Assessing mining productivity in Kazakhstan: industry and firm-level analysis

by

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Originality statement

I, Seribolat Azhibay, hereby declare that this submission is my own work. To the best of my knowledge, it contains no materials previously published or written by another person or substantial proportions of material that have been accepted for the award of any other degree or diploma at Nazarbayev University or any other educational institution except where due acknowledgment is made in the thesis.

Any contribution made to the research by others with whom I have worked at NU or elsewhere is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my work, except to the extent that assistance from others in the project's design and conception or style, presentation, and linguistic expression is acknowledged.

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Abstract

Productivity plays an essential role in the mining industry: its improvement is significant for domestic producers' long-term economic growth and competitiveness in the world market. Starting from the late nineteenth century, productivity has been increasing due to accessibility of high-grade ores, development in technology, innovations, improvement of the quality of healthcare, and workers' education. However, in recent years, productivity has been decreasing worldwide. The main reasons cited for this decline are resource depletion, increasing costs for extracting lower quality and less accessible reserves, and reduced efficiency of existing, outdated technology and techniques. Understanding various factors affecting productivity can lead to better counteracting of these effects. Thus, mining productivity and factors that impact it need to be studied.

This study investigates labor productivity in Kazakhstan's mining industry from 2001 to 2020 with the main focus on energy consumption, expenditures on labor, capital, also on growth rates of production, employment, investment, and wages. In addition, it analyzes the relationship between productivity and key factors: capital per worker, energy intensity, recovery rate, head grade, waste ratio, and copper share, in the local firm KazMinerals. The results of statistical analysis for industry-level and regression analysis for the firm-level data indicate that regional industrial labor productivity has increased over the past twenty years by more than 5% on average. Furthermore, the research shows a high correlation between productivity and ore grade, recovery rate, energy consumption, and capital per worker.

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1. Introduction

1.1. Background

Kazakhstan's economy highly depends on mineral resources: 21% of Gross Domestic Product relates to petroleum and mining sectors, of which mining contributes less than 5%. More than half of total government revenues and above 3/5 of the country's export value accounted for the petroleum industry at the peak of the oil boom, which started in the 2000s. Therefore, to decrease the economy's oil dependence, the Government of the Republic of Kazakhstan (2012) developed projects to improve other industries, including mining. Since the local mining industry is one of the world's most attractive new markets for natural resources, the country is one of the top ten nations in terms of mineral reserves: 99 elements of the periodic table were explored, of which 70 are mined as deposits. There were 493 deposits in the country in 2018, where more than 1200 varieties of mineral raw materials were mined. Kazakhstan has 30% of the world's chrome ore deposits (383 million tons), 25% of manganese ore reserves (635 mil tons), 10% of iron ore reserves (18.6 billion tons), 5.5 percent copper (39mil tons), 10% lead (17 mil tons), and 13% zinc reserves (40 mil tons). In addition, the country is ranked in the top ten worldwide in reserves of tungsten (2.1 mil tons), silver (53 thousand tons), uranium (1.6 mil tons), and coal (150 billion tons). Moreover, Kazakhstan is also ranked among the top twelve countries in the production of these minerals: chrome – 3.6 mil tons per year, manganese – 2.4 mil t/y, iron – 22 mil t/y, copper – 440 thousand t/y, lead – 120k t/y, zinc – 377k t/y, tungsten – 2600 t/y, silver – 77 t/y, uranium – 18k t/y, and coal – 108 mil t/y (Mineral Commodity Summaries, 2019).

According to Karenov et al. (2016), Kazakhstan is ranked at the top regarding reserves and production volumes of mineral raw materials. Since the mining sector is crucial for the economy, it is hugely significant to identify the sector's development priorities. Furthermore, it is essential to plan for long-term developments in technological and scientific innovations that would be highly productive by collaborating the industry with the state. Thus, despite having a long mining history and being well-positioned worldwide in terms of mineral reserves and production volumes, Kazakhstan´s mining industry is exhibiting low productivity. Since productivity demonstrates how efficiently a company uses its resources to produce commodities, higher productivity will allow it to generate more income and remain competitive in the global market.

1.2. Problem statement

Productivity in the mining industry has been increasing since the late nineteenth century due to increased accessibility of high-grade ores, development in technology, innovations, improvement of the quality of healthcare, and workers' education (Humphreys, 2020). However, in the past two decades, mining productivity has been decreasing worldwide, mainly, due to resource depletion, increasing costs for extracting lower quality and less accessible reserves, and reduced effect of outdated technologies and techniques (Deloitte, 2014). Yet, it is difficult to determine precisely the impact of each factor over the years as there are limited data available.

Unlike other mining-dependent countries, Kazakhstan inherited old enterprises in the sector, which impede productivity increases. More than half of the equipment of the domestic mining companies is outdated, which leads to low-operating productivity and a high degree of material and energy usage. Selective replacement of time-worn equipment is highly ineffective, compared to foreign enterprises that focus on production and manufacturing improvement with a high-quality final product. To increase productivity, radical change is needed by the use of new technologies to decrease energy and resource utilization and cut production costs.

There are not many studies regarding mining productivity in Kazakhstan. Therefore, it is necessary to analyze its mining productivity and identify factors that will allow improvements.

1.3. Significance to the industry: justification of the research project

Kazakhstan is one of the major global suppliers of minerals and its economy highly benefits from it. The government of Kazakhstan aims to improve the mining industry further. However, there are few studies regarding productivity levels in local mining.

This project will benefit the industry because it analyses the factors influencing productivity over the past two decades and provides an understanding of how the mining industry can increase productivity and stay competitive globally.

1.4. Objective, Hypothesis, and Scope of work

1.4.1 Main Objective

The main objective of this research was to analyze mining productivity in Kazakhstan from 2000 to 2020: at the industry and firm levels.

1.4.2 Hypothesis

It was the hypothesis that the mining productivity in Kazakhstan increased between 2000 – 2020.

1.4.3 Scope of work

The scope of work of this project included:

1. Literature review on productivity-enhancing practices.
2. Collection of productivity data for Kazakhstan's mining industry from 2000 to 2020. The data included the industry's expenditures on fuel, power, coal, and water; the number of employed people and their wages; investment; and output value.
3. Collection of productivity data for KAZ Minerals mining company from 2010 to 2020. The data was collected for the whole mining company and partially for the individual mine sites within the firm. The data included ore grades; the value of copper and by-products produced; recovery rate; the intensity of energy, power, and diesel usage; the number of employed people and their wages; output value. Analysis of the data for the period of 2000 – 2020.
4. Discussion of results, conclusions, and recommendations.

1.4.4 Study limitations

The study did not consider productivity data from before 2000 due to significant disruptions in many industries in Kazakhstan during the first decade of its independence.

Another limitation of this study is a lack of free access to the mining data of the country's industry and firms. Thus, not all types of productivity-enhancing practices could be examined. Nevertheless, the results support the findings of scholarly work surveyed in the literature review section. In addition, this research contributes new insights on local mining productivity for the past twenty years, which was not done before.

2. Literature review

This literature review was submitted as a part of the Research methods SMG 520 course to Nazarbayev University in 2021.

According to Humphreys (2020), productivity-enhancing factors in the mining industry are innovation, change in technology, government regulations, quality of workers, and many other factors. Although productivity in the mining industry has been increasing over the past 150 years, it is difficult to determine precisely the contribution each input factor had made over the years as there are no sufficient data to undertake statistical analysis. Nevertheless, the contribution of some factors seems more evident, such as innovation and technology development, improvement of the quality of healthcare and workers' education, and economies of scale.

At the same time, some factors decrease productivity in mining:

1. talent shortage: unqualified or unexperienced employees have to do more work due to the short supply of skilled workers,
2. reduction in the quality of minerals: high-grade ores were mined many years ago, and there are only low grades in many existing old mines,
3. high cost of inputs and inefficient investment spending: at the beginning of the project a mining company spends capital on establishing infrastructure: roads, railways, electricity, water, permitting fees yet most of these investments do not return in the initial stages of production.
4. start of production: most companies over-spend at the beginning (Deloitte, 2014).
5. some factors increase costs, such as deeper and older mines with high safety risks and increasing extraction costs or expansion of the mining in remote regions, which affect the construction cost of infrastructure, transportation, and utilities. In addition, environmental and local regulations influence the price (Humphreys 2020).

Humphreys (2018) describes several significant changes in the mining industry that resulted from the commodity boom of 2004-2012. Firstly, the market continues shifting towards developing countries, especially in Asia, because these countries highly rely on building, infrastructure, and consumer durables. Secondly, the change in the market's location resulted in shifting from long-term to short-term contract businesses, which means that prices will not be stable. This made long-term planning in the mining industry even harder. Moreover, the commodity boom assisted companies from emerging economies to gain access to global capital markets and increase their role in the worldwide industry. In the meantime, the cost of mining grew due to depletion (decline in ore grades), ore quality issues, the necessity to excavate deeper in both surface and underground mines, limitations of the economics of scale (it is unlikely to find larger ore bodies or construct more giant trucks). The new mines are in remote locations that demand infrastructure construction, environmental expenditures, and complicated permitting processes while the investment volume depends on government policies. Moving towards sustainable cost management requires increasing cut-off grades, prioritizing low-cost projects, workers' training and long-term career development, and training of the local labor for critical positions (Deloitte, 2014).

Therefore, the challenge is to find a way to have profitable operation while producing sustainable benefits for a host country

2.1.Reserves

Mineral Resources and Mineral Reserves are the foundation for a mining company's future viability. They provide the fundamental data for many of its significant investments and the foundation for the mines' long-term mining plans. Mineral Reserves are depleted every year due to mining activities; hence fresh additions to the Resources and Reserves are critical to profitability. A Mineral Resource is a distribution of minerals in such forms that their grade value, properties, and size make it mining economically viable. Mineral Resources are ranked into Inferred, Indicated, and Measured to increase geological confidence. A Mineral Reserve is part of a Measured and Indicated Mineral Resource that can be feasibly mined. It is characterized by studies at the Pre-Feasibility or Feasibility level. However, it includes also the use of Modifying Factors and diluting substances that increase mining costs. Such research demonstrates that extraction might be justifiable at the time of reporting. To increase confidence, mineral Reserves are classified into Probably Mineral Reserves and Proved Mineral Reserves (Boliden, 2021).

In the mining industry, the availability of natural resources influences productivity. Although natural resources significantly affect mining productivity, standard productivity estimators do not consider the changes in the quality of natural resources as an input. As mineral resources are finite and heterogeneous, the reserves' quality and approachability decrease with ongoing extraction. Mining operations focus primarily on deposits that are easily accessible and of the highest grade since they provide the highest return. To mine lower-grade deposits containing more impurities or deposits located remotely or deep underground, higher capital and labor are required. This leads to decreased productivity because inputs (spending) will grow while outputs (tons of metals produced) will remain at the same level or will decrease. Therefore, it can be said that mining productivity demonstrates the efficiency of production and alterations in the quality and accessibility of deposits (Topp et al., 2008).

According to Topp et al. (2008), mineral resources can be characterized by the ore grade and quality and the ratio of an overburden, depth of a mine, transportation distance of outputs or inputs, and mine site geology complexity. Nevertheless, it is difficult to measure the exact mineral resource input due to the heterogeneity of the ore reserves. The deposits ownership price and amortization rate cannot be used as input indicators since their price does not reflect the quality of ore grades. Furthermore, a mining company may spend additional capital on exploration and development before production. There is generally a long-time lag (up to 10 years and more) between acquisition, exploration, development of the deposit, and the start of the extraction. This time factor is a long lead time between new capacity investment and subsequent results. As investment is made in the mining sector, it is immediately calculated as input. However, the development of this investment will be visible only after several years. With the change in the investment rate, an adverse impact on productivity will occur that will not show accurate efficiency results. Therefore, there is no sufficient way to estimate mineral reserve influence level on labor productivity, although it is a significant factor.

2.2. Ore grade

Wedge (1973) estimated that Canada's calculated low productivity growth would be far more significant if ore grade input were included in initial calculations. Stollery (1985) calculated that grade decline in Canadian mines led to cost increases since it required more spending and processing and was more energy-intensive. Lasserre and Ouellette (1988) stated that ore grade quality is the missing and explicit factor of the mining productivity equation. Young (1991) proved econometrically that low grades and hard accessibility lowered the productivity index in copper-mining companies. Recent studies by Rodriguez and Arias (2008) showed that ore depletion affects extraction costs by 1.3 % annually in coal mines in Canada. Overall, there is an understanding of the negative impact of ore depletion on productivity, however, there is a lack of detailed analysis and evaluation of the impact.

2.3. Innovations, technology and work organization

The main drivers of productivity at the firm level are developing and implementing new technologies or work organizations. Management decisions related to technology selection for particular products and how this production would be organized significantly influence output. On one hand, productivity can be increased without changing the technology. To achieve that, current technologies need to be used more efficiently with more innovative work required to reach the limits of present production possibility. On the other hand, firms can adopt or develop new technologies or organizational systems to push production output far more (Gordon, Zhao, and Gretton, 2015). Diewert and Fox (2008) stated that most technological tools have a certain minimum level of efficiency and, usually, their mean costs are lower as the purchase number increases. However, a firm's expenditure may lead to utilization rate growth and to the adaptation of new technologies or new organizational forms that require less spending (Sheng et al., 2014). Although innovations and technology adaptation requires additional expenses, their investment return occurs in a shorter period of time (Gordon, Zhao, and Gretton, 2015).

Aguirregabiria and Luengo (2016) state that historically, significant breakthroughs in mining techniques and technologies have led to an increase in resource reserves and a reduction in production costs. For example, the introduction of mass mining that uses large-scale machinery and mass mining methods in production, which allow lowering costs of production. Mechanization allowed to profitably mine low-grade ores due to economies of scale (Mikesell, 2013). According to Slade (2013), further significant development was introducing the flotation process. This process was utilized to concentrate sulfide ores significantly increasing the metal's recovery rate (from 75% to 90%), which in turn decreased the costs of processing. Mechanization and mineral processing using flotation led to a decrease in production costs by 20 percent and an increase in production by almost four times, despite the decline in ore grades (Radetzki, 2009).

Lizuka, Piotrebelli, and Vargas (2019) agreed that technological innovation in the emerging countries' mining areas had been limited due to the mines' infrastructure installed initially during mine contraction and may restrict the use of technological innovation alterations. They suggest that innovation would be more beneficial in other forms, such as efficient work organization, production processes, collaboration with the research centers, industrial organizations, universities, and other mining firms to find specific short-term and Research & Development long-term solutions. These collaborations are critical for the sector and highly developed in the top mining countries such as Australia and Canada. In addition, such collaborative programs may increase the number of innovations. However, there is not sufficient statistical information on the impact of these types of programs, even though they have been functioning for several years.

Investigation of other developing countries, including Chile and Peru, with GDPs resource-dependent similarly to Kazakhstan or any other emerging countries' case, shows that between 1992 to 2009, Chile and Peru's copper production rate more than tripled and held about 50% of worldwide production (Jara, Perez and Villalobos, 2010). Jara, Perez, and Villabolos (2010) demonstrated that improvement in production levels or conditions of exploitation is not sufficient to boost productivity. In the case of these countries, the reason for the copper mines' labor productivity growth was mainly innovation, adoption of new technologies, and adjustments in the management toward the international standards. In addition, political situations and regulations influenced the productivity increase.

2.4. Digitization

It is necessary to distinguish between the short- and long-term productivity drivers to evaluate the industry's current and future efficiency drivers. Industry leaders (CEOs of the top mining firms in the world) believe that digitization will be the new major productivity-increasing factor soon. Digitization includes high-powered computing and big data, the Internet of Things, and operating technology-information technology (OT-IT). These factors could benefit the industry by increasing computing and communication capacities (Humphreys, 2020).

Meanwhile, Barnewold and Lottermoser (2020) researched and identified the most used digitization tools in the mining industry. The vital digital technologies in the sector are automation and robotics, the Internet of things, Big data and Real-time data, Artificial intelligence and machine learning, and 3D Printing. The use of some digital tools, such as sensors, helps to monitor the condition and status of the workplace, rock, and trucks, spot hazardous gases and other dangerous conditions immediately, and in other operations that help improve productivity, reduce costs, and change mining ways. However, the use of many digital technologies in mining is limited, and their full potential is not unlocked yet. In addition, many of the new technologies are yet to be adopted in the industry. Implementation of these technologies demonstrates economic viability. Nevertheless, the significant obstacles to their slow adoption are production scale, existing infrastructure, trained staff, Rand research, and Development capacities. Large companies with sufficient funds, personnel, and large-scale operations are more efficient in implementing new technology. However, the correct digital tools have proven significantly beneficial in both large- and medium-scale mining companies. The results of the analysis could differ for individual countries and companies. It is suggestable to conduct individual case studies for some companies about their productivity projects.

Ernst and Young Global Mining (EYGM, 2018) company report that the top risk facing the mining industry is the growing gap between the potential of digital effectiveness and its successful implementation. However, the main idea is not to utilize all the available digital tools but to construct a digitization plan and implement the right technology for the mining operation. Demartini, Evans, and Tonelli (2019) state that Digital technologies, such as, artificial intelligence and augmented reality, make visible the situations or issues that previously were hidden or unclear. Thus, engineers can focus their improvements where they are most needed. Digital equipment provides management and workers with operational information, collects and notify about potentially hazardous conditions and incidents, and details working conditions, equipment state, and productivity. These benefits help make faster and more accurate decisions to protect employees, the environment, and facilities, to increase profit and efficiency. Demartini, Evans, and Tonelli (2019) argue that the successful implementation of these technologies helps to make the industry more sustainable and flexible and boosts productivity, which is seen in case studies of actual industry operations. Tyuleneva (2020) states that the competitiveness of the mining sector is significantly impacted by operational excellence and productivity. Thus, digitization is one of the critical factors that will allow companies to stay competitive in the future.

From the start of the mining industry, its operations, such as mineral extraction, processing, and ore transportation, have been separated parts with minimum integration between them. However, now, digitization provides the opportunity to implement the system approach that connects them in one digital system. Nevertheless, there are limited studies similar to Demartini, Evans, and Tonelli (2019), showing the influence of digitalization on productivity.

2.5. Employees' health and skills

As Humphreys (2020) states, improving the quality of healthcare and workers' education is one of the long-term factors contributing to the growth of mining productivity in the past century and a half. Workers´ education and improvements to their well-being can be enhanced with the use of digital technologies, which would contribute to the increase in productivity.

2.6. Cyclical nature of mining business

Tilton (2014) argues that this productivity determinant is cyclical: as commodity prices are high, companies hire new labor that mostly comes with inadequate training and experience. And vice versa, when companies struggle financially, they start to fire workers and keep only high expertise and quality personnel. Furthermore, strikes, accidents, and any other forms of stoppages play a cyclical role in the productivity index. These stoppages in mines significantly decrease productivity. However, when prices are high, companies usually push their production limit, subsequently causing these accidents (Tilton, 2014).

Another cyclical factor described by Tilton (2014) is government regulations as the volume of investment in the sector and mining companies' durability highly depends on government policies. Government laws on taxes, environmental safety, labor safety, and any other important issues may impact productivity in both ways: to increase or decrease it.

The Organization for Economic Co-operation and Development (2018) states that increasing the competitiveness of the country's mining industry by improving technology, legislation, or any other way is the top national priority for Kazakhstan's government. Well-developed legislation and regulations will boost the sector by attracting and ensuring more investors. Some steps towards this are already done. For instance, the "First come, first served" licensing model is implemented, which means that extraction licenses are guaranteed to the company making exploration in the area. Also, authorities committed to allowing free access to geological data. Despite these and other signs of progress, there are more challenges to address. For example, mining operators are taxed not by the most common sales/profit–based mechanism but by mineral reserves. This is a considerable risk for the companies since they have to pay taxes despite reserves' financial viability. In addition, mining companies need authorities' approval for any change in the mine plan, including both exploration and extraction stages' methods and technologies. This limits operator's capability to adapt to the altering market conditions. Thus, this policy could be used if only the new mine plan causes environmental or other damages. It is recommended to come closer to the international models and standards in the mining industry since potential investors and operators are more comfortable working with these approaches.

Tilton (2014) adds more cyclical productivity boosters to the list. They are economies of scale, capacity utilization, investment lags, resource depletion, and ore quality. They all are profitable only in the short term. For instance, when mineral markets are depressed, the mining companies cut back on investment, temporary or permanent closure of some unprofitable mine sites, increase cut-off grade, and recession in previously designed capacity to improve productivity. On the other hand, mining companies do the opposite when mineral markets are booming, increasing production rates and subsequently declining productivity. Furthermore, the capacity utilization impact is described in more detail by Gordon, Zhao, and Gretton (2015). The demand of the market impacts firms' output. Thus, when the demand changes over time due to different reasons, firms also change their production. However, when the demand is low, firms can lower their outputs but not reduce their capital and labor since these inputs will be necessary when the demand increases again. Subsequently, that means that companies would be underutilizing their inputs. On the other hand, companies will over-utilize their inputs when the demand is high, for instance, using machines and equipment for longer shift hours and for more capacities than they are designed to be utilized by manufacturers. These may lead to shorter equipment life that will require additional spending in the future. Nevertheless, its output would be calculated at this time, while the input (additional expenditure) in the future. Hence, estimated productivity impacted by capacity utilization would be cyclical.

Therefore, cyclical productivity boosters, such as employee training, government regulations, and capacity utilization, can be beneficial only for short-term productivity improvement, as they do not provide continuous enhancements.

3. Research design and methodology

There are several ways to estimate productivity, although only two of them are most commonly used Partial Factor Productivity (PFP) and Total Factor Productivity (TFP). PFP is the most straightforward measure mainly used for capital or labor productivity. For instance, labor productivity is estimated as the relation of mined or produced ore to the employee's working hours or the number of employees. Although it does not show the specific contribution exclusively, it is often interpreted that way. Meanwhile, TFP combines inputs such as labor (number of workers, working hours, wages, and benefits of employees), capital (investment, spending on equipment), and intermediate products (cost of raw materials, cost of energy: diesel, electricity, power). TFP is an efficiency indicator of the utilization rate of labor and capital inputs to produce product and service outputs. Such factors influence this efficiency as management, technology, work practices, and skills (Aydin, 1999).

3.1. Data analysis methods

For this research, three types of analysis were conducted: descriptive statistical analysis on industry-level data, regression analysis on firm-level data, and information collection on case studies in local firms.

3.1.1 Industry-level analysis

The industry-level research was divided into two time frames: 2001 – 2010 and 2011 – 2019. The former indicates the period of generally rising mineral prices, while the latter is considered the period of generally declining mineral prices. In the first step, the utilization of the critical resources (fuel, power, coal, water, labor, and capital) in different mining sectors were examined. The ratios of expenditures on these resources to mining output value was calculated according to Eq. 1

$$Key\ resource\ ratio\ (\%) = \frac{Expenditure\ on\ a\ resource\ (KZT\ mln)}{Mining\ output\ value\ (KZT\ mln)} * 100 \qquad Eq. 1$$

Labor expenditures were deflated by using the Consumer Price Index (CPI) to account for different variations in price changes. Whereas spending on other vital resources and output values were}e deflated by using the relevant Producer Price Indices (PPI). The relevant values of both (CPI and PPI) were taken from the website of the Ministry of Economy.

Equation 1 allows to observe the intensity of utilization of the resources and to calculate capital and labor contributions in different mining sectors. In addition, the capital-labor ratio was estimated to note changes in two decades according to Eq. 2:

$$Capital - worker\ ratio = \frac{Amount\ of\ capital\ (KZT\ mln)}{Labor\ compensation\ (KZT\ mln)} \qquad Eq. 2$$

Subsequently, the growth rates in mining sectors based on the number of employees and their wages, investment, output value, and labor productivity were investigated. Labor productivity was calculated as output value in the industry per number of people employed in this sector as per Eq. 3:

$$Labor\ productivity = \frac{Output\ value\ (KZT\ mln)}{Labor\ compensation\ (KZT\ mln)} \qquad Eq. 3$$

From the available data, the shares of primary products and by-products in the monetary output value and the number of workers related to these differently–priced products were unclear. Therefore, growth rates were calculated according to Eqs. 4 and 5:

$$Growth\ rate\ (\%) = \frac{present\ value - past\ value}{past\ value} * 100 \qquad Eq. 4$$

$$Growth\ rate\ (\%) = \left(\sqrt[number\ of\ years]{\frac{present\ value}{past\ value}} - 1 \right) * 100 \qquad Eq. 5$$

The analysis provides information on expenditure values on critical resources, growth rates of some key productivity drivers, level of labor productivity, in different mining sectors by two decades and their influence on labor productivity alteration.

3.1.2 Firm-level analysis

The productivity at a firm-level can be estimated as output value per employee or working hour. If using working hours, the estimations can be more precise since it is considered unplanned stoppages or other stoppages due to weather conditions or by contractual arrangements. However, due to data availability, the analysis was based on output value per employee according to Eq. 6, which was modified from Aydin (1999):

$$q_{it} = \beta_0 + \beta_1 k_{it} + \beta_2 energy_{it} + \beta_3 G_{it} + \beta_4 R_{it} + \beta_5 waste_{it} + \beta_6 share_{it} + \varepsilon_{it} \qquad Eq. 6$$

where *q* is copper output per worker, *i* is the indicator for the mine, *t* is the time indicator, and all variables are in the natural logarithm form. *k* is capital per worker, *energy* is energy per ton of ore extracted, *G* is ore grade, and *R* is recovery rate at the mineral processing facility, *waste* is a ratio of waste rock weight to the weight of extracted ore, and *share* is the share of copper in total revenue. β – coefficients that show relationship of variables to the q. βo – intercept, which shows value of q when all independent variables are equal to 0. ε – disturbance or error term (for possible unexpected disturbances, weather conditions, accidents that delay production). Several models were run with different energy sources as energy proxy (power, diesel and energy in total). These models were estimated using the Linear Correlation analysis to observe which factors can be estimated as productivity predictors.

3.1.3 Firm-level analysis – case studies

Local firms' cases on improving labor productivity were analyzed for KazMinerals, ERG, Kazakhmys, and AltynAlmas. Their official websites were utilized to collect data on some challenges, implemented projects, and their efficiency. These companies were the only local firms that provided information on popular productivity-enhancing trends. Furthermore, these results would be helpful to support results and suggestions from the statistical analysis.

3.2.Data acquisition

To achieve this objective, quantitative, secondary data on the industry- and firm-level productivity were collected. Quantitative information represents measurable values. Secondary data include data not collected by the primary user. Qualitative data about productivity-enhancing practices were collected from the websites of local mining companies.

For the industrial level analysis all the necessary data was collected from the Statistics Committee of the Ministry of National Economy of the Republic of Kazakhstan from 2001 to 2019 (reference). Firm-level data was obtained from the annual and quarterly reports of KAZ Minerals company for 2010 – 2020. These sources were chosen because KAZ Minerals was the only firm that provides publicly available information on productivity factors. However, not all productivity-impacting drivers were included in these reports and the reports contain data for only particular time intervals: 2001 – 2019 for the industrial level and 2010 – 2020 for the firm level. KAZ Minerals' annual and quarterly reports since were used in the analysis.

The data in the industrial reports were separated by sectors, which are coal mining, ferrous metals, non-ferrous metals, and other mining. All of these sectors provide data on the same indicators:

1. Production value – output measure of revenue in million tenges (KZT mln) the sector makes annually.
2. A number of firms of main activity – input value- demonstrates the number of companies that work in this sector.
3. Employment in main activity – input value that shows the number of employees that work in this sector, excluding workers not directly involved in mining activities.

4. Wages of main activity personnel – input measure of average monthly salaries in KZT of employees in the main activity.
5. Producer Price Index – an indicator of changes in Producer price in percentage to the previous year.
6. Investment – input measure of capital invested in the sector annually in KZT mln.
7. Investment Index – an indicator of investment value changes in percentage to the previous year.

Also, there are input values on annual expenditures on fuel, power, coal, and water.

Furthermore, KAZ Minerals reports demonstrate many data beginning from 2010. However, not all measures are annually reported up to 2020, and new indicators appear from 2014 – to 2016. The reasons for these changes were the following:

1. In 2014, KAZ Minerals branched out from another mining company Kazakhmys,
2. In 2015 – 2016, new central open pits Aktogay and Bozshakol started their production (Rakishev, 2019).

Therefore, only consistent data from the firm's reports are used. These are primarily accounted for in quarterly reports for Q1 2016 – Q4 2020, and some are in annual reports for the same period.

In addition, data were separated by different mine sites within the firm: Aktogay (oxide and sulphide), Bozshakol, East region, and Bozymchak. These data are:

1. Tons of ore extracted.
2. Tons of ore processed.
3. Copper production values.
4. Average copper grade.
5. Average recovery rate.
6. The intensity of energy, power, and diesel usage.
7. Values of waste.
8. Capital per worker.

4. Results

4.1. Industry-level data analysis

Firstly, expenditures on critical resources in the country's mining industry were analyzed. These resources are coal, fuel, power, water, labor, and capital. Labor expenditures were deflated by using the Consumer Price Index to account for varying degrees of price changes. Expenses on other resources were deflated by relevant Producer Price Indices. Values of CPI and PPI were taken from the website of the Ministry of Economy. In both cases, 2010 was chosen as the base year. The industry subsectors were coal, metal mining, and other minerals, including industrial minerals.

The figures 4.1-4.6 contain ratios of expenses on critical resources to the mining output value. In the first decade, coal mining resource intensity was generally low (less than 1-1.5%) except for the coal usage percentage that steadily increased under 2-2.5% in the second half. At the beginning of the second decade, resource intensity rose. The highest percentage was power usage (more than 5% in 2012) with a subsequent decline to 2 percent before increasing again after 2016. The usage of all other resources slowly decreased to under 1 percent by the decade's end (see Figure 4.1).

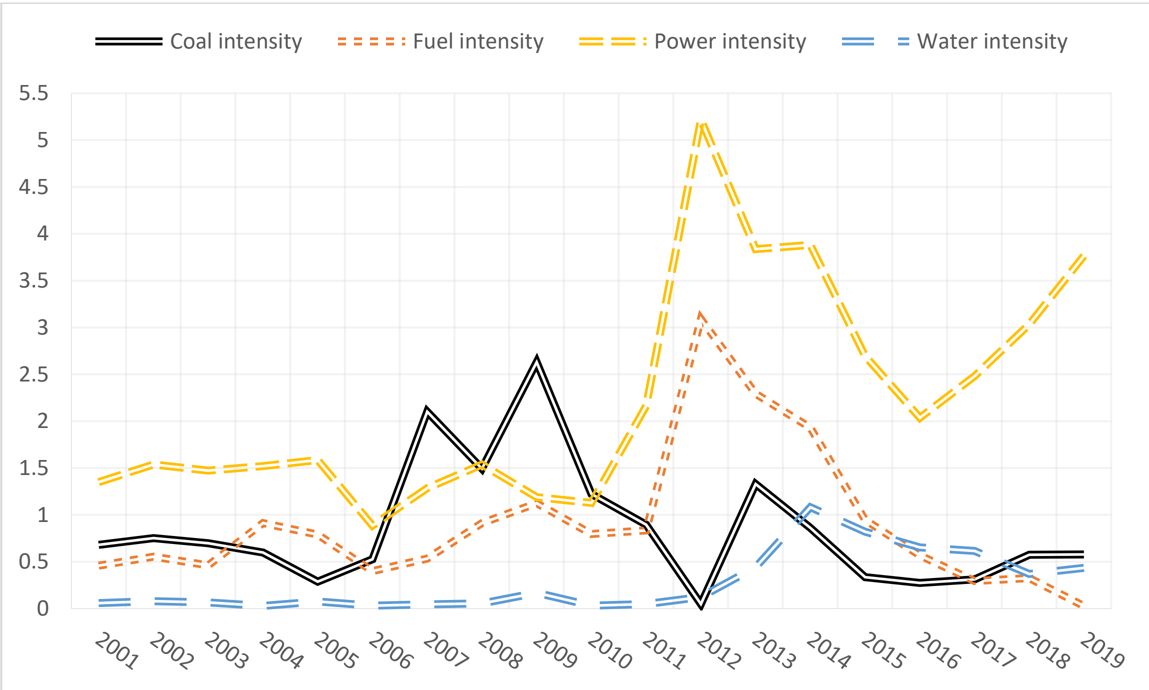

Figure 4.1. Ratios of costs of key resources to the coal mining output value

The capital share was around 10% for both decades while expenses on labor were about 15% in the 2000s, and slightly grew to under 25-30 percent in the next decade. In addition, the capital-labor ratio was significant (around 80%) in the first period. However, it declined by under 50 percent in the second period (see Figure 4.2).

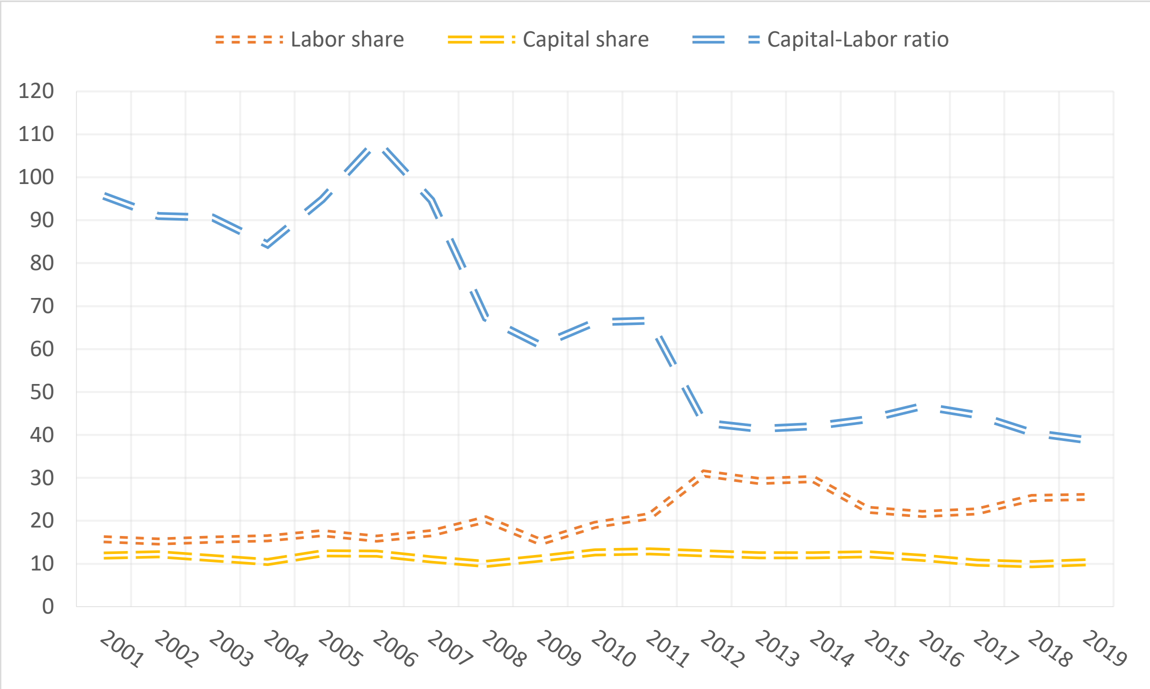

Figure 4.2. Shares of costs of key resources, percent of coal mining output value

In industrial minerals mining, water intensity was scarce (less than 0.5 percent) for about twenty years. Coal usage had reached 1-1.5% in the initial years, but it had been under 0.5 percent after that. Expenses on fuel and power fluctuated around 1.5 – 2.5% in the first decade before reaching the peak usage percentages in 2012 (more than 3% for power and above 6% for fuel). Subsequently, fuel intensity started its sharp decline and fell under half percent by the end of the 2010s. Similarly, power intensity slightly declined under 1.5% (see Figure 4.3).

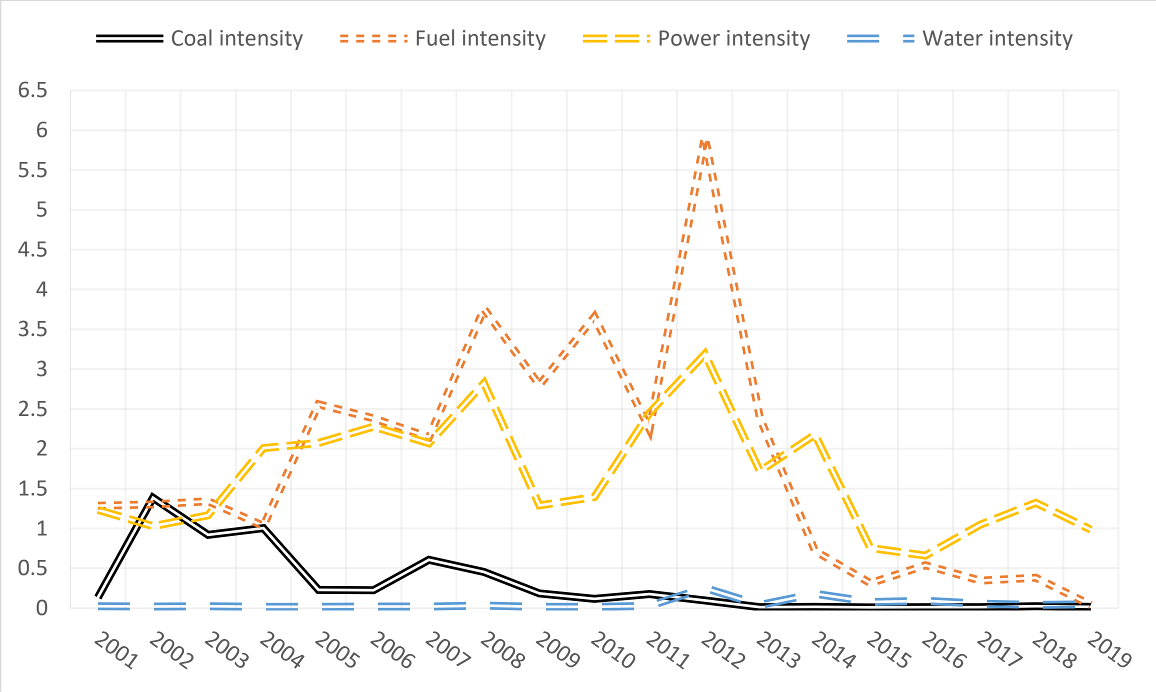

Figure 4.3. Ratios of costs of key resources to the industrial minerals mining output value

Capital share in industrial minerals mining was under 10 percent for the whole period. At the same time, the labor share was around 15% in the first decade. It was slightly increased up to 20 – 25% in the next period. The capital-labor ratio significantly fell from 70 percent to about 30% in the 2000s. Subsequently, it fluctuated around 35% in the second decade (see Figure 4.4).

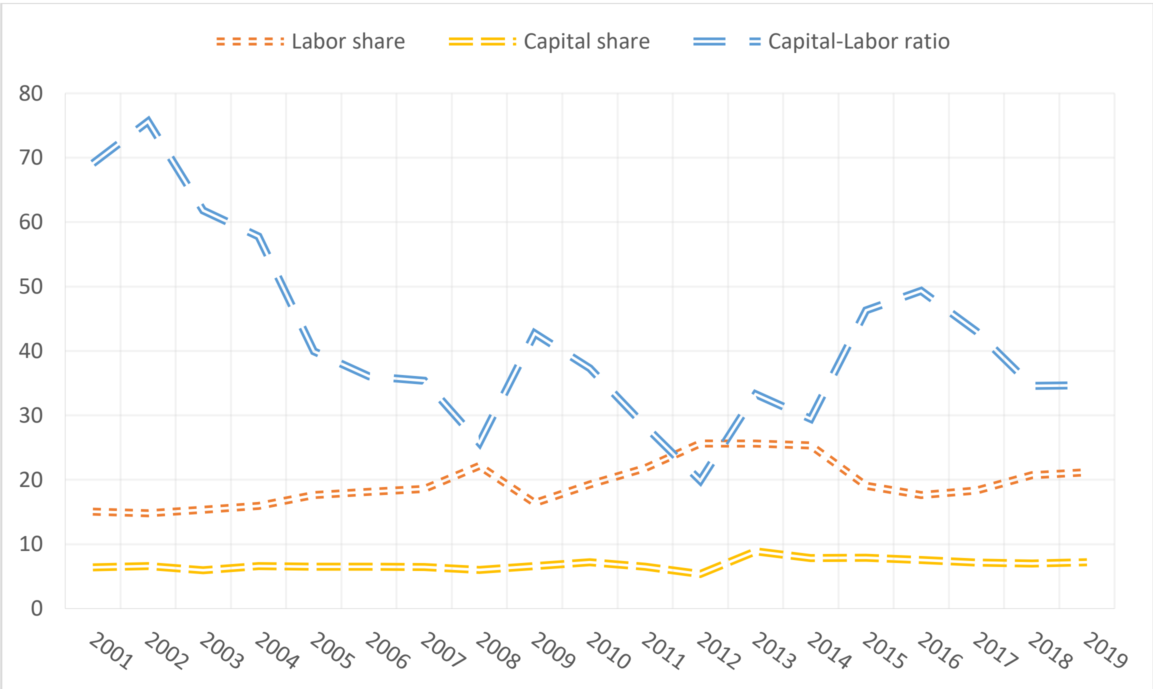

Figure 4.4. Shares of costs of key resources, percent of industrial minerals mining output value

In metals mining (see Figure 4.5), fuel intensity almost tripled from 1.5 percent in 2005 followed by a steady decline and was under 0.5 percent at the end of the 2010s. Expenses percentages of other energy sources mainly were under 0.5% for two decades except for 2004 – 2008 when power intensity was just above half percent, and for 2014 when water intensity was almost 1 percent in the sector. It is worth noting that the ratio of water cost to the metals mining output value was not given for the first period, while in the second decade, it was significantly low (less than 1%).

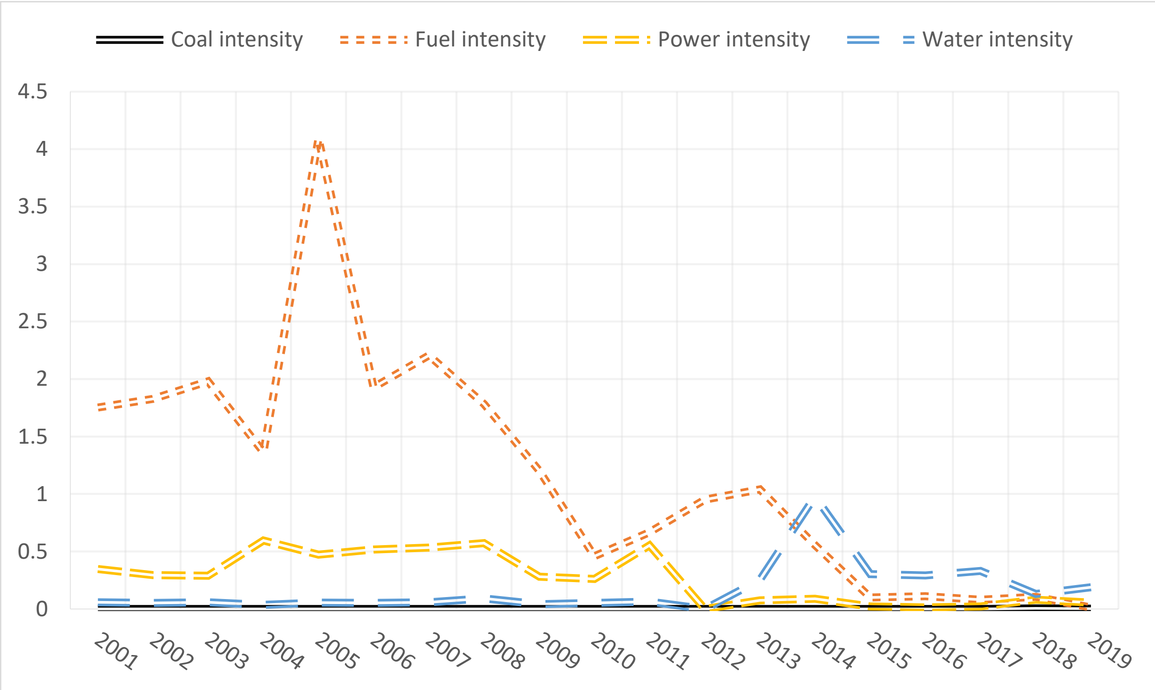

Figure 4.5. Ratios of costs of key resources to the metals mining output value

The capital share was around 10% for about twenty years. Labor share fluctuated around 30 percent in the same period. The capital-labor ratio had been steadily declining from 60% to under 40% in the first decade and then it fluctuated around 35 percent in the next decade (see Figure 4.6).

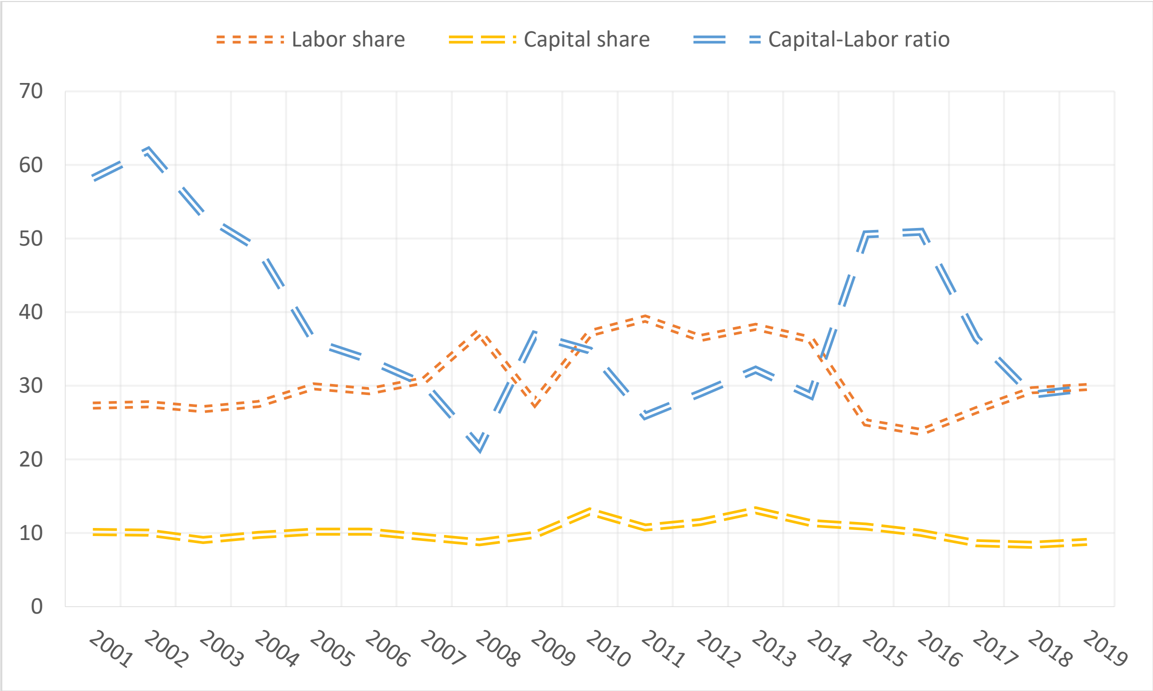

Figure 4.6. Shares of costs of key resources, percent of metals mining output value

Table 4.1 represents average percentages of resource intensity for two decades from the figures 4.1-4.6. In coal mining, power usage more than doubled. Other energy sources' usage percentage stayed around or under 1 percent. There was no significant increase in energy usage percentage in other sectors, except for water intensity which had grown almost five times in both sectors. Nevertheless, its rate still was under 0.5% in the industrial minerals mining sector. In both decades, the capital share was similar for all sectors (around 10% for coal and metals mining and about 7% for industrial minerals). Meanwhile, expenses on labor were about 30% in the first decade for the metals mining sector, and almost two times less for the other two sectors. Then it grew about five and 9percentt for industrial and coal mining in the next decade, respectfully. While for metals mining, labor share stayed almost at the same level. The capital-labor ratio had declined in all three sectors: around 7 and 12 percent in the metals and the industrial minerals mining, respectively, while in the coal sector, the decline was 40%.

Table 4.1. The average share of costs of key resources, percent of mining output value

	Coal		Metals		Industrial minerals	
	2001-10	2011-19	2001-10	2011-19	2001-10	2011-19
Fuel, %	0.69	**1.14**	1.86	0.40	2.23	1.43
Power, %	1.35	**3.23**	0.42	0.10	1.74	1.59

Coal, %	1.10	0.58	0	0	0.53	0.04
Water, %	0.06	**0.51**	0.06	**0.28**	0.02	**0.09**
Labor, %	16.71	**25.37**	30.13	31.62	17.33	**21.70**
Capital, %	11.54	11.49	10.03	10.38	6.48	7.26
Capital-labor ratio	85.39	45.24	41.50	34.69	48.15	35.44

Next, the industry sub-sectors growth rates of crucial mining performance indicators were analyzed (Figures 4.7-4.12). The mean production value of all sectors grew steadily in the first decade. The highest growth rate is demonstrated by ferrous metals mining (under 18%) compared to 7-9 percent in other sectors. However ferrous metals mining showed a production decline of less than 1% in the next decade. At the same time, other sectors continued their favorable growth rates. In coal and other minerals, mining was almost twice as lower as the decade before. Non-ferrous metals mining was the only sector that illustrated a steady growth in both periods (see Figure 4.7).

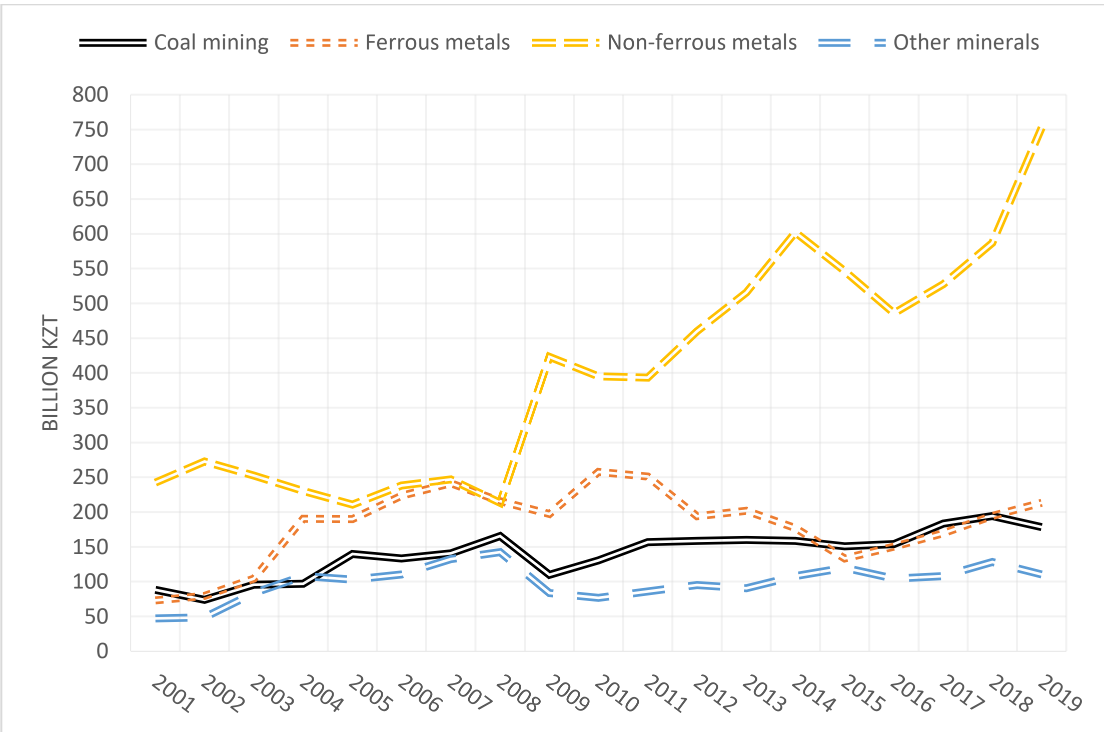

Figure 4.7. Production value

Figure 4.8 shows the number of firms of the main activity in the sectors. In coal and ferrous metals mining, the average number of companies did not change in two decades: 40 and 10 firms, respectively. In non-ferrous metals, mining means the quantity of companies grew from above 40 in the first period to under 70 in the next. The highest increase is demonstrated by the other minerals mining sector, where in the first decade the number of firms was about 240 on average. Then, it almost doubled in the next period.

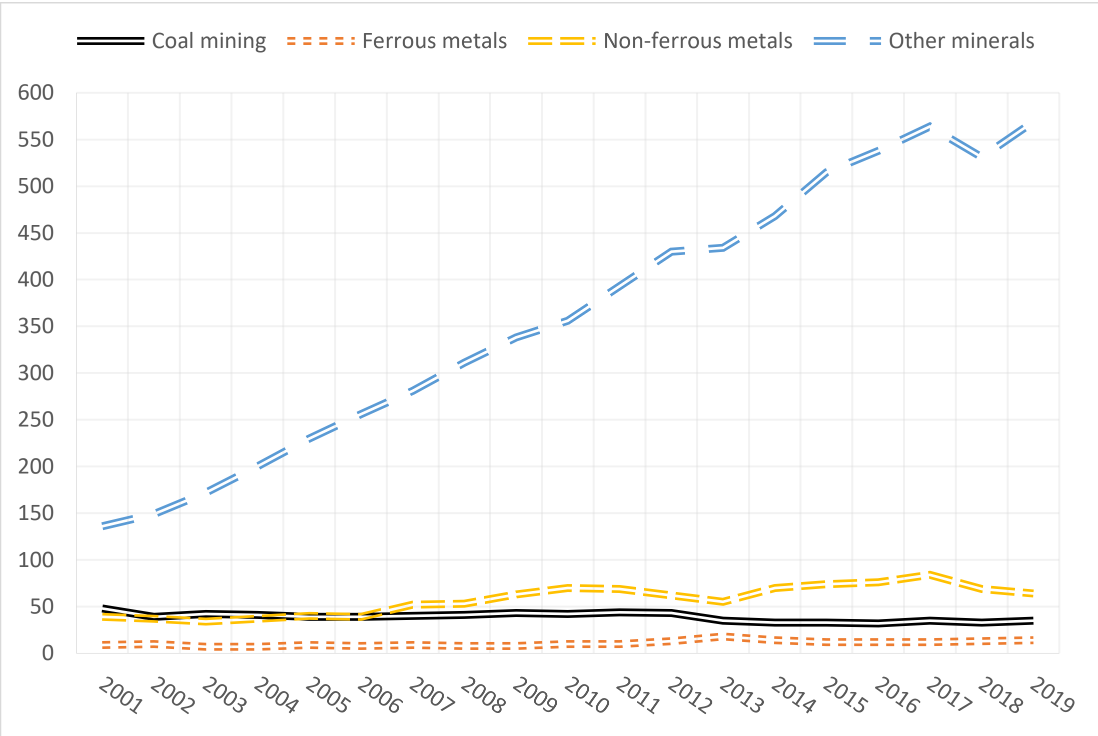

Figure 4.8. Number of firms

Despite the most significant number of firms in the other minerals sector and their further increase, the number of employees in the sector declined in both periods, by under 1% in the 2000s and by almost 4% in the 2010s (Number of employed people exclude administrative and other personnel not directly involved in mining activities). The other three mining subsectors demonstrated an increase in employment growth rates in the 2000s. Coal and non-ferrous metals mining illustrated more than 4 and 1 percent, respectively. They had almost doubled these indicators in the next decade. In ferrous metals mining percentage of labor stagnated (grew by only 0.1 percent) in the 2010s, which was six times slower than the decade before (see Figure 4.9).

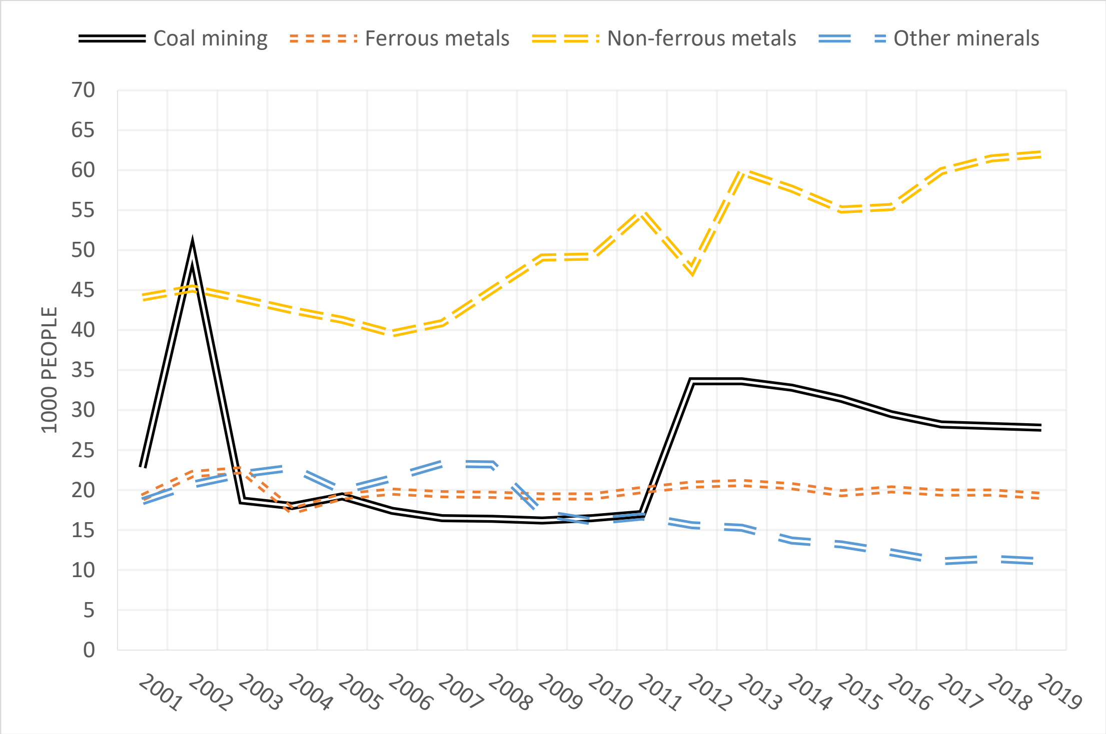

Figure 4.9. Employment

In all sectors, main activity labor wages grew by 6.5-8.5 percent in the first decade (see Figure 4.10). Ferrous metals mining demonstrated the highest production value increase in this period (more than twice in other sectors). In the next decade, average wages per month continued to grow. However, only in coal mining was the growth rate at the same level (6.5%) as in the decade before while in the other three sectors it decreased almost twice (3 - 4.5%).

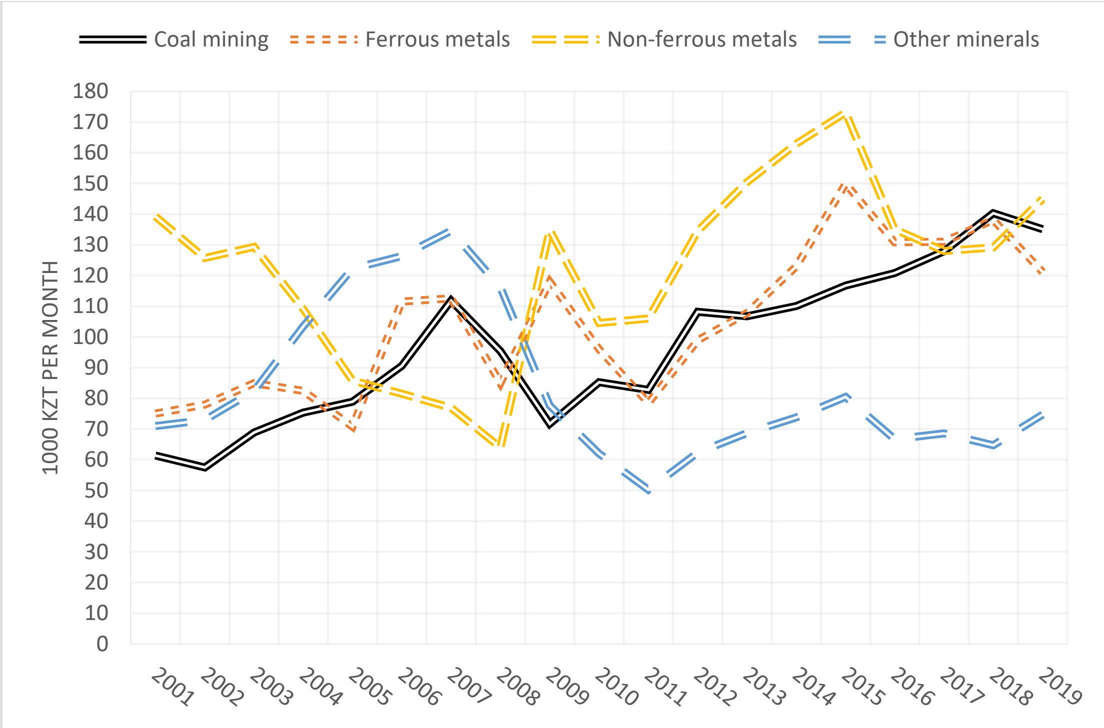

Figure 4.10. The wage of main activity personnel

Similar to the production value and wage rates, investment amount increased in all sectors in the first ten years (by 16-23%). While in the next ten years it was growing by lower percentages (9-14%). Except for ferrous metals mining, which investment rate decreased by 0.8 percent on average. Overall, it can be suggested that stagnation or decrease in investment value led to the same results in production rates (see Figure 4.11).

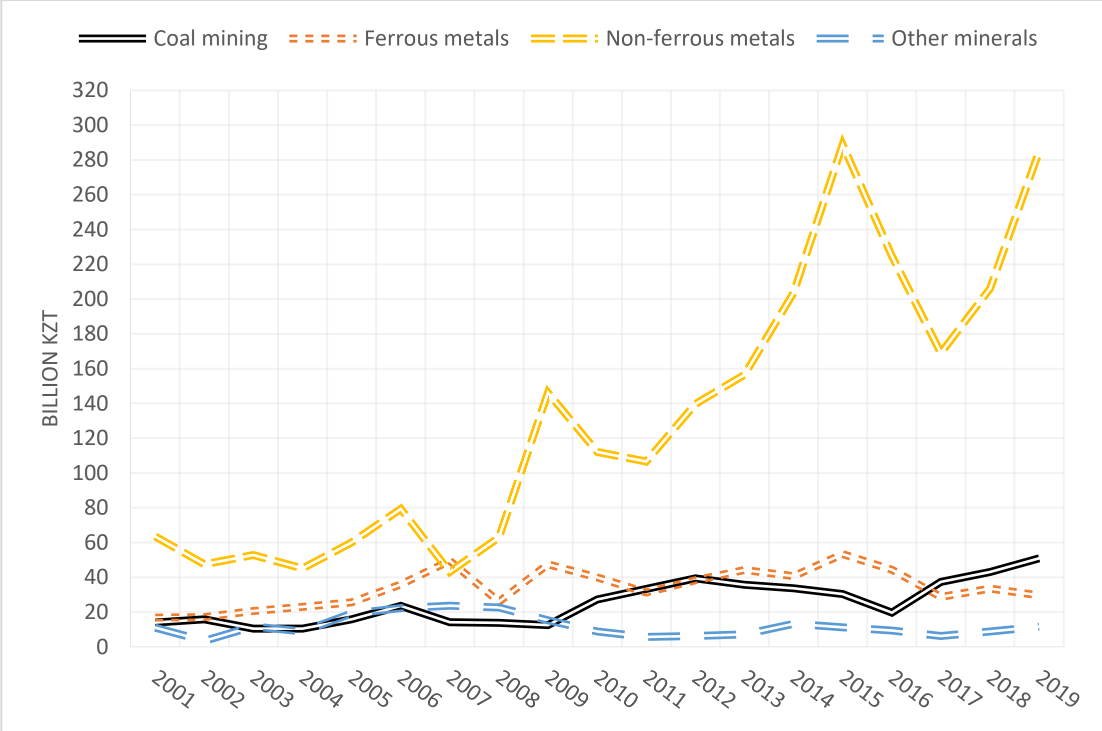

Figure 4.11. Investment value

A decrease in production output value led to a labor productivity decline (see Figure 4.12). In the first decade, when investment, production, and employment growth rates were high, labor productivity also grew steadily by 6-9% on average in all sectors. However, in the next period, it stagnated or declined. In coal mining, its growth rates were almost 40 times less than before and stagnated. The reason for this was a double decrease in productivity growth and a nearly two times increase in employee number, with the same wages growth rate. In ferrous metals mining, labor productivity was decreased by 1 percent due to a significant decrease in output value. Labor productivity growth rates stayed almost at the same level in the other two sectors. Although the mean production value of the mining sector of other minerals was about four times less, the employee number decreased four times more than in the period before. The same productivity indicator was achieved by investment growth.

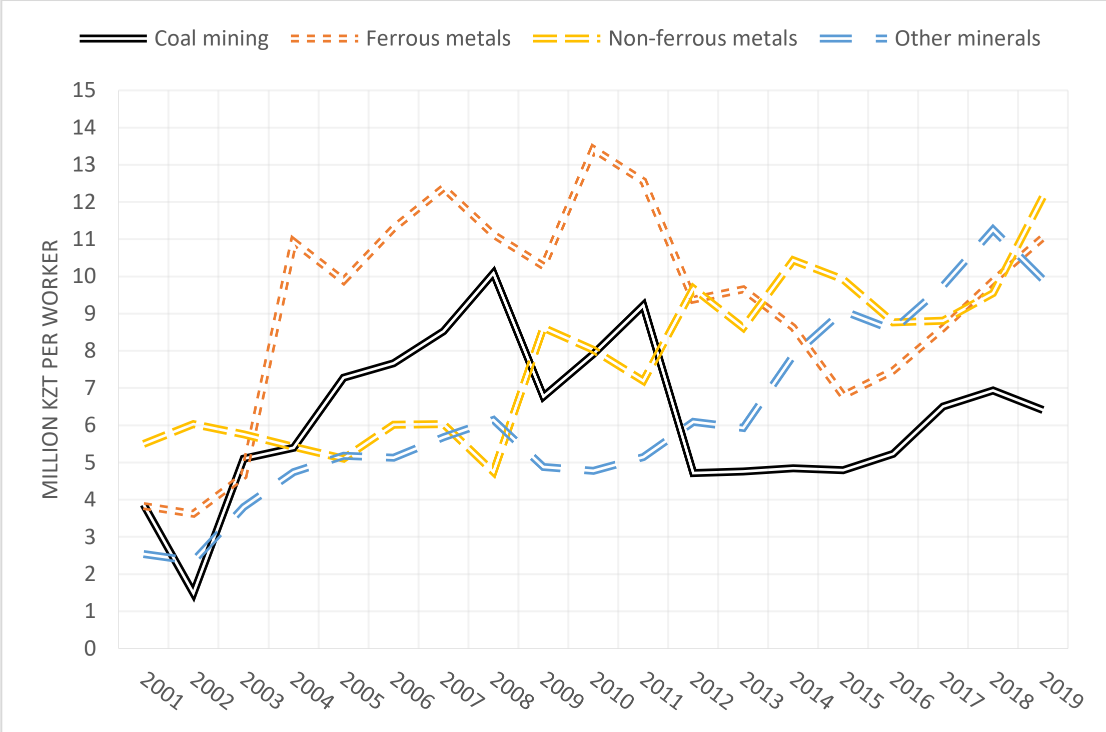

Figure 4.12. Labor productivity

Overall, the data indicates that only the non-ferrous metals mining sector demonstrated steady performance across all the indicators. In ferrous metals mining, all performance indicators, except for wages, decreased or stagnated after the end of the first decade. In coal mining, labor productivity stagnated in the second decade due to the lower growth rates of the indicators compared to the previous period. Other minerals mining sector continued steady productivity increase by the stable investment growth. Thus, in the last twenty years, the Labor productivity of the country's mining industry was increasing by more than 5% on average. Although, it is primarily the merit of the first ten years (almost 8% in the first decade and less than 4% in the next).

In addition, it is possible to interpret changes in the Capital – Labor ratio in Table 4.1 by investigating both Tables (4.1 and 4.2).

Table 4.2. Growth rates of key mining industry performance indicators, percent per year

	Coal		Ferrous metals		Non-ferrous metals		Other minerals	
	2001-10	2011-19	2001-10	2011-19	2001-10	2011-19	2001-10	2011-19
Production	6.9	3.9	17.7	-0.9	9.2	8.1	9.4	4.8
Employment	4.9	9.1	0.6	0.1	1.3	3.1	-0.9	-3.9
Investment	16.0	11.5	15.8	-0.8	16.2	13.7	23.2	9.0
Labor	8.5	0.2	6.2	-1.0	7.2	6.0	9.3	9.3

productivity								
Wages	6.5	6.5	6.9	3.2	8.6	4.4	6.6	4.4

Capital resource indicates the contribution of both human-made and natural goods, where the natural capital is the value of underground mineral resources thus, its value is dependent on the commodity prices, discovery and depletion of resources, and improvement in techniques or technologies of their production.

In the second period, the capital-labor ratio was lower than in the first, in all sectors. However, it was lower by only 7-12% in the Metals, and other minerals mining sectors, wherein coal mining decreased by almost two times (40%). The only difference in the coal sector is that its employment growth rates nearly doubled after 2010. Investment growth rates were high in all sectors (except for ferrous metals, whose investment rate after 2010 declined by 0.8 percent on average or close to stagnation). Therefore, it can be suggested that in all sectors, the capital-labor ratio was decreasing due to depletion and fall of commodity prices. Moreover, coal mining fell significantly because of the massive increase in employment growth rates.

4.2.Firm-level data analysis

KazMinerals is a high-growth copper firm that mainly focuses on extensive open-pit mining, which is cost-efficient in Kazakhstan and the region. In addition to copper, the company extracts gold, silver, zinc, and other by-products. According to the firm’s official website, the company’s history started in 1930 with the establishment of the Balkhash copper smelting complex, which was owned by another company – Kazakhmys (“Who”, 2021). Therefore, these two well-known mining companies have started as one and hence share the same history.

In 2014, Kazakhmys company’s independent shareholders decided to reconstruct the firm into two separate companies. It was agreed that mature assets, which are 14 mines, four processing plants, three auxiliary power plants, and two copper smelters, account for a total employee number of more than 40,000 and are mainly located in Zhezkazgan and Central Kazakhstan region would be owned by Kazakhmys. Whereas the newly formed firm KazMinerals would own production assets in eastern Kazakhstan, including four operating mines and three processing plants, the Bozymchak mining complex in Kyrgyzstan. In addition, future production expansion projects are Aktogay and Bozshakol mining and processing plants, and Koksay copper deposits, all of which 3 three are located in Kazakhstan. The employee number in KazMinerals assets accounted for about 10,000.

KazMinerals inherited mines in the eastern region: Artemyevskaya, Orlovskaya, and Irtyshskaya underground mines. These mines extract copper-zinc polymetal ores with a total production capacity of more than 3 million tons of ore in a year. In addition, Bozymchak open-pit mine was inherited. This mine has a production volume of 1 million tons of copper, silver, and gold ores per year. Furthermore, an expansive open-pit copper mine – Aktogay, started cathode copper production in 2015 and met its design production level in 2016. Moreover, copper production in concentrate from sulfide ore began in 2017. After a total increase in production, the annual ore processing capacity of the existing concentrator will be 25 million tons. A similar large-scale open-pit mine – Bozshakol, began production in 2016 and reached its design capacity of production in 2017. The mine's annual ore processing volume is about 30 million tons per year with a mean copper grade of 0.36%.

KazMinerals obtained the rights to Russia's copper project in 2019: Baimskaya located in the Chukotka region. Baimskaya is one of the world's most highly-prized mine sites that have full potential to become a large, cost-efficient open pit, similar to Aktogay and Bozshakol. However, the production will not start before 2027 ("Group history", 2021).

KazMinerals Ore output from continuing operations increased from 4350 kt to 4628 kt in 2014. This 6% growth was due to the start of operation in the Bozymchak mine. At the same time, cathode equivalent production grew from 77 to 84 kilotons because sections with higher grades were exploited in the Orlovsky mine. Furthermore, there is a 30% improvement in Maintenance spending per tonne of the cathode, which decreased from 935 to 631 dollars per tonne for continuing operations. It was achieved by spending on infrastructure and modernization of Nikolaevsky concentrator and projects to improve operations efficiency, including an upgrade in IT systems to minimize operating costs and downtown and advance distribution of materials.

In 2015, ore output from continuing operations increased three times as Aktogay and Bozshakol mining operations launched. 14537 kt of ore extracted: 3003 kt from Aktogay and 7099 in Bozshakol while the remaining were from mines in the East Region and Bozymchak. Similarly, in 2016 Ore output from continuing operations increased more than three times (49022 kt) due to an increase in extraction in 2 significant projects: Aktogay and Bozshakol, with the extraction of 16086 and 28272 kilotons, respectively.

In 2017 KazMinerals adopted ore processing KPI instead of Ore output. This year, 41,671 kt ore was processed more than 2.5 times before (2016:15,688 kt). It was accomplished by expanding volumes processed at Bozshakol and the start-up of the sulphide concentrator in Aktogay. At Bozshakol, ore processed grow from 11068 to 24558 kt because the sulphide facility come near its design capacity, and the clay plant proceeded with its build-up. Meanwhile, At Aktogay, the sulphide concentrator started operation in February 2017 and processed 12,941 kt of sulphide ore.

Ore processed in 2018 was about 30% higher than in the prior year (53250 kt compared to 41671 kt). It was driven by the ramp-up of operations in Aktogay sulphide concentrator and Bozshakol sulphide and clay plants since both mines reached their design capacities. Moreover, the clay plant at Bozshakol undertook some optimization improvements: installing wear-resistant crusher parts and backup equipment on the crusher.

In 2019, ore processed increased from 53250 kt to 58491 kt (10% growth). This was achieved due to Aktogay and Bozshakol sulphide concentrators operating at design capacity over the whole year. Overall, the volume of ore processed was obtained by a combination of consistent ore throughput, high grades, and the postponement of Aktogay mill maintenance for the year. In 2020, Ore processed grew from 58491 to 59222 kilotons due to increased performance at the Bozshakol clay plant. Ore processed in this site increased by 7% (to 31618 kt from 29470 kt) because of the clay plant's increase in ore processed in 2020. During three months in 2019, this plant was suspended from operations due to upgrades to the water and reclaim systems process.

The efficiency increased by the low strip ratios of the Bozshakol and Aktogay mine sites, which require limited amounts of waste rock to be removed per ton of extracted copper. In addition, these new assets use large-scale processing plants and the modern grinding and floatation technologies in these plants. In the meantime, KazMinerals constantly tries to improve the diesel use efficiency, which the primary consumer is the haul truck fleet. Thus, their movements in Aktogay and Bozshakol are real-time monitored using automated remote dispatch systems. To optimize truck dispatching to loading units, reduce the required quantity of haul trucks, and park any unnecessary vehicles to minimize diesel consumption. In addition, Bozshakol and Aktogay gain from close nearness to pre-existing rail infrastructure utilized to transport copper concentrate to customers, hence eliminating the need for diesel trucks for transportation.

Overall, as KazMinerals had increased production from its new open-pit mines (Aktogay and Bozshakol), efficiency was improved, and the use of large-scale processing plants reduced the energy intensity. In addition, the company improves its employees' professional development through safety and professional education training, uses autonomous and modern large-scale equipment, utilizes monitoring technologies for a reduction in amounts of energy and water consumption, upgrades IT systems, and modernizes mining plants to minimize operational costs and downtowns and to advance distribution of materials. All of these steps allowed KazMinerals to increase its copper production by 80% from 2014 to 2017, which strengthened its reputation as one of the most productive copper mines in the world (“Annual reports”, 2021).

KazMinerals quarterly data for Q1.2016 – Q4.2020 over four mine sites allows evaluation theoretical model of the company’s labor productivity. In Table 4.3, each variable's coefficients (with standard deviations) are presented. Stars indicate the significance level of these coefficients according to the t-test. Positive coefficients indicate that increase in variables’ quantities will lead to productivity growth. The number of variables with negative coefficients should decrease to that productivity to rise.

Table 4.3. Estimation results of firm-level labor productivity model

	Model 1	**Model 2**	**Model 3**	**Model 4**
Capital per worker	0.332 (0.211)	0.322*** (0.136)	0.244** (0.143)	0.566*** (0.132)
Energy intensity	-1.108*** (0.095)	-1.106*** (0.091)	Na	Na
Power intensity	Na	Na	-1.101*** (0.098)	Na
Diesel intensity	Na	Na	Na	-1.024*** (0.079)
Recovery rate	1.156*** (0.149)	1.158*** (0.144)	1.233*** (0.154)	0.888*** (0.135)
Grade	0.824** (0.400)	0.826*** (0.396)	0.845*** (0.417)	0.547 (0.378)
Waste ratio	-0.44 (0.049)	-0.045 (0.047)	-0.079* (0.049)	0.064 (0.047)
Copper share	-0.003 (0.051)	Na	Na	Na
Constant	-18.307*** (1.035)	-18.317*** (1.017)	-19.434*** (1.168)	-17.102*** (0.889)
No observations	80	80	80	80
No of mines	4	4	4	4
R^2 within	0.7737	0.7737	0.7489	0.7937
R^2 between	0.8717	0.8690	0.7716	0.9318
R^2 overall	0.8485	0.8459	0.6974	0.8933

*Significance level: *** - 1%, ** - 5%, * - 10%*

The findings show that explanatory variables jointly account for 70-90% of labor productivity variation across time and mine sites. The capital amount per worker is significant as its 10 percent growth leads to a 2.5-5.6% productivity increase. The recovery rate is even more critical. Because a 10% increase in processing plant efficiency is associated with 9-12% productivity growth. Similarly, an 8% productivity increase results in a 10 percent higher grade.

It is found that the waste ratio's impact on labor productivity is insignificant. Similarly, the statistical insignificance of the "copper share" variable indicates that the share of by-products in a firm's output does not affect productivity.

Production's energy intensity decrease generates a powerful positive effect on labor productivity. An 11% productivity increase is associated with a 10% energy intensity reduction. It is worth noting that the model, which uses diesel consumption per ton of extracted ore as a proxy for energy intensity, is the same model with the highest predictive power (according to R^2 within, R^2 between, and R^2 overall). It indicates that the company managed to increase its labor productivity mainly by controlling the use of diesel and improving the recovery rates of processing plants.

4.3. Case studies

As mentioned previously in the Literature review section, some of the popular productivity-enhancing practices in the global mining industry are change in technology, use of innovations, employee skills, education, economies of scale, and high-grade minerals mining. These factors are recognized to have more contribution than others to the labor productivity increase over the past 150 years. Despite it being hard to determine each input factor's contribution over the years precisely, there is no sufficient data to undertake statistical analysis. On the other hand, mining companies face issues that increase mining costs, negatively affecting productivity. These challenges are decreasing minerals quality, more profound and remote location of deposits, old mines with used equipment and non-modern technologies, and limitations of the economics of scale.

In this subsection, information on local firms' projects for labor and productivity increase is collected. It would be beneficial in addition to the statistical analysis. The sources of data are mainly the companies' websites.

Eurasian Resources Group (ERG) is a significant mining player with many assets in Kazakhstan and worldwide: more than 75,000 people are employed in 15 countries in total. ERG is important cobalt, copper producer, the Republic of Kazakhstan's lone producer of high-grade aluminum, and one of Eurasia's leading suppliers of alumina and iron ore ("Group", 2021).

Eurasian Resource Group launched a 10 million US dollars worth of "Smart Mine" project in one of their local assets: Kacharsky. In addition, they planned to expand it to the rest of the company assets starting from 2018. The project employs advanced monitoring and artificial intelligence technology that allows monitoring of the mine's performance and production cycle. Operators can now construct ideal production scenarios and schedule product dispatch and delivery. This technology is also connected to the firm's systems of assets planning and geo-data. This implementation will lead to productivity growth through real-time mine monitoring, which can timely detect changes, and allocate mining trucks and equipment. The initiative should enable ERG to boost equipment productivity by over 10%. This is supposed to aid in the making of investment decisions, the reduction of failures, the elimination of unscheduled downtime, the acceleration of equipment movement and allocation, and the reduction of expenses. ERG had spent more than $250 million to modernize its IT systems. It plans to spend a total of $1.8 billion between 2018 and 2025 to enhance efficiency by 10% per year by implementing new innovative technology in its Kazakhstan operations ("Eurasian", 2021).

Another ERG project is the modernization of its assets. For instance, the renovation of smelting furnaces at the Aksu Ferroalloy Plant of JSC TNC Kazchrome. Workshop No.6's furnace reconstruction is projected to be finished in 2024, as planned. After completion, the workshop's productivity will grow to 503 ktpa of ferrochrome, up from 269 ktpa in 2018, and energy usage will be lowered by 20%. Furnace No. 64 was shut down in 2017 for a significant refurbishment, and it was removed and replaced with a new furnace. This was more than a cosmetic update to the furnace. It entailed switching to wholly new technology to boost output while lowering unit energy usage per tonne of metal produced. The new furnace's environmental protection features include two state-of-the-art gas scrubbers. Furthermore, the ferroalloy gas is collected and used to assist in the heating of charge material during feeding, reducing the danger of accidents. After a comprehensive inspection of all systems, which are entirely automated and equipped with monitoring equipment, the furnace was commissioned ("New", 2021).

Kazakhmys is a vertically integrated holding corporation focused on mining and non-ferrous metallurgy. «Kazakhmys» is among the world's top 20 companies in both: copper concentrate production (271 000 tons) and cathode and blister copper production (more than 350 000 tons, including tolling). Half of the country's silver production comes from Kazakhmys. Kazakhstan was ranked 11th in the production of silver worldwide in 2020 (mainly because of Kazakhmys with 279 tons). In the same year, the firm was among the top three electricity generators in the country, with 7,267.53 million kWh of production capacity. Mining, enrichment plants, and copper smelters are all part of the «Kazakhmys» company, which employs around 37,000 people across three production sites (Balkhash, Zhezkazgan, and Karaganda) ("About company", 2021).

The inspections at Kazakhmys showed that the Enterprise Resource Planning (ERP) system's implementation sped up the receiving of management reports by 22%, order processing by 11%, manufacturing expenses by 7%, and labor productivity by 9%. Nearly 13,000 man-hours were spent on the ERP deployment, which began roughly five years ago. Three hundred automated positions were established in personnel service, accounting, and divisions responsible for transferring and distributing products and supplies during that period. ERP, in reality, replaced three different information systems simultaneously, allowing these services to collaborate more effectively in a single location. Due to thoughtful and centralized planning, rapid and reliable reporting from the business management, and a single and centralized cycle from the accounting department, the production got a better and more timely supply of goods and materials ("One", 2021).

Furthermore, the company acknowledges its employees as its most important asset and spends hundreds of millions every year increasing labor wages, improving working and living conditions, and conducting professional training ("Kazakhmys"). Other measures to increase productivity are an update of worn-out mining equipment to more autonomous ones ("Kazakhmys updates"), the use of the latest generations of advanced and innovative technologies for the geophysical study of deposits ("Aerogeophysical"), modernization of concentration mill ("Non-stop", 2021).

Another local mining company is Altynalmas, a gold mining, and processing enterprise with a comprehensive geological, mining, and processing cycle. It operates nine gold mines in Kazakhstan that it owns. The company's holdings are spread over four Kazakhstan oblasts: Zhambyl, Karaganda, East-Kazakhstan, and Akmola. The company processes the minerals in gold recovery plants: Akbakai, Dolinnoe, and Aksu, as well as the processing plant Pustynnoe and the precious metals recovery facility Altynalmas Technology. More than 11,000 highly qualified professionals work for the organization. In the manufacturing process, more than 120 mining equipment units are used ("Gold producer", 2021).

Gold mining company AltynAlmas plans to increase production productivity by up to 5%, reduce operating costs by up to 15%, and reduce temporary routine operations by up to 20-30%. Therefore, as part of the introduction of digital technology and elements of industry

4.0, an innovative R&D project, “Digital Mine,” was launched in 2017. The project includes high-speed internet connection, automation of ordering, dispatching, and transportation systems, real-time monitoring, and data acquisition that allows access to reports for any date and plan maintenance works. Most importantly, it allowed faster and automatic communication between all mining departments of the company (“Digital Mine”, 2021). According to the Official Information Source of the Prime Minister of the Republic of Kazakhstan (2018), this project increased the utilization rate of the mining equipment from 55% to 76%, 21 percent of fuel costs were saved per year, so the overall cost of mining was reduced by about 20%.

In 2018, the company began implementing the Mine to Mill (M2M) Program on the Pustynnoye Project, making it Kazakhstan's first firm to adopt such a work algorithm. Mine to Mill is a way for developing an integrated strategy for ore mining, crushing, and grinding process optimization to lower one-ton costs and boost production profitability. After introducing M2M at the Pustynnoye mine, reduced oversize yield during mining and increased rock extraction efficiency were achieved. Because all modifications in ore mining directly impact plant operations, such adjustments at Pustynnoye GRP have resulted in fines yield after crushing was minimized, ore crushing and grinding power consumption being reduced, and GRP manufacturing output rose from 270 to 350 tons per hour. This strategy has allowed the project to meet its annual ore target of 2.5 million tons for mining and processing at the Pustynnoye mine in a short amount of time (“Mine to Mill”, 2021.).

Table 4.4 Common productivity-enhancing trends

Trend	Types	Number of firms
Digitization	Upgrade of IT technologies, Use of the latest technologies, Monitoring sensors, Data collection	4/4
Automatization	Use of more autonomous equipment, Use of autonomous systems for enterprises,	3/4
Modernization	Renovation of old plants according to the latest innovations, Use of latest technologies	3/4
Labor benefits	Wage increase, Better living conditions, Professional development training,	2/4

5. Discussion

The industry-level results indicate that labor and capital costs significantly contribute to the output in the mining sector. However, the impact of water and energy sources is minimal. Furthermore, findings support the thesis hypothesis since labor productivity grew in the industry over the period. Although, productivity was close to stagnation in coal and ferrous metals mining subsectors in the second decade. Mainly it was because production growth rates were lower than the growth rates of employment and employee wages. In addition, investment growth rates were high in both decades in the mining industry. In the second period, the capital-labor ratio was lower in all sectors, most significantly lower in coal mining. It indicates that stagnation or low capital growth during the high increase of labor expenses led to labor productivity stagnation. Since the investment amount was high, it can be suggested that productivity was affected by old mining technologies and equipment. Moreover, natural capital might influence production rates, such as ore depletion, remote and deep underground deposit location, and low commodity prices. Therefore, high mining productivity can be achieved by mining higher grade minerals or by increasing financial capital, which is spent on improving equipment, facilities, and mining technologies.

The firm-level analysis provides similar results. Productivity increase has a high correlation with higher mineral grades (natural capital), an increase in recovery rate (improvement of processing plant efficiency), growth of capital amount per worker (wages, bonuses, professional training, working and living conditions), and with a decrease of energy intensity (mainly diesel usage).

Therefore, the negative effect of natural capital and increase of employees (while production value is low) on labor productivity can be counterbalanced by investments in a technology upgrade, modernization of plants and facilities, equipment improvement, expenses on labor in the forms of education, wages, working and living conditions improved.

In addition, the case studies demonstrate that popular productivity-enhancing trends in local firms are similar to the factors used worldwide and which are proven over time to be effective. Also, some trends are directly related to the results from regression analysis. For instance, the Recovery rate, which is calculated to be highly effective in increasing labor productivity, is a part of the Modernization trend. In digitization, monitoring sensors control energy, power, and diesel intensity. Therefore, it can be said that the qualitative investigation supports the quantitative analysis.

6. Conclusion and recommendations

6.1. Conclusion

The research objective of this study was to analyze Kazakhstan's industry and firm-level mining productivity from 2000 to 2020. For this, descriptive analysis of the industry indicators and regression and case studies investigation on firm-level productivity-increasing factors were conducted. The industry-level factors analyzed are expenses on energy, water, labor, capital, and growth rates of production, employment, investment, and wages. Firm-level factors are capital per worker, energy intensity, recovery rate, grade value, waste ratio, and copper share.

It was found that local mining productivity has been rising for the past twenty years by more than 5%. The industry-level analysis shows that the rise was mainly due to the extraction of higher-grade minerals, investment growth for modernization and automation of mining facilities and equipment, technology upgrade, and an increase in labor expenses.

Firm-level studies support these conclusions through the high positive correlation between labor productivity and recovery rate, mineral grade, capital per worker, and a strong negative correlation between productivity and intensity of diesel, energy, and power. Case studies on productivity-enhancing practices in local firms demonstrated that the same practices are also used in other top mining companies in forms of digitization, modernization, automation, and labor benefits.

It was estimated that a 10% decrease in energy usage leads to 10-11% labor productivity growth. Whereas, a 10% growth of recovery rate in processing plant gives an 8-12% rise in productivity. Mining of 1% higher grade ore provides with 0.8% productivity boost. 2.4-5.6% growth in productivity can be achieved by a 10% increase in capital per worker.

6.2. Recommendations

Due to the lack of mining data provided in open access, it can be recommended for future studies:

1. To test more productivity-affecting factors at a firm level.
2. To conduct in-depth firm-level analysis for a higher number of companies.
3. To expand the time interval of the analysis.

For the mining firms in order to improve their productivity it is recommended:

1. To invest on increasing recovery rate of processing plants.
2. To decrease the use of diesel, power and other energy sources.
3. To allocate more capital per worker.

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