Innovation and Drivers of Productivity

Subjects: Mineralogy

Contributor: Shabbir Ahmad

Innovation and technology are important tools for delivering efficiency and productivity improvement in the minerals sector. The uptake of technologies has proven to be an important lever for increasing the productivity of the mining sector.

mining innovation technology efficiency and productivity

1. Introduction

The mining industry's productivity has steadily fallen over the last few decades [1][2][3]. These fluctuations in commodities sectors' efficiency and productivity have presented challenges to global demand and supply balances. Mining exporting countries, in particular, are vulnerable to delayed growth due to low productivity [4][5][6]. The significant growth in resource demand caused by global industrialisation and urbanisation has put great pressure on mining companies to boost productivity. Industry leaders have primarily focused on using partial measures of productivity (e.g., labour productivity) as performance indicators, which do not fully reflect the factors underpinning their productivity [7][8]. Unlocking productivity potentials and studying alternatives for reversing falling trends are critical for a country's economic success. The recent reduction in mining productivity has attracted the interest of policymakers and corporate executives.

Innovation in mining has been a key agenda for both mining businesses and policy makers. In recent years, the mining industry has focused on using innovation to increase productivity through a number of productivity-enhancing initiatives and technologies, such as mine automation, artificial intelligence (AI), and electric vehicles [1][9][10]. The advancements in technology (through the automation of processes) is increasing productivity by either maintaining the same workforce or directly reducing the number of employees required in production [11][12]. Conversely, the fall in ore quality across commodities as a result of the exploitation of low-quality resources is negating productivity improvements by increasing the costs of extraction and capital investment. Furthermore, the utilisation of input mixes and expansion in the scale of production have impacts on productivity patterns. The extent to which these varied elements influence production is still unknown. Therefore, it is critical to determine how all of these different elements explain the mining sector's productivity.

Understanding the causes of productivity decline is difficult. Several factors influence mining industry productivity and efficiency, including management approaches, effective resource allocation, scale economies, and, most importantly, innovation [13]. Embracing new technologies and optimal management practices also significantly influences the efficiency and productivity of the mining industry [14]. Automation and advancements in robotics technology, for instance, contribute to decreases in carbon emissions and increases in mining industry productivity [10]. The development of technologies and their use in the mining industry have enhanced mineral recovery while lowering production costs and energy use [11].

2. Innovation and Drivers of Productivity

The idea of productivity and its decomposition into its components, such as technical efficiency and allocative efficiency, was first introduced by Farrell his seminal work [15]. Farrell pointed out that a producer is always concerned with expanding the output level of the firm without using more resources. Excessive use of inputs for a given level of output or the production of less output from a given level of inputs results in technical inefficiency, while the inappropriate use of the mix of inputs leads to allocative inefficiency. After Farrell's work, other measures were developed, including scale efficiency [16][17]. Technical efficiency is usually measured using either an input- or an output-oriented approach. Input-oriented technical efficiency is defined as the ability of a firm to minimize its input use to produce a given level of output (or hold output mixes fixed in the case of multiple outputs), while output-oriented technical efficiency is defined as the maximisation of output using a given level of inputs (or holding input mixes fixed in case of multiple inputs).

Researchers have attempted to understand the causes of declining productivity trends and examined the many variables that account for variations in mining performance. However, most of the existing literature has focused on partial productivity (such as labour) or aggregate-level productivity using residual approach [12][18][19][20]. Partial productivity (e.g., labour productivity) measures provide useful insights about a firm's performance, but they can be limited in scope to providing an overall picture of the firm. On the other hand, the TFP and its associated measures of efficiency change can provide a comprehensive picture and identify areas that require improvement.

To examine productivity and its various drivers, researchers have widely used this approach in almost every field of economics and business. Researchers have made extensive use of data envelopment analysis (DEA) methods to compute the components of technical change and technical, allocative, and scale efficiency. Both input- and output-oriented approaches have been adopted to measure technical and allocative inefficiencies [21][22]. Applications range from agriculture [23][24][25] to manufacturing [2][26] and the services sector [27][28][29]. There are also other important drivers of TFP, including scale and scope economies and technical change, which need further investigation to identify comprehensive policy insights [13]. For instance, it would be interesting to know whether the uptake of technologies driving the productivity or scale and scope economies (as a result of appropriate output and input mixes) are important levers of TFP in the mining sector.

Over the past few decades, policy discussions have centered on the efficiency and productivity of the mining industry. Many studies have concentrated on the theoretical and empirical foundations of efficiency and productivity and relate these concepts to various factors, including innovation and technical change, the adoption of technologies, scale and scope economies, investment lags, capacity utilisation, and input quality [10][29][30]. However, most studies have examined the productivity of the mining sector using aggregate data [18][20][31][32][33]. For instance, Topp used data from the Australian mining industry to estimate productivity and find a downward trend in mining TFP between 2001–2002 and 2006–2007, concluding that the depletion of resources and capital adjustment contributed to the drop in TFP [33]. The analytical approach proposed by Grifell-Tatje and Lovell, on the other hand, divides changes in productivity into variations in capacity utilisation and price recovery. They pointed out that an analysis of Chile's mining industry productivity by [34] using the Solow residual approach suggested that research and development (R&D) spending and technology appear to be important productivity drivers.

Other studies used either mine-level or aggregate data to investigate the efficiency and productivity of specific commodities [14][29][35]. de Solminihac et al., used the Solow residual approach to compute the TFP of the Chilean copper sector and concluded that the rising input costs and declining ore quality reduced labour productivity [34]. They also note a 42% decline in labour productivity from 1999 to 2010. Oliveira et al., used a limited dataset of 25 gold mining companies and noted a marginal improvement in environmental efficiency [36]. Some previous studies used global gold mine-level data for 2019 to estimate a carbon-adjusted efficiency and technology gap between different production environments and technologies, such as open pit and underground [12]. They noted significant disparities in efficiency (ranging from 18% to 100%) between mines, attributed to the technology gap.

Most of the available research on the mining industry's productivity and efficiency is either constrained to TFP analyses at the aggregate level or uses sparse firm- and mine-level data. To identify numerous performance-enhancing factors, a thorough investigation of the mining sector's productivity is required. It would be crucial to determine whether more resources should be devoted to R&D or innovation and technology adoption to increase productivity. This report attempts to offer a thorough overview of TFP and its significant drivers in the mining industry.

References

1. Matysek, A.L.; Fisher, B.S. Productivity and Innovation in the Mining Industry. BAE Research Report, Retrieved from Canberra. 2016. Available online: https://www.baeconomics.com.au/ (accessed on 7 November 2023).
2. Chen, J.; Zhu, Z.; Xie, H.Y. Measuring intellectual capital: A new model and empirical study. J. Intellect. Cap. 2004, 5, 195–212.
3. Lala, A.; Moyo, M.; Rehbach, S.; Sellschop, R. Productivity in mining operations: Reversing the downward trend. AusIMM Bull. 2016, 2016, 46–49. Available online: https://www.ausimm.com/bulletin (accessed on 7 November 2023).
4. Duan, L. Estimation of export cutoff productivity of Chinese industrial enterprises. PLoS ONE 2022, 17, e0277842.
5. Weldegiorgis, F.S.; Dietsche, E.; Ahmad, S. Inter-Sectoral Economic Linkages in the Mining Industries of Botswana and Tanzania: Analysis Using Partial Hypothetical Extraction Method. Resources 2023, 12, 78.

6. Yasmin, T.; El Refae, G.A.; Eletter, S.; Kaba, A. Examining the total factor productivity changing patterns in Ka-zakhstan: An input-output analysis. J. East. Eur. Cent. Asian Res. JEECAR 2022, 9, 938–950.
7. Fernandez, V. Copper mining in Chile and its regional employment linkages. Resour. Policy 2021, 70, 101173.
8. Garcia, P.; Knights, P.F.; Tilton, J.E. Labor productivity and comparative advantage in mining: The copper industry in Chile. Resour. Policy 2001, 27, 97–105.
9. Gruenhagen, J.H.; Parker, R. Factors driving or impeding the diffusion and adoption of innovation in mining: A systematic review of the literature. Resour. Policy 2020, 65, 101540.
10. Humphreys, D. Mining productivity and the fourth industrial revolution. Miner. Econ. 2020, 33, 115–125.
11. Sánchez, F.; Hartlieb, P. Innovation in the Mining Industry: Technological Trends and a Case Study of the Challenges of Disruptive Innovation. Min. Met. Explor. 2020, 37, 1385–1399.
12. Lovell, C.A.K.; Lovell, J.E. Productivity decline in Australian coal mining. J. Prod. Anal. 2013, 40, 443–455.
13. Ahmad, S. Estimating input-mix efficiency in a parametric framework: Application to state-level agricultural data for the United States. Appl. Econ. 2020, 52, 3976–3997.
14. Ahmad, S.; Steen, J.; Ali, S.; Valenta, R. Carbon-adjusted efficiency and technology gaps in gold mining. Resour. Policy 2023, 81, 103327.
15. Farrell, M.J. The Measurement of Productive Efficiency. J. R. Stat. Soc. Ser. A Gen. 1957, 120, 253–290.
16. Färe, R.; Grosskopf, S.; Norris, M.; Zhang, Z. Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries. Am. Econ. Rev. 1994, 84, 66–83.
17. Nishimizu, M.; Page, J.M. Total Factor Productivity Growth, Technological Progress and Technical Efficiency Change: Dimensions of Productivity Change in Yugoslavia, 1965–1978. Econ. J. 1982, 92, 920–936.
18. Mahadevan, R.; Asafu-Adjaye, J. The productivity–inflation nexus: The case of the Australian mining sector. Energy Econ. 2005, 27, 209–224.
19. Parida, M.; Madheswaran, S. Effect of firm ownership on productivity: Empirical evidence from the Indian mining industry. Miner. Econ. 2021, 34, 87–103.
20. Syed, A.; Grafton, R.Q.; Kalirajan, K.; Parham, D. Multifactor productivity growth and the Australian mining sector. Aust. J. Agric. Resour. Econ. 2015, 59, 549–570.

21. Charnes, A.; Cooper, W.W.; Rhodes, E. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 1978, 2, 429–444.
22. Schmidt, P.; Lovell, C.K. Estimating technical and allocative inefficiency relative to stochastic production and cost frontiers. J. Econ. 1979, 9, 343–366.
23. Ahmad, S.; Shankar, S.; Steen, J.; Verreynne, M.-L.; Burki, A.A. Using measures of efficiency for regionally-targeted smallholder policy intervention: The case of Pakistan's horticulture sector. Land Use Policy 2021, 101, 105179.
24. Bravo-Ureta, B.E.; Pinheiro, A.E. Technical, Economic, and Allocative Efficiency in Peasant Farming: Evidence from the Dominican Republic. Dev. Econ. 1997, 35, 48–67.
25. Kalirajan, K.P. On measuring economic efficiency. J. Appl. Econom. 1990, 5, 75–85.
26. Ahmad, S.; Burki, A.A. Banking deregulation and allocative efficiency in Pakistan. Appl. Econ. 2016, 48, 1182–1196.
27. Burki, A.A.; Ahmad, S. Bank governance changes in Pakistan: Is there a performance effect? J. Econ. Bus. 2010, 62, 129–146.
28. Drake, J.; Swisdak, M.; Che, H.; Shay, M. Electron acceleration from contracting magnetic islands during reconnec-tion. Nature 2006, 443, 553–556.
29. Fukuyama, H.; Weber, W.L. Estimating output allocative efficiency and productivity change: Application to Japanese banks. Eur. J. Oper. Res. 2002, 137, 177–190.
30. Isaiah, M.; Johane, D.; Dambala, G.; Fiona, T. Environmental and Technical Efficiency in Large Gold Mines in Developing Countries. MPRA Paper. 2021. Available online: https://ideas.repec.org/p/pra/mprapa/108068.html (accessed on 7 November 2023).
31. Shao, L.; He, Y.; Feng, C.; Zhang, S. An empirical analysis of total-factor productivity in 30 sub-sub-sectors of China's nonferrous metal industry. Resour. Policy 2016, 50, 264–269.
32. Grifell-Tatjé, E.; Lovell, C.A.K. Productivity, price recovery, capacity constraints and their financial consequences. J. Prod. Anal. 2014, 41, 3–17.
33. Topp, V. Productivity in the Mining Industry: Measurement and Interpretation; productivity commission staff working paper; Australian Productivity Commission: Canberra, Australia, 2008.
34. Ilboudo, P.S. Foreign Direct Investment and Total Factor Productivity in the Mining Sector: The Case of Chile; Connecticut College: New London, CT, USA, 2014.
35. De Solminihac, H.; Gonzales, L.E.; Cerda, R. Copper mining productivity: Lessons from Chile. J. Policy Model. 2018, 40, 182–193.
36. Oliveira, R.; Camanho, A.S.; Zanella, A. Expanded eco-efficiency assessment of large mining firms. J. Clean. Prod. 2017, 142, 2364–2373.