such as ASX news, Newspapers, gazettes etc.	Likely	3	
Generic	Notable AHS content published in journals or bulletins. Or published in mainstream media or seasonal reports but the AHS content is not the most dominant message.	Likely	10	

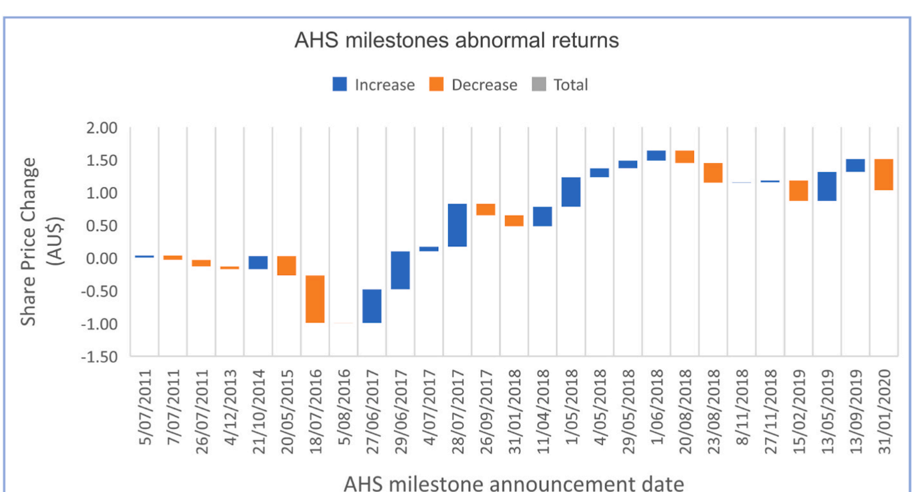

Fig. 6. Abnormal stock returns against AHS milestone announcements.

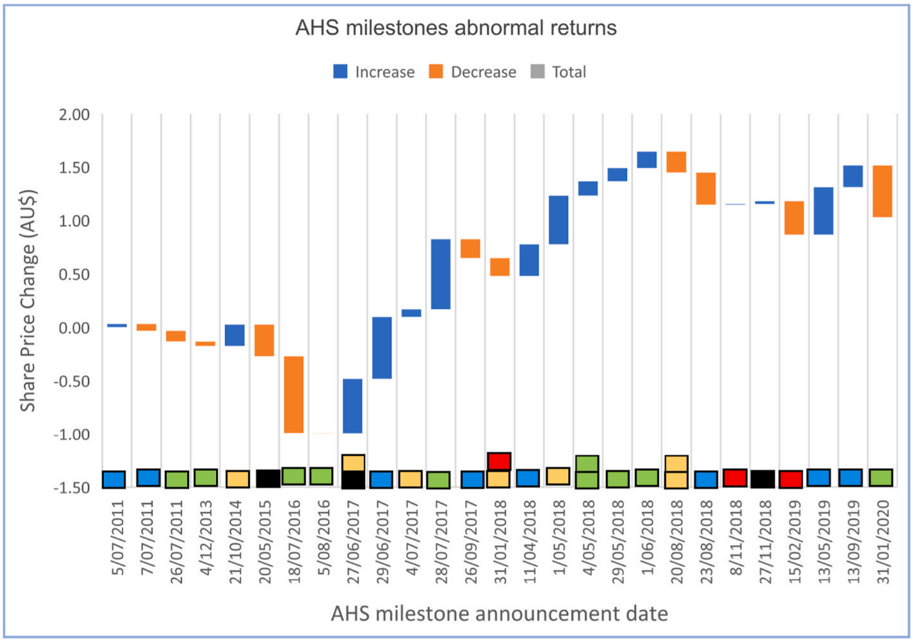

Fig. 7. Announcement type and impact on abnormal stock returns.

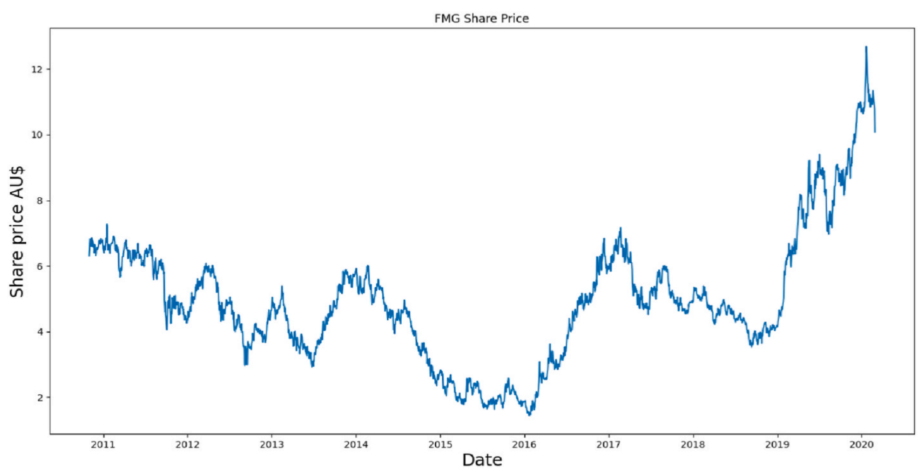

Fig. 8. FMG stock price trend over AHS implementation period.

announcements resulted in positive abnormal returns.

The outcome of the Event Studies exercise pointed to an evident relationship between AHS implementation and share price performance. It gave scope for further investigation into the impact of AHS implementation on FMG share price. This was taken further by testing the metrics impacted by AHS to see how they related with share price performance over the technology implementation period.

4.8. AHS impact on productivity and financial metrics

The impact on the share price of mining productivity improvement, the resultant financial performance, and the macroeconomic factors was investigated by tracking the factors trend against that of the share price. The investigations were carried out graphically to depict the relationships over the AHS implementation period as shown in Figs. 9–12. The

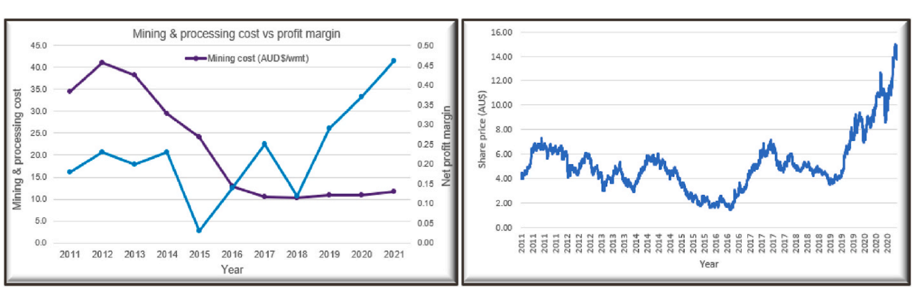

Fig. 9. Mining & processing cost, and profit after tax vs share price performance.

next task would be to express the observed relationships in empirical terms to represent the framework. It is important to note that the list of factors outlined so far is not exhaustive. However, for the purpose of checking for the possibility a foundation upon which to build a framework, the selected factors suffice.

4.9. The conceptual framework determination

Considering that the variables explored so far are of time series type, it is prudent to use statistical methods to champion the development of the empirical framework being sought after. Traditionally, many statistical methods such as Multiple Linear Regression Analysis (MLRA), Support Vector Regression (SVR), Autoregressive Moving Average (ARMA), and Autoregressive Integrated Moving Average (ARIMA) have been used to develop frameworks for share price prediction (Shakhla et al., 2018; Vijh et al., 2020). The applicability of these methods varies with the type of input data being used. The SVR, ARMA, MLRA and ARIMA methods use technical analysis indicators as input data to predict strock market movements (Rustam and Kintandani, 2019; Sharaf et al., 2021). However, MLRA has been taken a step further to predict Stock Market Index price using fundamental factors (Enke et al., 2011). This makes MLRA a more suitable tool to use to establish a conceptual empirical relationship framework between mining technology driven metrics and the share price performance. This is based on the fact that the identified firm-specific metrics and the macroeconomics factors tested in this research are all fundamental factors.

In other industries it is established that by thoroughly analysing the fundamentals, which are the economic conditions, the industry outlook, and the firm-specifics, a company's stock price can be predicted (Isidore and Christie, 2019) using statistical tools such as the MLRA. This study seeks to apply the same philosophy to mining technological innovation driven metrics and share price performance.

Based on the selected factors, the framework can established in the form of MLRA. The MLRA is expressed in the form:

$$\text{Share price, } Y = \mathbf{b_0} + \sum_{1}^{n} b_i X_{i,t-1} + \boldsymbol{\varepsilon}$$

Where, $\mathbf{b_0}$ is a Y-axis intercept value.

$\mathbf{b_i}$ is the factor of unitary change of X_i on the share price,
X_i is a share price-determining factor (mining-specific and macroeconomic), and
$\varepsilon$is an unexplained error term of the framework.

Based on the metrics tested in this study, the variables X_i would be mining and processing cost per tonne, profit margin, ROE, ROA, net gearing ratio, current ratio, AUDUSD exchange rate, and iron ore price. Other mining technology-driven factors which can be added to input into the framework are ore tonnes mined per man-day, stripping ratio, net interest cover, and any other metric that can be deemed to be impacted by the implementation of AHS.

5. Results

A suitable technology was identified which could be used to champion the research. AHS was chosen as its application yielded considerable metrics which were tackable. The technology is also sustainable. FMG was the selected company for the case study as it was a single commodity company. Other companies implementing AHS, BHP Billiton and Rio Tinto, had other businesses which would dilute the impact of AHS in driving the share price. As such they were set aside.

The Event Studies technique results showed that the implementation of AHS was significant as 67% of the milestone announcements resulted in positive abnormal stock returns. This signalled the presence of a relationship between the technology implementation and the share price performance. This opened an opportunity to identify some metrics which were impacted by the technology implementation and assess their performance in relation to share price performance during the implementation period.

The identified metrics were mining and processing cost per tonne, profit margin, ROE, ROA, net gearing ratio, and current ratio. Their trends during the technology implementation period were determined. AHS reduced the mining cost and caused the profit margin shoot up at the completion of the implementation. With the improvement of profitability, ROE and ROA shot up at the completion of implementation. As AHS improved profitability, the net gearing and current ratios improved significantly at the completion of implementation. In all these scenarios, the share price responded positively by shooting up at the completion of AHS implementation. Exchange rate was in a steady decline during the implementation period. Iron ore price declined and then steadily rose towards the end of the implementation. The share price performance trended sideways over the period when iron ore price and the exchange rate were in a steady decline. It appears that the effect of these macroeconomic factors on the share price performance neutralised each other. The neutralisation effect left the mining-specific factors to determine the ultimate direction of the share price.

The findings from the case study were critical because they determined whether a framework for evaluating the impact of mining technological innovation on company's stock market value could be postulated. Going back to literature, it was found that MLRA was a viable tool to adopt in developing the framework being sought after. The metrics driven by the AHS implementation and the macroeconomic factors were suitable inputs into the MLRA function.

The results of the study could be compromised to some extent due to other interfering factors. The methodology has limitations in that only one case study company was used. If there were other factors that affected the impact of technology which were specific to FMG, these could go unchecked as there was no other company to validate the results with. While the emphasis was on AHS implementation, there were other less visible technologies being implemented in other sections of the business. They also impacted on the profitability of the company. The contribution of these technologies was not accounted for in this research. No detailed statistical significance testing was conducted on the impact of the trends of the chosen metrics on the share price performance. Deductions were drawn from visual observations of the trends

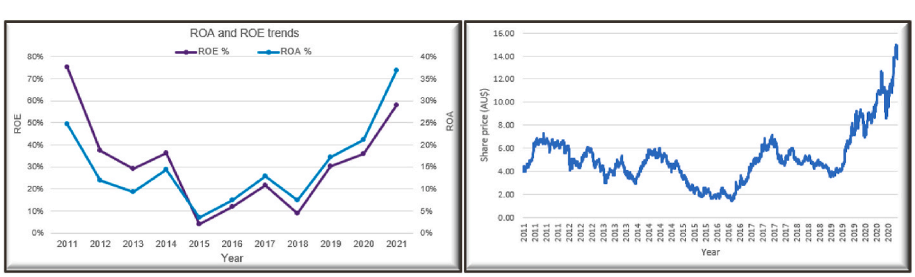

Fig. 10. ROE and ROE trends vs share price performance.

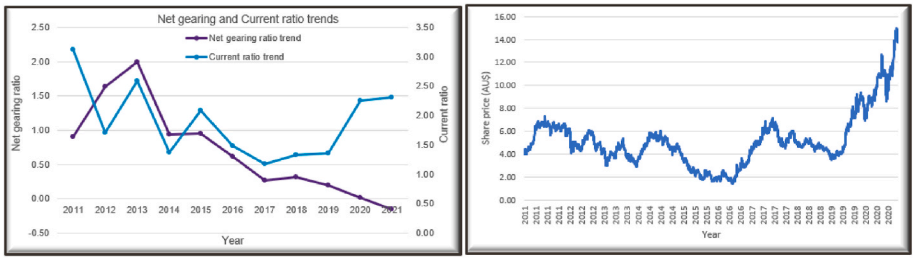

Fig. 11. Net gearing ratio and Current ration trends vs share price performance.

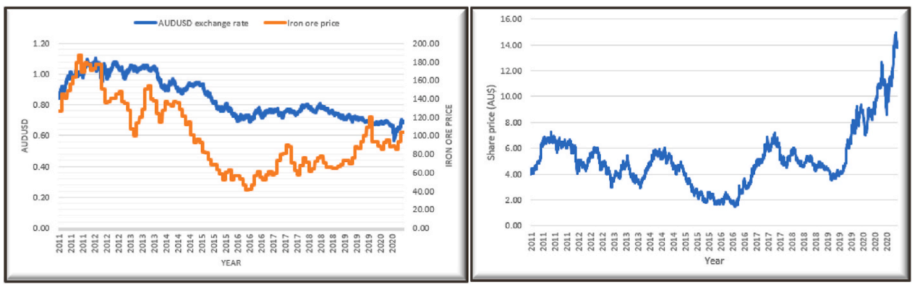

Fig. 12. AUDUSD exchange rate and Iron ore price trends vs share price performance.

over the technology implementation period. There may also be some factors which caused the share price to shoot up at the end of the AHS implementation period which were not captured in this study. The Covid-19 pandemic could have possibly contributed as it created supply-demand imbalance in the iron ore market. This aspect was not explored, just to name one possibility. The accuracy of MLRA framework may be compromised if the key assumptions that should hold true for a MLRA methodology are not fully satisfied in the input data set.

6. Conclusions

It is demonstrated that mining technological implementation positively impacts productivity based on the data from the history of mining technological development. The FMG case study helped bring technology-driven productivity to company stock market value terms. This was demonstrated by share price performance in response to the improvement in metrics-driven by technological innovation implementation.

The mining technological impact on share price performance was considered together with the macroeconomic factors, which had a big potential to influence share price performance. These were iron ore price and foreign currency exchange rate. Their respective trending over the AHS implementation period was considered together with the firm-specific factors. The latter appeared to dominate in determining the direction of the share price. It was also demonstrated that both the AHS implementation driven factors and macroeconomic factors could be used in an empirical relationship expression, the MLRA.

Based on the results, the technology-driven productivity metrics present as a considerable basis for a framework to evaluate the impact of mining technology on a mining company's share price. However, attention must be given to macroeconomic factors that impact stock price performance because they can override the positive impact of mining technological innovation implementation. Otherwise, MLRA is a good starting point to construct the framework. A more refined framework can be constructed using more exhaustive capabilities of artificial intelligence tools. Overall, the current results have revealed the possibility of utilising the impact of mining technological innovation to evaluate a company's stock market value.

Referee suggestions

Professor Harmony Musiyarira; Namibia University of Science and Technology, Namibia; Email: hmusiyarira@nust.na; Phone: +264816609220.

Dr Tabeth Jiri; Jackson State University, USA; Email: tabeth_jiri@jsi.com; Phone: +16012126014.

Dr Robson Chiambiro; University of Auckland, New Zealand; Email: robson.chiambiro@auckland.ac.nz; Phone: +64210593902.

Author statement

Pilot Mugebe:Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation, Visualization, Investigation.

Mehmet Kizil:Supervision, Reviewing and Editing.

Mohsen Yahyaei: Supervision, Reviewing and Editing.

Rand Low: Supervision, Reviewing and Editing.

Declaration of competing interest

None

Data availability

Data will be made available on request.

Acknowledgements

Sincere gratitude goes to the university research advisors for their support and encouragement. The University of Queensland is equally acknowledged for providing the necessary resources for the research.

References

Accenture, 2010. Using Autonomous Equipment to Achieve High Performance in the Mining Industry. Accenture.

Agarwal, H., Agarwal, R., 2017. First industrial revolution and second industrial revolution: technological differences and the differences in banking and financing of the firms. Saudi Journal of Humanities and Social Sciences 2, 1062–1066.

Astakhov, A., Havranek, T., Novak, J., 2019. Firm size and stock returns: a quantitative survey. J. Econ. Surv. 33, 1463–1492.
ASX, 2021. Fortescue Metals Group. Online: https://www2.asx.com.au/markets/company/FMG. (Accessed 18 June 2021).
Avdalovic, S.M., 2018. The impact of firm specific factors on the stock prices: empirical evidence from belgrade stock exchange. Industrija 46 (2).
Aveh, F.K., Awuyo-Victor, D., 2017. Firm-specific Determinants of Stock Prices in an Emerging Capital Market: Evidence from Ghana Stock Exchange. Cogent Economics & Finance.
Bartos, P.J., 2007. Is mining a high-tech industry?: investigations into innovation and productivity advance. Resour. Pol. 32, 149–158.
Bellamy, D., Pravica, L., 2011. Assessing the impact of driverless haul trucks in Australian surface mining. Resour. Pol. 36, 149–158.
Benkovskis, K., Wörz, J., 2013. What drives the market share changes? Price versus non-price factors. BOFIT Discussion Papers 2013 (18), 1–47.
Bhattacharyya, S., Williamson, J.G., 2016. Distributional consequences of commodity price shocks: Australia over A Century. Rev. Income Wealth 62, 223–244.
Bhp-Billiton, 2023. BHP Billiton operations [online]. Available from: https://www.bhp.com/news/media-centre/image-gallery/our-operations, 11/05/2023 2023.
Brown, A., 2020. Autonomous hauling milestone for Caterpillar. Construction Europe 31, 12.
Brown, C., 2012. Autonomous vehicle technology in mining: how it works and how it's applied from user assist to full autonomy.(Autonomous Mining). E&MJ - Engineering & Mining Journal 213, 30.
Brundrett, S., 2014. Industry Analysis of Autonomous Mine Haul Truck Commercialization. Simon Fraser University.
Cable, J., Holland, K., 1999. Modelling normal returns in event studies: a model-selection approach and pilot study. Eur. J. Finance 5 (4), 331–341.
Chaney, P.K., Devinney, T.M., Winer, R.S., 1991. The impact of new product introductions on the market value of firms. J. Bus. 573–610.
Coalage, 2018. ASI launches first major autonomous haulage project in the US. Coal Age 1996 (123), 40.
Coulson, M., 2012. The History of Mining: the Events, Technology and People Involved in the Industry that Forged the Modern World. Harriman House Ltd, Great Britain.
Da Costa, M.B., Dos Santos, L.M.A.L., Schaefer, J.L., Baierle, I.C., Nara, E.O.B., 2019. Industry 4.0 technologies basic network identification. Scientometrics 121, 977–994.
Demir, C., 2019. Macroeconomic Determinants of Stock Market Fluctuations: the Case of BIST-100. Econimies.
Doukas, J., Switzer, L., 1992. The stock market's valuation of R&D spending and market concentration. J. Econ. Bus. 44, 95–114.
Enke, D., Grauer, M., Mehdiyev, N., 2011. Stock market prediction with multiple regression, fuzzy type-2 clustering and neural networks. Procedia Comput. Sci. 6, 201–206.
Fan, S., Yan, J., Sha, J., 2017. Innovation and economic growth in the mining industry: evidence from China's listed companies. Resour. Pol. 54, 25–42.
Fisher, B.S., Schnittger, S., 2012. Autonomous and Remote Operation Technologies in the Mining Industry. BAeconomics Pty Ltd (February).
Flynn, E.J., 2000. Impact of technological change and productivity on the coal market. Energy Information Administration, Issues in Midterm Analysis and Forecasting 2000, 10.
FMG, 2020. Fortescue Automation Deployment Reaches Significant Milestone. FMG News.
Garcia, L.G.U., Almeida, E.P., Barbosa, V.S., Caldwell, G., Rodriguez, I., Lima, H., Sørensen, T.B., Mogensen, P., 2016. Mission-critical mobile broadband communications in open-pit mines. IEEE Commun. Mag. 54, 62–69.
GMG, 2020. Guideline for Applying Functional Safety to Autonomous Systems in Mining. Global Mining Guidelines Group.
Gölbaşi, O., Dagdelen, K., 2017. Equipment replacement analysis of manual trucks with autonomous truck technology in open pit mines. In: Proceedings of the 38th International Symposium on the Application of Computers and Operations Research (APCOM 2017) in the Mineral Industry.
Guerado, E., 2017. Scientific societies and the third industrial revolution – the future role of the OTC. Injury 48, S1–S4.
Harris, F., 2019. Guideline for the Implementation of Autonomous Systems in Mining. Global Mining Guidelines Group.
Hartwick, J.M., Olewiler, N.D., Preuss, R., 1986. The Economics of Natural Resource Use.
Hovis, L., Mouat, J., 1996. Miners, engineers, and the transformation of work in the western mining industry, 1880-1930. Technol. Cult. 37, 429–456.
Humphreys, D., 2019a. The mining industry after the boom. Mineral Economics 32, 145–151.
Humphreys, D., 2019b. Mining productivity and the fourth industrial revolution. Mineral Economics 33, 115–125.
Idawati, W., Wahyudi, A., 2015. Effect of earning per shares (EPS) and return on assets (ROA) against share price on coal mining company listed in Indonesia stock exchange. Journal of Resources Development and Management 7, 79–91.
Igor, T., Sergey, D., Ilya, K., 2017. Soft computing models in an intellectual open-pit mines transport control system. Proc. Comput. Sci. 120, 411–416.
Index, M., 2021. Market Index - Iron Ore.
Isidore, R.R., Christie, P.J., 2019. Drivers of stock investment decision: an orthogonal linear transformation approach. J. Private Equity 22, 55–65.
Jenkins, H., Yakovleva, N., 2005. Corporate social responsibility in the mining industry: Exploring trends in social and environmental disclosure. The ESRC Centre for Business Relationships, Accountability, Sustainability and Society (BRASS), 55 Park Place, Cardiff, CF10 3AT, UK. Available online 26 April 2005.
Kenett, R., Swarz, R.S., Zonnenshain, A., 2020. Systems Engineering in the Fourth Industrial Revolution: Big Data, Novel Technologies, and Modern Systems Engineering. Wiley, Hoboken, NJ.
Khan, M.N., Zaman, S., 2012. In: Business, Economics (Ed.), Impact of Macroeconomic Variables on Stock Prices: Empirical Evidence from Karachi Stock Exchange, Pakistan. Financial Sciences, and Management, pp. 227–233.
Kiymaz, H., 2011. Stock splits, stock dividends, and dividend reinvestment plans. In: Dividends and Dividend Policy.
Koch, J.V., Fenili, R.N., 2013. Using event studies to assess the impact of unexpected events. Bus. Econ. 48 (1), 58–66.
Kodithuwakku, S., 2016. Impact of firm specific factors on the stock prices: a case study on listed manufacturing companies in colombo stock exchange. International Journal for Research in Business, Management and Accounting 2 (3), 9.
Koellinger, P., 2008. The relationship between technology, innovation, and firm performance—empirical evidence from e-business in Europe. Res. Pol. 37, 1317–1328.
Koku, P.S., Jagpal, H.S., Viswanath, P., 1997. The effect of new product announcements and preannouncements on stock price. J. Mark.-Focused Manag. 2 (2), 183–199.
Lee, H., Smith, K.G., Grimm, C.M., Schomburg, A., 2000. Timing, order and durability of new product advantages with imitation. Strat. Manag. J. 21, 23–30.
Lee, R.P., Chen, Q., 2009. The immediate impact of new product introductions on stock price: the role of firm resources and size. J. Prod. Innovat. Manag. 26, 97–107.
Leonida, C., 2019. Optimising autonomous haulage. Eng. Min. J. 220, 36–43.
Marovelli, R.L., Karhnak, J.M., 1982. The mechanisation of mining. Sci. Am. 247, 90–104.
Mary, J.B., 2007. The incumbent discount: stock market categories and response to radical technological change. Acad. Manag. Rev. 32, 703–720.
Matysek, A.L., Fisher, B.S., 2016. Productivity and Innovation in the Mining Industry. BAE Research Report.
Mcnab, K., Garcia-Vasquez, M., 2011. Autonomous and Remote Operation Technologies in Australian Mining. *Prepared for CSIRO Minerals Down under Flagship, Minerals Futures Cluster Collaboration, by the Centre for Social Responsibility In Mining, Sustainable Minerals Institute*. The University of Queensland, Brisbane.
Mitra, S., 2019. Depletion, technology, and productivity growth in the metallic minerals industry. Mineral Economics 32, 19–37.
Montagna, J.A., 1981. The Industrial Revolution. Yale-New Haven Teachers Institute.
Mullins, M.R., 1990. Stock Market Prices: Determinants and Consequences. London School of Economics.
Nebot, E.M., 2007. Surface mining: main research issues for autonomous operations. Robotics Research (Springer).
Nicolau, J.L., Santa-María, M.J., 2013. The effect of innovation on hotel market value. Int. J. Hospit. Manag. 32, 71–79.
Njike, N.A., Kumral, M., 2019. Mining corporate portfolio optimisation model with company's operational performance level and international risk. Mineral Economics 32, 307–315.
O'Faircheallaigh, C., Corbett, T., 2005. Indigenous participation in environmental management of mining projects: The role of negotiated agreements. Environmental Politics 14 (5), 629–647.
Parreira, J., 2013. An Interactive Simulation Model to Compare an Autonomous Haulage Truck System with a Manually-Operated System. University of British Columbia.
Parreira, J., Meech, J., 2011. Autonomous haulage systems–justification and opportunity. In: International Conference on Autonomous and Intelligent Systems. Springer, pp. 63–72.
Ponikvar, N., Tajnikar, M., 2012. The impact of foreign trade on markup size. E. Eur. Econ. 50, 46–64.
Price, R., 2017. Autonomous haulage systems-the business case. AusIMM Bull. (Australas. Inst. Min. Metall.) 80.
RBA, 2021. Historical Data. Historical Data. Reserve Bank of Australia: Reserve Bank of Australia.
Redwood, N., 2018. Autonomous Haulage Systems Financial Model Assessment. Whittle Consulting.
Ren, H., Zhao, Y., Xiao, W., Hu, Z., 2019. A review of UAV monitoring in mining areas: current status and future perspectives. International journal of coal science & technology 6, 320–333.
Rio-Tinto, 2023. Rio Tinto operations [online]. Available from: https://www.riotinto.com/operations, 11/05/2023 2023.
Rustam, Z., Kintandani, P., 2019. Application of support vector regression in Indonesian stock price prediction with feature selection using particle swarm optimisation. Model. Simulat. Eng. 2019.
Samavati, M., Palmer, A.W., Hill, A.J., Seiler, K.M., 2019. Improvements in plan-driven truck dispatching systems for surface mining. Mining Goes Digital.
Saens, R., 2006. Measuring Event Impacts Using Thinly Traded Stocks: the Case of Chile. Ph.D. (unpublished). University of Connecticut, Ann Arbor.
Sánchez, F., Hartlieb, P., 2020. Innovation in the mining industry: technological trends and a case study of the challenges of disruptive innovation. Mining, metallurgy & exploration 37, 1385–1399.
Schroeder, R.G., Scudder, G.D., Elm, D.R., 1989. Innovation in manufacturing. J. Oper. Manag. 8, 1–15.
Shakhla, S., Shah, B., Shah, N., Unadkat, V., Kanani, P., 2018. Stock price trend prediction using multiple linear regression. Int. J. Eng. Sci. Inven.(IJESI) 7 (10), 29–33.
Sharaf, M., Hemdan, E.E.-D., El-Sayed, A., El-Bahnasawy, N.A., 2021. StockPred: a framework for stock Price prediction. Multimed. Tool. Appl. 80 (12), 17923–17954.
Sood, A., Tellis, G.J., 2009. Do innovations really pay off? Total stock market returns to innovation. Market. Sci. 28, 442–456.

Sorescu, A., Sorescu, M.S., Armstrong, J.W., Devoldere, B., 2018. Two Centuries of Innovations and stock market bubbles. Market. Sci. 37, 507–529.
Sorescu, A.B., Spanjol, J., 2008. Innovation's effect on firm value and risk: insights from consumer packaged goods. J. Market. 72, 114–132.
Tilton, J.E., 1989. Changing trends in metal demand and the decline of mining and mineral processing in North America. Resour. Pol. 15, 12–23.
Tilton, J.E., 2014. Cyclical and secular determinants of productivity in the copper, aluminum, iron ore, and coal industries. Mineral Economics 27, 1–19.
Tilton, J.E., 2018. Assessing the market power of mineral commodity producers. Mineral economics : Raw Mater. Rep. 31, 71–76.
Topp, V., 2008. Productivity in the Mining Industry: Measurement and Interpretation.
Upstill, G., Hall, P., 2006. Innovation in the minerals industry: Australia in a global context. Resour. Pol. 31, 137–145.
Vellingiri, S., Tandur, D., Kande, M., 2013. Communication architecture for remote monitoring and diagnostics in open pit mine. In: 2013 IEEE 18th Conference on Emerging Technologies & Factory Automation (ETFA). IEEE, pp. 1–6.
Vijh, M., Chandola, D., Tikkiwal, V.A., Kumar, A., 2020. Stock closing price prediction using machine learning techniques. Procedia Comput. Sci. 167, 599–606.
Von Benda-Beckmann, F., 2001. Legal pluralism and social justice in economic and political development. IdS Bulletin 32 (1), 46–56.
Walker, S., 2014. Autonomy gradually gains momentum. Eng. Min. J. 215, 32–37.
Wang, J., 2014. Development and prospect on fully mechanised mining in Chinese coal mines. International Journal of Coal Science & Technology 1, 253–260.
Wellmer, F.-W., Scholz, R.W., 2017. Peak minerals: what can we learn from the history of mineral economics and the cases of gold and phosphorus? Mineral Economics 30, 73–93.
William, A., Reese, J., Robins, R.P., 2017. Performing an event study: an exercise for finance students. J. Econ. Educ. 48 (3), 206–215.
Wong, W.Y., 2020. A Study of the Factors that Affect Share Price Movements of REITs in Malaysia.
Wright, G., Czelusta, J., 2003. Mineral resources and economic development. In: Conference on Sector Reform in Latin America, Stanford Center for International Development Nov, pp. 13–15, 2003.