



Green mining in China: Fintech's contribution to enhancing innovation performance aimed at sustainable and digital transformation in the mining sector

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ABSTRACT

Green mining is at the heart of the sustainable development goals of 20,230 by United nation therefore, this empirical study thoroughly investigates the influence of digital transformation, green finance, and various forms of innovation on the innovation performance of Chinese mining companies. In addition, it explores the moderating effect of Fintech in strengthening this relationship. The study focuses on a sample of 1254 firms listed in the Chinese National Green Mine Directory, offering a comprehensive perspective of the current state of the sector. At the core of this study lies the interaction between financial strategies driven by sustainability and technological innovation. The findings indicate a significant correlation between green finance initiatives and enhanced innovation performance in mining firms. This highlights the pivotal role of environmentally sustainable investments in fostering innovative advancements within the sector. The moderating effect of Fintech is particularly noteworthy. It not only strengthens the influence of digital transformation and various forms of innovation on performance but also enhances the effectiveness of green innovation strategies. This indicates that Fintech is a crucial enabler in the pursuit of sustainable mining practices, acting as a catalyst that bridges innovative technological solutions with environmentally conscious financing. In conclusion, the study provides critical insights into how digital modification, underpinned by green finance and supported by Fintech, is reshaping innovation in the Chinese mining industry. These results have significant implications for policy formulation and strategic decision-making, emphasizing the need for a more robust alignment between technological progress and sustainable financial practices to foster innovation. The study makes a substantial contribution to comprehending the synergy among sustainability, finance, and technology in augmenting the innovation landscape of the mining sector.

1. Background

Industry 4.0, which emerged in the early 2000s, is the outcome of the extensive adoption of digital, interconnected, and intelligent technology (Rajamanickam et al., 2023). Industry 4.0 has the potential to completely transform the current models of industrial production and service by seamlessly integrating information technology and manufacturing technologies. Industry 4.0 smart factories are the result

of a process known as digital transformation (DT), which is crucial but insufficient for the widespread adoption of Industry 4.0. In their recent publication, Ancillai et al. (2023) emphasized the significant impact of digital technologies, including cloud computing, robotics, Internet of Things (IoT), blockchain, and big data, on traditional business practices and the adoption of innovative ideas. The recognition of innovation as a crucial method to achieve sustainable development is gaining prominence in the realm of business research. Therefore, exploring the

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mechanisms of DT and its impact on innovation is highly valuable. In the Chinese mining sector, the introduction of DT is reshaping operations, resulting in enhanced efficiency and heightened safety. By incorporating advanced technologies, such as IoT, AI, and automation, mining companies are revolutionizing resource management, minimizing environmental impact, and pioneering innovative approaches to mineral exploration and processing. Previous research on DT has mainly focused on aspects such as economic efficiency, environmental performance, and business models (Feroz et al., 2021). Zhai et al. (2022) conducted a study on Chinese listed firms spanning from 2009 to 2019 and found that DT contributed to an overall increase in firm performance. Recent literature has utilized DT as a mediating variable to investigate the influence of the digital economy on innovation (Ding et al., 2021).

At present, there are significant challenges hindering the attainment of global sustainable development. Nations across the globe are placing great emphasis on green finance and enterprise innovation as crucial approaches to address environmental issues and overcome past limitations. In the report of the 19th CPC National Congress, great emphasis was placed on the importance of firmly implementing the new development concept of “innovation, coordination, green, openness, and sharing.” The report highlights the importance of green finance in fostering environmentally sustainable development, a priority emphasized by General Secretary Xi Jinping (Yin, 2019). China is currently undergoing a substantial transition toward industrial upgrading and the pursuit of high-quality development. The utilization of green finance becomes crucial in steering companies toward their environmental initiatives and offering specific support for the development and transformation of tangible businesses. At the 19th National Congress of the Communist Party of China, General Secretary Xi Jinping emphasized the crucial role of innovation in driving development. Innovation is important for the success and growth of any business. It helps promote long-term progress and development. According to a well-regarded scholarly article, the availability of bank credit plays a pivotal role in fostering innovation across various industries. However, the article also highlighted the negative impact of the market’s weak financial structure on companies’ ability to innovate (Liu et al., 2023). It is evident that the external financial environment has a significant impact on the innovation performance of firms. Despite the notable advances in economic development since China’s reform and opening up, the environmental situation continues to be unfavorable. There has been a significant rise in environmental pollution, energy inefficiency, resource depletion, ecological harm, and industrial structure imbalances due to the prevalence of practices prioritizing pollution over treatment. In addition, the simultaneous occurrence of pollution and treatment has contributed to these issues. When dealing with environmental issues, it is imperative to not only contemplate traditional solutions that address the problem after it occurs but also adopt a proactive approach from the outset. Thorough investigation of various vantage points is important to achieve sustainable economic development while safeguarding the environment. This involves considering factors such as FSC certification, taxation policies, financial strategies, resource distribution, and incentive systems. Green finance has the potential to effectively address the intertwined problems of innovation and environmental degradation. Green finance policies originated in Europe during the 1970s as a method of funding environmental initiatives (Falcone, 2020). The green finance sector in China has had a slow start and has only made modest progress (Lin et al., 2022). At present, there are challenges in achieving a symbiotic relationship between green finance and innovation, hindering their simultaneous progress.

In recent years, the Chinese government has made substantial progress in the advancement of green finance (Wang et al., 2021a, b). The green finance market has undergone a noteworthy resurgence, entering a new promising phase of growth due to the implementation of environmentally conscious policies (Kenis and Lievens, 2016). The interconnection between “green” and “innovation” is apparent, leading to favorable outcomes for both the environment and the economy. This

study delves into the correlation between green finance and corporate innovation performance, making a significant contribution to the fusion of environmental sustainability and innovative practices. It highlights the significance of preserving the natural environment and fostering sustainable business practices while contributing to social progress and economic prosperity.

The performance of innovation serves as a reflection of innovative efforts (Li et al., 2023; Xu et al., 2022, 2024). A comprehensive examination has been conducted on various aspects of green finance, encompassing both internal and external dimensions. Internally, it involves scrutinizing the overall organizational structure and individual employees at a more granular level. Ji and Zhang (2023) highlighted the importance of green finance in fostering innovation within the mining industry, demonstrating how environmentally focused investments play a crucial role in promoting sustainable technological advancements and enhancing the overall innovation performance of the sector.

Research has shown that the integration of advanced technological solutions in the financial sector, known as Fintech, has a profound impact on innovation performance. By streamlining financial processes, fostering creative developments, and enhancing efficiency, Fintech has proven to be a game-changer in multiple sectors. China is a prime example of how FinTech has greatly influenced the innovation performance of manufacturing firms. This can be attributed to the country’s remarkable blend of rapid technological progress and industrial expansion. Chinese manufacturing companies have been embracing FinTech solutions to streamline operations, reduce costs, and improve supply chain management. Thanks to this integration, operations have been optimized, which enabled real-time financial management and improved decision-making abilities. Technologies such as mobile payments, blockchain, and AI-driven analytics have substantially enhanced financial transactions and enabled firms to drive innovation in product design, customer engagement, and market expansion. The result is a remarkably flexible manufacturing sector that can quickly adapt to changes in the market and meet the demands of consumers, further establishing China’s position as a leading player in global manufacturing. The transformation of China’s mining industry, driven by the integration of finance and technology, exemplifies the significant impact of this fusion in fostering innovation and bolstering competitiveness in the modern global economy.

The study was conducted on a sample of Chinese mining manufacturing firms listed in the green “mine” directory. China’s mining sector, comprising over 1500 large-scale operations, with 75% situated underground, is extensive and substantial. Generating an annual revenue exceeding USD 400 billion, this sector significantly contributes to the nation’s economy. The national resources tax yielded a large sum of USD 27 billion in 2020, representing a contribution of 1.1% to the total national tax revenues. Annually, China allocates a substantial financial investment of around USD 200 billion to mining supplies and services. In recent years, considerable effort has been devoted to increasing public knowledge regarding environmentally sustainable mining practices. A notable transition toward environmentally sustainable practices became apparent by 2021 when 1254 mining companies were included in the nationwide green mining directory. China has made substantial advancements in intelligent mining, as evidenced by its approximately 40,000 mines. Nationwide, a cumulative sum of 71 intelligent mine demonstration projects has been established. It is anticipated that the intelligent development infrastructure and integrated platforms market will be worth approximately RMB 200 billion whereas the intelligent equipment market will be worth approximately RMB 800 billion. Furthermore, the market for processing stock from coal mines is expected to attain trillions of RMB. Due to the expansion of the noncoal mining sector, the green mining industry in China is anticipated to experience substantial growth over the next two decades. Organizations that provide mining technology and sustainable mining solutions stand to gain substantially from this development.

2. Literature review

2.1. Digital transformation and innovation performance

The seamless integration of digital technology has notably improved the flow of information within and between organizations, effectively overcoming previous barriers (Jones et al., 2021). Technological advancements have resulted in greater flexibility in organizational structures. As a result, each company in the postmodern business era has its distinct set of internal and external policies, which may vary from one company to another (Weisbeck and Hess, 2020; Jin et al., 2024; Xu et al., 2023). Through the utilization of digital technologies, companies can transcend their resource and capability constraints and tap into external resources and capabilities to effectively execute strategies for market expansion and product innovation (Xing et al., 2023). A study conducted on Chinese manufacturing A-share listed companies between 2016 and 2019 has reported remarkable improvements in collaborative innovation performance with the implementation of blockchain technology (Wan et al., 2022). The emergence of digital transformation (DT) has caused considerable disruption in numerous countries and industries (Jones et al., 2021; Jiang and Xu, 2023; Dong, 2023). The utilization of digital technology is a widely adopted approach to enhance and advance corporate development, particularly when it comes to achieving sustainability goals.

The domain of enterprise digitalization encompasses a broad spectrum of subjects, including digital capabilities, digital theory, DT, the influence of DT on business performance, and the fundamental mechanisms involved in DT (Konopik et al., 2022). Hanelt et al. (2021) discriminated between DT and digitalization and argued that DT involves the use of technology to drive DT whereas digitalization involves converting analog information into a digital format. According to Benitez et al. (2022), the ability to digitize is a reflection of the technical infrastructure, human capital, and managerial competencies related to information. DT involves the integration of cutting-edge digital technologies by companies to substantially enhance business performance, streamline operations, elevate customer experience, and establish innovative business models (Hongyun et al., 2023). The process of DT involves the adoption of cloud computing, social media platforms, big data analytics, and other related technologies (Feroz et al., 2021). Based on the information processing view, when the ability of an organization to handle information aligns with its needs, it can lead to improved business performance (Reis et al., 2021). Businesses can utilize digital technology to improve their information processing capabilities and reduce disruptions caused by unwanted data (Akter et al., 2022; Hu et al., 2022; Zhao et al., 2023). Data is an essential component in acquiring valuable knowledge, and businesses can reap the rewards of digital tools that effectively retrieve pertinent data (Abu-ALSondos, 2023; Chen et al., 2023; Chen et al., 2024). Companies that possess strong data management capabilities can better adapt their innovation strategy promptly in response to new information or market demands (Del Giudice et al., 2021). Businesses can leverage digital technologies to enhance their innovation by gaining deeper insights into product sales and consumer demand. Extensive research has demonstrated a strong connection between ICI practices and rates of innovation. This correlation can be further bolstered by improving the capabilities of information processing.

2.2. Green finance and innovation performance

The interconnection between green finance and innovation performance is robust and mutually influential, exerting a substantial impact on shaping economic growth (Abbas et al., 2021). Additional funding can markedly boost businesses' innovation capabilities (Lerner and Nanda, 2020). Concurrently, investing substantial financial resources in innovation endeavors is crucial to the success of any enterprise. Miao et al. (2020) contended that for green financial institutions to establish

efficient mechanisms for the prevention, management, and elimination of risks, it is essential to employ highly skilled professionals and technical personnel. They further argued that by effectively facilitating the execution of innovation activities, green finance can markedly boost innovation performance. In recent years, there has been a growing awareness of environmental issues, which has given rise to a new area of study known as "green finance." Akomea-Frimpong et al. (2022) argued that an increasing number of individuals are choosing to embrace a way of life that prioritizes environmental sustainability. They continued and argued that the promotion of green products and lifestyles by government agencies is driving a significant change toward ecological consumption, inspiring individuals to make more environmentally friendly choices.

This is reinforced by the government's clear commitment to promoting environmentally conscious consumption through procurement. Simultaneously, there have been several tax and subsidy measures implemented to encourage the uptake of environmentally friendly consumption, which is becoming increasingly popular compared with traditional consumption. The nationwide effort to promote sustainable and environmentally conscious consumption has a significant impact on consumers. Companies have a strong ability to identify and address a series of eco-friendly measures, which motivates them to develop new sustainable technologies. There are means to improve the effectiveness of innovation. For example, Arsawan et al. (2022) argued that developing a financially sustainable system can enhance companies' grasp of competition, fostering a culture of innovation. Ultimately, businesses will experience a significant improvement in their innovation performance. Furthermore, they contended that green financing aims to discourage businesses that hide environmental data by imposing more operational challenges on them. Nevertheless, this approach also emphasizes these companies' commitment to social responsibility and environmental consciousness, which in turn attracts a greater number of investors and encourages them to embrace sustainable practices. As a result, these businesses experience an increase in their innovation output. However, in the context of global market competition, numerous companies are actively pursuing fresh opportunities for innovation, collaboration, and heightened consumption.

Green finance covers a range of financial services that can support environmentally conscious initiatives (Al-Amin et al., 2023). It distinguishes itself from conventional finance by prioritizing environmental and social sustainability, along with the long-term viability of human society (Desiderio, et al., 2022). The primary objective is to attain long-term economic and social progress through effective financial administration, all while safeguarding the natural surroundings. Enterprises invest in initiatives to enhance the environment, which is commonly known as enterprise environmental investment. According to a highly regarded research paper, the amount of investment in environmental protection plays a pivotal role in distinguishing products with similar designs and production processes (Wang et al., 2021a, b). Investing in green initiatives can provide significant benefits to businesses, both in terms of the environment and their financial performance. The growth of green finance is crucial for facilitating these initiatives. Investing more in the environment can substantially enhance businesses' ability to innovate (Khalil & Nimmanunta, 2023). Investing in the environment is of utmost importance as it not only promotes innovation and advancement in businesses but also propels technical progress. Businesses can also benefit greatly from investing in environmental protection by prioritizing innovation in green sectors. The use of state-of-the-art products and technology allows for the achievement of environmentally conscious practices that are highly effective and cost-efficient.

2.3. Fintech and innovation performance

FinTech represents a potent amalgamation of finance and technology, driving innovation and leaving a substantial imprint on diverse

industries. This literature review seeks to address a research gap by investigating the influence of financial technology (FinTech) on the innovative capabilities of manufacturing companies (Wang et al., 2023). This topic has attracted considerable scholarly attention. The analysis delves into the impacts on operational efficiency, innovation outcomes, and the incorporation of FinTech solutions into manufacturing processes. The introduction of FinTech into production represents a major milestone in the evolution of financial management, highlighting a departure from outdated methods toward cutting-edge, technology-driven alternatives (Cumming et al., 2023). In recent years, financial technology applications have completely transformed the way manufacturing companies manage their finances, supply chains, and customer interactions. The transformation has been substantially influenced by digital payments, smart contracts, and blockchain technology (Sun et al., 2022). Furthermore, these technologies have not only enhanced efficiency but also facilitated the development and implementation of groundbreaking approaches for products and services. Several studies have demonstrated the significant benefits of incorporating FinTech into the manufacturing sector. Businesses have reaped significant benefits from the adoption of FinTech solutions, enjoying advantages such as enhanced resource management, more accurate forecasting, and streamlined financial operations (Lăzăroiu et al., 2023). The enhanced potential for innovation arises from these advancements, facilitating a more efficient allocation of resources toward research and development. Furthermore, the ability of FinTech to enhance financial transactions allows fabricate companies to quickly adjust to changes in the market. There is a clear focus on encouraging a culture of continuous innovation and adaptability. However, there are challenges to the integration of FinTech into the commercial enterprise industry. The main focus is to incorporate state-of-the-art technology into current systems, offer extensive training on advanced financial tools to organizations, and ensure the utmost confidentiality of critical substance in a digital financial setting (Allioui and Mourdi, 2023). To effectively address these issues and fully leverage the game-changing potential of FinTech while minimizing its inherent risks, it is imperative to embrace a strategic approach.

The influence of forthcoming FinTech trends on the manufacturing sector is expected to be substantial. Utilizing cutting-edge technologies can substantially enhance the innovation capabilities of manufacturing companies. For example, blockchain technology can be employed to promote transparency in supply chain operations, whereas AI can be harnessed for financial analytics (Dutta et al., 2022). These emerging technologies have the potential to provide remarkable insights into financial management. This research has the potential to revolutionize manufacturing methods, making them more efficient and adaptable to changing market demands. Without a doubt, FinTech has become an essential driver of technological innovation in the industrial sector. Its impact results in heightened efficiency in financial operations, improved agility in market responsiveness, and the avocation of novel opportunities for product development (Syed et al., 2020). To stay ahead in the ever-changing digital world, manufacturing companies need to strategically integrate FinTech solutions. Due to the dynamic nature of the global financial system and the rapid progress in technology, it is necessary for future research to explore the long-term impact of FinTech on creativeness in the manufacturing sector. Thorough and ongoing research is crucial to fully understand and harness the transformative potential of FinTech in the industrial sector.

There has been a considerable amount of scholarly interest in the intricate connection among FinTech, digitization, and innovation performance in the manufacturing sector. FinTech plays a crucial role in facilitating the DT of manufacturing companies through the integration of financial services and technology. This transformation is characterized by the integration of state-of-the-art data analytics solutions, automated payment systems, and advanced financial management tools (Barroso and Laborda, 2022). Driven by the FinTech revolution, it has gained considerable momentum. Advancements in digital technologies

such as cloud computing, the Internet of Things (IoT), and artificial intelligence (AI) have enabled the manufacturing industry to effectively leverage financial technology (FinTech) solutions.

The impact of financial technology on the innovative capacity of manufacturing companies is substantial. By using FinTech, these companies can optimize their financial operations, allowing for the allocation of more resources toward innovation and advancement. Technologies such as blockchain have revolutionized supply chain management by enhancing transparency and streamlining processes (Dutta et al., 2020). Operating at such a high level of efficiency not only enhances operations but also fosters an environment that promotes innovation. The utilization of AI and big data analytics in financial technology can provide manufacturers with valuable insights into market trends, customer preferences, and potential areas for innovation. This can help them improve their competitive edge and foster innovation.

The existing literature discusses substantial concerns and obstacles related to the intersection of FinTech, digitization, and innovation. The introduction of new technology demands significant human and financial resource allocation. Manufacturers need to recognize the importance of investing in training and development programs on par with their investments in technology (Bosman et al., 2019). This approach empowers their workforce to adeptly utilize cutting-edge tools. Privacy and security have emerged as important concerns with the growing digitization and interconnectedness of financial and operational data. Further exploration is necessary to evaluate FinTech's impact on innovation performance, the role of regulatory frameworks in shaping this relationship, and the long-term sustainability of these technological integrations (Hussain et al., 2023). To propel advancements in manufacturing and encourage businesses to embrace digital and financial technologies for increased innovation, policymakers need an in-depth understanding of the complexities associated with this interconnected landscape. There is a clear connection between the adoption of FinTech and the DT of manufacturing companies, leading to enhanced innovation performance, as indicated by the research findings. This partnership offers improved operational efficiency and market responsiveness (Tarigan & Siagian, 2021). However, it is important to effectively address the associated challenges. Furthermore, it is crucial to gain a deep understanding of how manufacturing firms can successfully adapt and thrive in an increasingly digitalized landscape. Understanding this field is essential for staying abreast of the constantly evolving technology and financial landscape.

Many studies in this area have shown that companies can enhance their competitive advantage and fulfill regulatory obligations by allocating resources toward environmentally sustainable technologies and practices, facilitated by green financing. Enterprises are actively engaged in the development of new products and procedures to contribute to environmental preservation (Liu et al., 2021). The shift toward sustainability is leading to innovative outcomes with substantial impact. Extensive research has demonstrated the significant impact of technological advancement and financial support on driving innovation in the manufacturing sector. FinTech plays a pivotal role in this particular context. The potential of Fintech to revolutionize the management and distribution of financial resources for companies is widely acknowledged (Hsu et al., 2021). This is due to its advanced capabilities in digital finance, blockchain technology, and data analytics. Financial technology can play a crucial role in promoting investments in environmentally responsible and innovative projects, thus facilitating the implementation of green financing.

3. Data and methodology

3.1. Data

The study was conducted on the initial sample of 1254 Chinese mining companies included in the national green “mine” directory.

Considering the notable impact of major events such as the 2008 financial crisis and the 2020 COVID-19 pandemic on our regression findings, the study focuses on the years 2009–2019. Financial data were obtained from the China Stock Market & Accounting Research Database (CSMAR) and the Wind database. After meticulously filtering out firms with substantial information deficiencies, a total of 10,009 firm-year observations remained. The variables (DGT, PRSIN, PRDIN, GRNCRD, GRNIN, and FNT) were used to assess their impact on innovation performance (INP). The details of the data points and their respective database systems are outlined in Table 1. The data summary is presented in the Table 2. The results and discussion section will provide further elaboration on the variables, including explanations and specifications.

3.1.1. Innovation performance index

We used the study by Liu et al. (2023) as a reference to develop PCA. This research has utilized the annual data for QUNIP and QULIP. However, it is noteworthy that relying solely on a single proxy, such as QUNIP or QULIP, can yield misleading outcomes. Furthermore, the consolidation of all the proxies into a single equation presents a significant challenge (Briscoe et al., 2023). Thus, PCA was employed to create a composite variable called the “Financial Inclusion Index” by combining two distinct financial measures. Using patent and invention patent applications, it accurately replicates the original data of the natural logarithm. We used the study conducted by (Ali et al., 2020) to develop PCA. The j th factor indices in PCA are expressed as follows (see Equation (1)):

$$INP_j = W_{j1}X_1 + W_{j2}X_2 \quad (1)$$

In this context, an innovation performance index is denoted by the symbol INP_j . The pertinent parameters are represented by the symbols W_{j1} and W_{j2} , respectively. Values of indicators are represented by the variables X_1 and X_2 . Replacing X_1 and X_2 with $QUNIP_1$ and $QULIP_2$, Equation (1) becomes

$$INP_j = W_{j1}QUNIP_1 + W_{j2}QULIP_2 \quad (2)$$

Table 1
Variables and measure.

Dependent Variable					
INP	Innovation Performance Index (section 3.1.1)	Quantity of Innovation QUNIP		The natural logarithm of using patent applications	Wingo
		Quality of Innovation QULIP		The natural logarithm of invention patent applications	Wingo
Independent Variable					
DGT	Digital Transformation			The logarithm of the frequency of digital-related words in financial annual reports	Wingo
FNT	Fintech	The level of Fintech development		Fintech is measured using the Baidu search index of financial technology keywords and entropy evaluation method	Baidu search index
TIN	Types of Innovation	Process innovation	PRSIN	The natural logarithm of the total number of process innovation patent applications of the enterprise in the current year	Cathay United Database (CSMAR)
		Product innovation	PRDIN	The natural logarithm of the total number of product innovation patent applications of the enterprise in the current year	
GRNF	Green Finance Index (section 3.1.2)	Green credit	GRNCRD	Percentage of interest expenses in energy-intensive industries	Cathay United database (CSMAR)
		Green investment	GRNIN	Investment in environmental pollution control as a proportion of GDP	
Control Variables					
Age	Firm age			Logarithm of the age of the enterprise	Cathay United database (CSMAR)
CSR	Total CSR score			ln of the total social responsibility score)	Cathay United database (CSMAR)
OC	Ownership concentration			Number of shares held by five largest shareholders	Cathay United database (CSMAR)
LEV	Leverage			The ratio of total liabilities to total assets	Cathay United database (CSMAR)
Size	Fir Size			The logarithm of the total assets	Cathay United Database (CSMAR)

Table 2
Summary statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
INP	10,009	1821	2.12110	0	6201
PRDIN	10,009	2470	1.92100	0	8120
PRSIN	10,009	1320	1.30181	0	7820
DGT	10,009	1870	1.42101	0	6170
GRFIN	10,009	−0.2411	2.38100	−1.605023	0.3210000
SIZE	10,009	7.6420857	1.1642445	0.5206659	14.9492560
OC	10,009	60.911335	7.1045013	15.0456170	82.9310000
LEV	10,009	0.291833	0.0266189	0.0016638	0.8965053
CSR	10,009	3.2301000	0.942420	−0.600000	4.860000
AGE	10,009	5.512319	1.368280	3.396000	8.1540000

3.1.2. Green finance index

Similarly, the green finance index is developed using four subconstructs, namely, green credit, green investment, green insurance, and government support. The j th factor indices in PCA are expressed as follows (see Equation (2)):

$$GRNF_j = V_{j1}Z_1 + V_{j2}Z_2 + V_{j3}Z_3 + V_{j4}Z_4 \quad (3)$$

In this context, green finance index is denoted by the symbol $GRNF_j$. The parameters that are pertinent are represented by the symbols V_{j1} , V_{j2} , V_{j3} and V_{j4} , respectively. Values of indicators are represented by the variables Z_1 , Z_2 , Z_3 , and Z_4 . Replacing Z_1 , Z_2 , Z_3 , and Z_4 with $GRNCRD_1$, $GRNIN_2$, $GRNINS_3$, and $GOVS_4$, Equation (4) becomes:

$$GRNF_j = V_{j1}GRNCRD_1 + V_{j2}GRNIN_2 + V_{j3}GRNINS_3 + V_{j4}GOVS_4 \quad (4)$$

3.1.3. Summary statistics of data

A comprehensive analysis of all variables was conducted, and detailed descriptive statistics were generated. The variables were estimated in their transformed versions to mitigate the impact of outliers and ensure that any nonlinear relationships that might have existed in the past have been converted into linear ones (Asuero and Bueno, 2011). Table 1 presents the summary statistics. In terms of INP, most companies excel in this area, achieving an impressive average score of 1821. Nevertheless, there is a noticeable disparity between the top and bottom

performers, as evidenced by the substantial standard deviation of 2.12110. The extensive range of values, spanning from 0 to 6,201, further highlights this variation. When comparing PRDIN with INP, a slight decrease in variation can be observed, but such a decrease remains significant, with an average score of 2470 and a standard deviation of 1.92100. The range of values, spanning from 0 to 8,120, indicates that there is significant variation in product innovation among these companies, which may have an impact on their overall innovation performance. The process innovation (PRSIN) scale has an average score of 1320 with a standard deviation of 1.30181. Here, 7820 represents the highest score, indicating substantial variations in innovation levels among different companies in terms of their processes.

The digitalization range spans from 0 to 6,170, with an average of 1870 and a standard deviation of 1.42101. Companies are incorporating digital solutions into their operations at different levels, indicating a moderate overall adoption of digital technologies. The fascinating aspect of green finance (GRFIN) is its remarkable standard deviation of 2.38100 and an average negative value of -0.2411. The extensive range of values, spanning from -1.605023 to 0.3210000, suggests that the majority of companies are not performing favorably in this area. This could potentially indicate a lack of enthusiasm toward environmentally friendly investments.

The firms seem to display moderate variation in firm size, with an average of 7.6420857 and a standard deviation of 1.1642445. This study discusses a wide range of firms, with sizes varying from 0.520665 to 14.9492560, indicating a diverse set of sizes. The firms' leverage levels exhibit a notable degree of consistency, spanning from very low to relatively high. This is evident from the average leverage (LEV) of 0.291833, which has a small standard deviation of 0.0266189. The firm's total CSR score has an average of 3.2301000 and a standard deviation of 0.942420. The range of values indicates a wide range of CSR performance among firms, spanning from -0.600000 to 4.860000. Lastly, the average age of a firm is 5.512319 years, with a standard deviation of 1.368280. The firms vary in age, with a range of 3.396,000–8.1540000 years.

3.2. Methodology

When estimating the aforementioned equations, it is essential to incorporate fixed-effects to account for variations across different groups or sections, as they help minimize the impact of unchanging factors (such as management systems, marketing strategies, geography, climate, and official language) on each firm, thus preventing any biases caused by omitted variables. We estimated each of the previous equations using fixed-effects for country and time. Time-fixed-effects are highly valuable in controlling potential global disturbances that may have affected all four nations during the study period. In our fixed-effects estimations, we utilized cross-sectional clustered errors, which are resilient against serial correlation and heteroskedasticity (Bai et al., 2021). The precise determination of the econometric impacts of different groups of independent variables on INP was achieved by carefully considering the variations in banks and industries while estimating each set of equations. There is a concern regarding the potential correlation between the predictors used in the fixed-effects (FE) models and the error term. This is because a reciprocal influence might be present from the INP on our independent variables, specifically those associated with product innovation and process innovation measures (Gao et al., 2017). Our goal was to determine the longevity of INP, which pertains to how much the current level of these activities is impacted by off-balance sheet activities in previous periods. To address this issue, we incorporated the lagged dependent variable as a part of the equation's right-hand side. Estimating a dynamic model using traditional static fixed-effects can be quite challenging due to the presence of autocorrelation, which occurs when the dependent variable lags are included as regressors. Because of this additional concern, it is imperative to develop a new approach for estimating dynamic panel models.

We conducted a regression analysis to address the endogeneity problem in the fixed-effects (FE) models. In this analysis, we regressed the dependent variable, INP, on lagged explanatory variables with greater depth. This approach was proposed by Zia (2022). It substantially decreases the likelihood of reverse causality and mitigates the impact of outliers on our results. Furthermore, it ensures that future values have no impact on past values (Mahabir, et al., 2020). The use of the instrumental variables (IV) approach is widely regarded as a highly effective method. These methods effectively address the potential endogeneity problem associated with INP, product innovation, and process innovation.

Considering the unique characteristics of our panel dataset, which includes variables of varying timeframes, we have decided to utilize the difference generalized method of moments (GMM) estimator suggested by Roodman (2009) and Olaniji and Odhiambo (2023). This approach employs the generalized method of moments (GMM) framework to estimate the first difference of the dependent variable. The estimation considers both the lag of the differenced dependent variable and the lag of the variables on the right-hand side that are considered to be endogenous. When considering the autocorrelation resulting from including the lagged dependent variable on the right-hand side, it is beneficial to use a dynamic specification of our model in addition to the traditional static FE models. The following are the precise details of the dynamic model:

$$y_{it} = \alpha_1 y_{it-1} + \alpha_1 x_{it} + \alpha_2 w_{it} + \varepsilon_{i,t} \dots \dots \dots (5)$$

$$\varepsilon_{i,t} = U_i + V_{i,t} \dots \dots \dots (6)$$

The econometric models for the current study are

$$\begin{aligned} INP_{it} = & \alpha_0 + \alpha_1 DGT_{it} + \alpha_2 FNT_{it} + \alpha_3 PRSIN_{it} + \alpha_4 PRDIN_{it} + \alpha_5 GRNFN_{it} \\ & + \alpha_6 AGE_{it} + \alpha_7 OC_{it} + \alpha_8 LEV_{it} + \alpha_9 CSR_{it} + \alpha_{10} SIZE_{it} + \mu_i + \lambda_t \\ & + \varepsilon_{i,t} \dots \dots \dots \end{aligned} \quad (7)$$

$$\begin{aligned} INP_{it} = & \alpha_0 + \alpha_1 DGT_{it} + \alpha_2 FNT_{it} + \alpha_3 PRSIN_{it} + \alpha_4 PRDIN_{it} + \alpha_5 GRNFN_{it} \\ & + \alpha_6 DGT_{it} * FNT_{it} + \alpha_7 PRSIN_{it} * FNT_{it} + \alpha_8 PRDIN_{it} * FNT_{it} \\ & + \alpha_9 GRNFN_{it} * FNT_{it} + \alpha_{10} OC_{it} \\ & + \alpha_{11} LEV_{it} + \alpha_{12} SIZE_{it} + \alpha_{13} AGE_{it} + \alpha_{14} CSR_{it} + \mu_i + \lambda_t \\ & + \varepsilon_{i,t} \dots \dots \dots \end{aligned} \quad (8)$$

The LM test of the Lagrange multiplier is a commonly used procedure to determine the CSD in panel data collection. The test was initially developed by Breusch and Pagan (1980). Here is the standard LM test, developed by Breusch and Pagan (1980):

$$LM_{BP} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^N \widehat{\delta}_{ij}^2 \quad (9)$$

where $\widehat{\delta}_{ij}^2$ is an estimated sample of the pairwise correlation coefficients. If T and N are sufficiently large, the LM test proposed by Breusch and Pagan (1980) is suitable. Alsamara et al. (2018) suggested that when the pairwise correlation approaches zero, the validity of the test is compromised. Thus, the LM test was improved by using a scaled version as the foundation, which effectively addressed the limitations of LM BP. In light of this, Alsamara et al. (2018) introduced a new test statistic. Despite the limitations of a small sample size and limited time frame, this test can still be employed.

$$Scaled \text{ LM test} = \left(\sqrt{\frac{N}{N-1}} \right) \left[\sum_{i=1}^{N-1} \sum_{j=i+1}^N (T \widehat{\delta}_{ij}^2 - 1) \right] \quad (10)$$

The test generates substantial size variations by using large N and small T. To address this issue, Pesaran et al. (2004) introduced a

differentiable CSD test suitable for large N and small T :

$$CD\ test = \left(\sqrt{\frac{2T}{N(N-1)}} \right) \left[\sum_{i=1}^{N-1} \sum_{j=i+1}^N \delta_{ij} \right] \quad (11)$$

The CSD test utilizes a standard normal distribution with large sample sizes and a large number of trials. This distribution follows an exponential pattern. This test consistently yields dependable results despite the presence of numerous multidimensional models and variations in the coefficients' slopes. To enhance the LM test, Baltagi et al. (2012) utilized the exact mean and variance of the LM statistics as follows:

$$LM_{adj} = \left(\sqrt{\frac{2T}{N(N-1)}} \right) \sum_{i=1}^{N-1} \sum_{j=i+1}^N \delta_{ij} \frac{(T-k)\rho_{ij}^2 - \mu_{Tij}}{\sqrt{v_{Tij}^2}} \quad (12)$$

According to Baltagi et al. (2012), the restrict mean and variance of $(T-k)\delta_{ij}^2$ are represented by the variables μ_{Tij} and v_{Tij}^2 , respectively.

The primary assumptions that were adopted in several studies, such as those by Levin et al. (2002) and Im et al. (2003), were CS independence and homogeneity. The studies employed first-generation unit root tests. It is possible that the results of the initial test will not be adequate if the variables being studied are diverse and unrelated to CSD. However, the CIPS-test, developed by Choi and Krause (2006), is highly reliable as it effectively considers both CSD and heterogeneity. The entire data analysis process is explained in Fig. 1.

4. Data analysis

The initial step in our analysis involved verifying the stationarity of our variables. We conducted tests on all variables using the Phillips–Perron method and the panel Fisher-type unit root test. This analysis was conducted to ensure the precision of our regression results and the stability of our variables. The Fisher-type unit root test was used to determine the unit root of the data. This test utilizes the four approaches proposed by Choi and Krause (2006) to combine the P -values from the panel-specific unit root tests and applies the augmented Dickey–Fuller test to all cross-sections. Three of the methods involve P -value transformation, whereas the fourth method usually adjusts the inverse χ^2 transformation when N is large. The test assumes the presence of a unit root in each panel, but this theory is currently under investigation. Based on the findings, it is clear that the null hypothesis cannot be accepted, indicating that the variables do not deviate from their initial values. It is assumed in the test's null hypothesis that a unit root is included in each panel. We have experimented with different lag lengths in the tests outlined in the test specification, but the statistically significant results remained consistent.

Pearson's correlation coefficients, which evaluate the level of

association between the independent variables in the study, are presented in Table 3. Based on Table 1, none of the independent variables exhibit a correlation coefficient exceeding 0.80. Based on the guidance of Kyriazos and Poga (2023), we examined the presence of multicollinearity using a correlation threshold of 0.8. There was no evidence of multicollinearity among the variables, as indicated by the correlation matrix. Collinearity exceeding 80% was identified using Pearson's correlation matrix on all variables. We identified two variables that were highly collinear: loan ratio and liquidity (Kyriazos and Poga, 2023). To avoid any potential errors in our model, we decided to exclude the loan ratio from our list of variables.

Several diagnostic tests were employed to determine the most appropriate estimates (see Table 4 for more information). To address the heteroscedasticity issues in our aggregate model, we began by conducting the White heteroscedasticity test. The test results indicate that our aggregate model strongly rejects the null hypothesis at a significant level of 5%, with P -values ranging from 0.0000 to 0.0020. We recommend utilizing random-effects estimates due to the presence of heteroscedasticity in the aggregate pooled model.

The choice between pooled OLS or random-effects estimations was made based on the results of the Breusch–Pagan LM test (Psaila et al., 2019). If the specific term for the cross-sections is zero, then the pooled OLS method produces a highly reliable estimator that remains unaffected by autocorrelation. However, if the test is unsuccessful, this may not be the situation. LM uses a chi-squared distribution with one degree of freedom when considering the null hypothesis. The null hypothesis was rejected, and it was determined that the cross-section individual effects were present when the computed value exceeded the tabulated chi-squared. Consequently, the random-effects model was selected as the preferred methodology. The results of the LM test are presented in Table 1, which indicate that the random-effects model performs better than the pooled OLS model. Deciding between a FE model and a random-effects model is the next logical progression. To compare the FE estimator μ_1 with the random-effects estimator μ_2 , the Hausman specification test was employed (Sheytanova, 2015). The underlying assumption is that the estimator μ_2 offers a precise and impartial forecast of the actual parameters. If this assumption holds true, the two estimators should be indistinguishable in every aspect. The results in Table 4 indicate robust evidence in favor of the FE model, suggesting that the null hypothesis should be rejected. The GMM analysis in this study involved the estimation of the Arellano–Bond test for zero autocorrelation, as presented in the table below. We conducted a comprehensive analysis using Pearson's test to assess the interdependence of each model across different time periods. The test results indicate the existence of cross-sectional dependence among the cross-sections. Feasible generalized least squares and panel-corrected standard error are two powerful methods for analyzing balanced panel datasets. However, we conducted extensive testing on each model using the

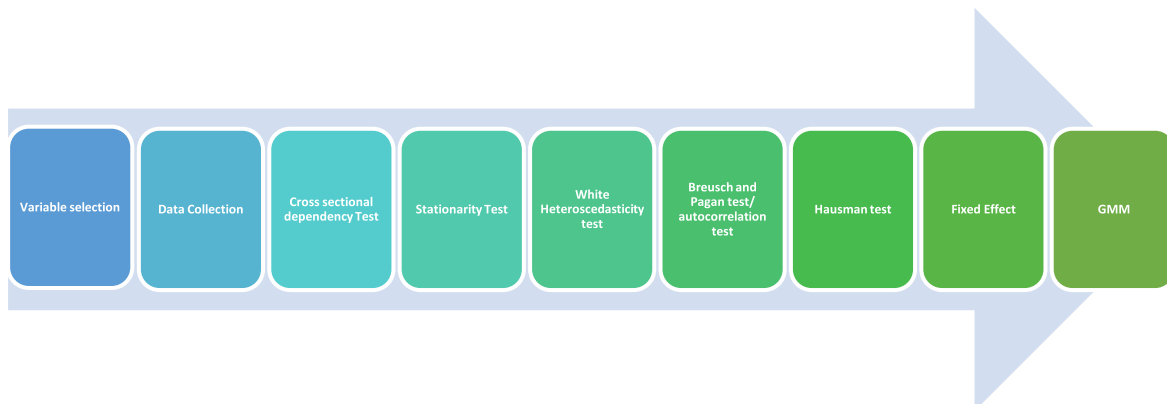


Fig. 1. Procedure for estimation.

Table 3
Correlation matrix.

Variables		1	2	3	4	5	6	7	8	9	10	11
<i>INP</i>	1	1										
<i>FNT</i>	2	0.1361	1.00									
<i>PRDIN</i>	3	−0.1090	0.3088	1.00								
<i>PRSIN</i>	4	0.1569	0.0104	−0.4533	1.00							
<i>DGT</i>	5	0.0139	0.2107	0.2195	−0.1154	1.00						
<i>GRFIN</i>	6	0.0425	−0.2254	−0.0501	−0.0552	−0.1007	1.00					
<i>SIZE</i>	7	0.1043	0.4154	0.8120	−0.3091	0.2643	−0.1191	1.00				
<i>OC</i>	8	0.1668	0.2305	0.1793	−0.0247	0.4181	−0.1009	0.2714	1.00			
<i>LEV</i>	9	0.3935	−0.1411	−0.5783	0.6582	−0.0537	0.1482	−0.3682	−0.0179	1.00		
<i>CSR</i>	10	0.0686	−0.1560	−0.0412	0.0181	0.2783	−0.0848	0.0325	0.4126	0.1431	1.00	
<i>AGE</i>	11	−0.1117	0.1172	0.0280	−0.0846	−0.1574	−0.0975	−0.0400	−0.2554	0.1301	−0.6649	1.00

Table 4
Results of the Diagnostic test.

Model	Statistics	Breusch–Pagan test/autocorrelation test	White heteroscedasticity test	Hausman test	Arellano–Bond test
1	Prob > chi2 Prob > z	0.0000	0.0000**	0.0023**	0.721
2	Prob > chi2 Prob > z	0.0000	0.0000**	0.0013**	0.711

robust and clustering options to account for the imbalanced nature of our panel datasets. The data was clustered across banks based on a highly regarded research paper.

In an identified model, we only require a single instrument for each endogenous variable in our GMM model. Because of the nature of our model, we were unable to test for overidentification restrictions as it relies on a single instrument for each endogenous variable. The accuracy of these instruments was determined via autocorrelation tests (e.g., Arellano–Bond test), which were provided after GMM estimation. Similarly, the Arellano–Bond test did not detect any signs of autocorrelation. Based on the analysis, the FE and GMM estimates are the most reliable for the aggregate model.

The results of the fixed-effects and difference GMM estimates of models 1 and 2 are shown in Table 5. The factors considered include innovation performance, Fintech, product innovation, process innovation, digitalization, green finance, ownership concentration, leverage, firm size, firm age, and the total CSR score of a firm. The results of the study indicate that the lag of INP is positive and substantial, which indicates that the INP of Chinese firms is positive and persistent over the sample period. Meanwhile, this is further supported by the considerable impact of product innovation (PRDIN) and PRSIN, highlighting the

crucial role that both forms of innovation play in helping companies maintain their competitiveness and adaptability in a rapidly changing business landscape.

The influence of Fintech (FNT) on the INP is positive and substantial in all models. The results of the study indicate the transformative role of financial technology in modern finance. This aligns with the theory of financial innovation, indicating that advancements in financial technologies can enhance the efficiency of financial markets and facilitate capital acquisition. The difference GMM method reveals an important relationship between Fintech and innovation performance, emphasizing the favorable outcomes of integrating technological and financial innovations. Moreover, the results of the interaction of Fintech and innovation types are positive and substantial across all models. The results indicate that product and process innovations in the presence of Fintech are substantial.

The significance of digital transformation (DGT) varies across two models, emphasizing the complex role of DT in diverse business contexts. The results of FE of both models indicate that DGT has an insignificant positive relationship with INP. However, the results of GMM indicate that DGT has a significant positive relationship with INP. The results of the study are consistent with the resource-based view (RBV) of the firm, which suggests that the strategic value of resources (such as digital capabilities) depends on how well they are utilized and integrated within the organization. The results of the interaction term of DGT*FINT are also significant and positive across both models, which indicate that Fintech controls the relationship between DGT and INP. The relationship between digital transformation (DGT) and Fintech substantially enhances the impact of DT on INP. The groundbreaking and dynamic capabilities of Fintech are essential in facilitating the full achievement of DT. Financial technology advancements enable businesses to enhance the efficiency and effectiveness of their innovation processes by leveraging their digital capabilities more efficiently. This discovery highlights the importance of integrating Fintech into digital strategies to foster a dynamic and competitive business environment.

The findings underscore a substantial and positive relationship between green finance (GRFIN) and innovation performance (IP). This observation is consistent with the principles of sustainable development and corporate social responsibility, emphasizing the significance of integrating environmental considerations into financial decision-making. The increasing emphasis on GRFIN indicates a broader shift in the business model toward sustainability and ethical investment. Furthermore, the interplay of Fintech and GRFIN substantially

Table 5
Regression results.

	Model 1		Model 2	
	Fixed Affect	Difference GMM	Fixed Affect	Difference GMM
<i>INP_{t-1}</i>		0.3675*		0.3874**
<i>FNT</i>	0.3125***	0.3957**	0.3125***	0.4102**
<i>PRDIN</i>	0.2418***	0.2826***	0.2418***	0.2826***
<i>PRSIN</i>	0.3012**	0.6091***	0.3012**	0.6091***
<i>DGT</i>	0.1234	0.3758***	0.1234	0.1758***
<i>GRFIN</i>	0.3013	0.462***	0.3013**	0.462***
<i>DGT * FNT</i>		0.8232***		0.9391***
<i>PRSIN * FNT</i>		0.2922**		0.3301**
<i>PRDIN * FNT</i>		0.8232***		0.9391***
<i>GRFIN * FNT</i>		0.2922**		0.3301**
<i>OC</i>	−0.3312**	−0.5331***	−0.3322**	−0.3199**
<i>LEV</i>	0.1024	0.1421	0.3732*	0.4431***
<i>SIZE</i>	0.2522**	0.2709**	0.3322**	0.3199**
<i>AGE</i>	0.2622**	0.2721**	0.3732*	0.4431***
<i>CSR</i>	−0.1222	0.3229	0.2622**	0.2721**
R-square	0.882		0.921	

influences the innovation performance of Chinese listed firms. The results imply that the presence of Fintech enhances the IP in conjunction with GRFIN. The combination of Fintech and GRFIN has a considerable impact on the IP of publicly listed Chinese firms, providing an intriguing perspective on modern financial approaches. This discovery indicates that the combination of GRFIN initiatives and Fintech has a positive impact on IP. The utilization of Fintech in GRFIN is expected to enhance and streamline sustainable investment processes by harnessing its advanced and flexible attributes. Collaboration among different entities enables businesses to effectively allocate resources toward environmentally friendly initiatives, leading to progress in sustainable practices. The findings clearly illustrate the dual impact of combining financial technology (Fintech) and GRFIN. It does not only make a substantial contribution to environmental objectives but also provides a distinct advantage in terms of fostering innovation. This highlights the various benefits of this strategic alignment within the framework of China's evolving financial landscape and commitment to sustainability.

The interaction between Fintech and GRFIN, which substantially influences the IP of Chinese listed firms, provides a compelling insight into modern financial strategies. This result implies that the integration of Fintech into GRFIN initiatives remarkably enhances IP. Fintech's advanced, agile capabilities, when applied to GRFIN, likely streamline and optimize sustainable investment processes. This synergy enables firms to more effectively allocate resources to environmentally friendly projects, driving innovation in sustainable practices. The findings indicate that integrating Fintech into GRFIN not only supports environmental goals but also provides a competitive edge in innovation, demonstrating the multifaceted benefits of this strategic alignment in the context of China's evolving financial landscape and commitment to sustainability.

OC typically has a detrimental effect, which can be understood from the perspective of agency theory. Concentrated ownership can give rise to conflicts of interest between majority and minority shareholders, which may affect the company's performance. Corporate governance practices should carefully consider the importance of maintaining a balance in ownership structures to improve decision-making and value creation. The inclusion of leverage (LEV), firm size (SIZE), and firm age (AGE) in the models highlights the impact of conventional business characteristics on strategic outcomes. According to the institutional theory, it is commonly observed that well-established and larger companies often enjoy stronger market positions and greater resources, resulting in more favorable strategic outcomes. The significance of leverage underscores the strategic importance of capital structure in effectively managing risk and return. The total CSR score of a firm (CSR) has considerable impacts on the different models. This is consistent with the stakeholder theory, which proposes that CSR initiatives are essential for establishing stakeholder trust and corporate reputation. Nevertheless, the way these factors are perceived and integrated into the firm's strategic framework can have varying effects on firm performance.

5. Conclusion

In the swiftly evolving business landscape of the 21st century, the Chinese mining industry has undergone a substantial transformation, largely propelled by the emergence of digitalization and financial technology (Fintech). This transition extends beyond simple technological integration, indicating a fundamental shift in the operational, strategic, and environmental paradigms within the sector. Digitalization has brought about a revolution in traditional mining practices with the integration of advanced technologies such as the IoT, AI, and big data analytics. These innovations have not only enhanced productivity and efficiency but also established themselves as strategic assets in line with the RBV of the firm. They enable Chinese mining companies to innovate, create value, and secure a sustainable competitive advantage in an increasingly technology-driven market. Simultaneously, the role of Fintech in transforming the financial landscape of the mining industry

cannot be understated. Fintech introduces innovative solutions for financing, investment, risk management, and transaction processing. The implementation of blockchain technology, for instance, has enabled a more transparent and efficient supply chain management, ensuring traceability and ethical sourcing of minerals. The synergy between digitalization and Fintech is particularly evident in their collective impact on green mining initiatives. Green mining, which focuses on minimizing the environmental impact of mining activities, is increasingly becoming a priority for Chinese mining companies. Digital tools facilitate accurate environmental impact assessments and effective environmental management strategies. Automation and AI play a pivotal role in optimizing energy consumption and minimizing waste, thereby making substantial contributions to carbon footprint reduction. IoT technologies facilitate real-time monitoring of environmental parameters, ensuring compliance with environmental regulations and standards. Concurrently, financial technology (Fintech) plays a pivotal role by providing essential financial support for green projects through innovative funding solutions such as green bonds and sustainable loans. These financial instruments provide the necessary capital for investments in environmentally friendly technologies and practices. The integration of Fintech also aligns with the theory of financial innovation, which emphasizes the importance of advancements in financial services for creating more accessible and efficient financial markets. In the context of the Chinese mining industry, Fintech has facilitated streamlined access to capital, improved risk management, and enhanced financial inclusion, particularly for smaller mining firms. The correlation between Fintech, digitalization, and innovation demonstration in the mining industry is robust. These technologies not only enhance operational efficiency but also drive innovative practices, enabling mining companies to explore new business models, develop new products and services, and penetrate new markets. Furthermore, this transformation considerably impacts market positions and consumer engagement. In an era where customers and stakeholders are increasingly aware of and concerned about environmental issues, Chinese mining companies adopting green and digital practices are better positioned to meet these evolving demands. This enhances their reputation and strengthens customer relationships. In conclusion, the incorporation of digitalization and Fintech in the Chinese mining industry serves as a strategic response to the complexities and possibilities of the contemporary business landscape. By adopting these technologies, Chinese mining companies are not only enhancing their operational efficiency and IP but are also spearheading the adoption of sustainable and responsible mining practices. This approach secures their long-term success and makes substantial contributions to broader social and economic advancements, positioning them as trailblazers in the global mining industry.

6. Policy implications

These insights carry profound implications for decision-makers who establish policies, regulations, and strategies within the Chinese mining sector. The substantial impact of Fintech and digitization highlights the importance of policies that nurture technological progress and innovation. Essential to this is the investment in research and development, incentivizing innovation, and creating a regulatory environment conducive to adopting technology and DT. The role of GRFIN highlights the need for policies that promote environmentally responsible investments and practices. Policymakers in China can facilitate green investments through regulatory frameworks, tax incentives, and subsidies to enhance environmental sustainability in mining.

Furthermore, robust corporate governance is pivotal, particularly in addressing the challenges of ownership concentration in the Chinese mining industry. Legislation and regulatory bodies should prioritize transparency and accountability within mining companies. This includes empowering minority shareholders and involving them more actively in decision-making processes.

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Shamim Akhtar: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Conceptualization. **Hongyun Tian:** Funding acquisition, Conceptualization. **Ibrahim Tawfeeq Alsedrah:** Software, Validation. **Ahsan Anwar:** Writing – original draft. **Shahid Bashir:** Methodology.

Declaration of competing interest

Authors have no financial or non-financial competing interests to declare.

Data availability

Data will be made available on request.

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