Inclusion of universities, enterprises, and regions of Kazakhstan in the process of technological upgrading of the mining industry: a triple helix approach

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Abstract: This paper investigates universities with educational programs in mining specialties, mining enterprises, and regions with a developed mining industry in developing countries on the example of Kazakhstan. The analysis showed that universities are the weakest link in the chain of universities-enterprises-regions, since their structure is poorly balanced in relation to business: though to a smaller extent, science does cooperate with education, while business in universities remains an alien element and does not generate income on its own. The creation of a mining cluster around a university with mining majors can help multiply collaborative efforts. The involvement of universities in the extraction of mineral resources and the accompanying processes within such a cluster will significantly change the type and role of the regional industry, and as a result, will become a driver of economic growth in the region.

Keywords: triple helix; third mission; university; mining; technological upgrading; cluster; region; Kazakhstan; KZ; webometric method; PLS-SEM; WarpPLS.

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1 Introduction

Middle-income countries such as Kazakhstan usually have a great interest in the development of science and innovation because they understand that without advanced technological development of the main sectors of the economy developing countries will not be able to catch up with developed countries.

In developing countries, the policy of technological modernisation is faced with problems such as lack of demand and supply for innovative products, underdevelopment of the service infrastructure, lack of a critical mass of innovative and venture entrepreneurs, lack of a system for generating and transferring knowledge to the country's economy, low penetration of open innovations, and weak scientific and technological potential (Resolution of the Government of the Republic of Kazakhstan, 2013).

The main form of technology transfer is the purchase of technological and production equipment and components with neither acquisition of engineering solutions nor development of relevant competencies. Most of the Kazakhstan's industrial enterprises are located at the lower levels of the technological chain of transnational clusters. The structure and potential of entrepreneurship, concentrated in the trade and intermediary sphere and the sphere of non-tradable services, require structural modernisation of the national business, formation of marketing, technological and engineering competencies in business, as well as a broad and modern corporate sector of the country.

The regions of Kazakhstan are faced with such problems as a growth in youth migration to cities, absence of international research centres, and low participation of educational institutions in regional socio-economic processes. It is necessary to develop local universities as drivers of local development.

Many regions of Kazakhstan have a developed mining sector. In 2019, the mining sector comprised 16% of the country's GDP (Bureau of National Statistics, 2021). Mineral fuels accounted for 67%, while solid minerals and metals accounted for 14% of export earnings (WITS, 2021).

The dramatic economic downturn in 2015–2016 has stimulated a number of national projects aimed at improving the investment climate, technological upgrading of manufacturing sectors, expanding opportunities of the private sector and changing the basic principles of economic policy in the mining sector. The government has embarked on a course of reforms to diversify economic activity and lessen the country's dependence on fluctuations in oil prices, stimulate geological exploration activities, and strengthen investor confidence through a more effective legal regime (OECD, 2018).

In this paper, we set the goal of analysing the potential of universities, mining enterprises and regions of Kazakhstan in terms of their participation in technological modernisation using the triple helix model for analysis. We will focus on the mining and related industries and universities, which come in close contact with these industries for personnel training.

We will focus on the mining and related industries and universities in close contact with such enterprises for personnel training. Based on the triple helix approach and technology upgrading literature, we investigate specifically the role of universities and firms in the mining sector in Kazakhstan and answer the question of how this sector can be technologically modernised.

2 Theoretical background

2.1 Triple helix approach

The idea of the triadic model emerged in the early 1980s as the concept of the entrepreneurial university as an academic institution actively involved in regional development (Etzkowitz, 1983). Etzkowitz (1993) drew attention to the triadic interaction by studying the reports of Carl Compton in the MIT archives. It was about broadening the understanding of so-called public-private partnerships with the aim of engaging academia in solving the problems of a declining industrial region.

Later, the concept of the triple helix was developed by Etzkowitz and Leydesdorff (1995). Then, the concept was expanded to a model for studying the economy based on knowledge (Etzkowitz and Leydesdorff, 2000). Triple helix systems are supported by three key aspects, namely the components in the systems, the relationships between the components and the functions of the systems. The main components are comprised of the institutional areas of the university, industry and government.

Despite advances in theoretical underpinnings, the explanatory power of the triple helix model still needs to be improved, for example, through mesoscale theories (Cai and Etzkowitz, 2020). As a universal model, the triple helix can be used to solve problems at the micro, meso and macro levels (Etzkowitz and Zhou, 2019). The authors of this paper also put forward their ideas for using the triple helix model at the micro level (Myrzakhmet et al., 2018a).

There are several types of the triple helix with different candidates for the actors (Zhou and Etzkowitz, 2021). Supporters of different social goals create their own triple helix. For example, the government-industry-labour triple helix can address the payment of benefits to employees; at a larger micro level, a triple helix for corruption may include a bank, an industrial corporation, and an audit department; a triple helix for a city redevelopment project could include the construction industry, municipal authorities, and the public as the main actors.

Soon after the triple helix model has been proposed observers were tempted to add an extra helix to solve problems beyond innovation, thus breaking the original purpose and not providing any logical methodology, different from just complementarity. The question of whether a fourth spiral exists has been studied (Leydesdorff and Etzkowitz, 2003). As a result, a new hybrid entity is formulated, synthesised from parts of the three realms, which can collectively do what neither of them can do individually.

The actors in the triple helix are people, who have a conscience and motivation, involving interacting institutional spheres, and thus are not equivalent to a mixture of elements (human or non-human) in an innovation system. Zhou and Etzkowitz (2021) argue that there are *N* triple helixes, but there is no *N*-fold helix. The quadruple, quintuple, or even *N*-fold helix, which views the actors in the helixes as subsystems, exacerbates the misunderstanding.

The first step towards the triple helix is usually collaboration between the institutional spheres most involved in innovation using their traditional roles (Etzkowitz, 2003). A typical strategy is to establish a research centre to accelerate the production of academic research. Long-term academic development took place from a teacher training college to a research university (the first academic revolution) and then from a research university to an entrepreneurial university (the second academic revolution). The first stage in the emergence of entrepreneurial science is the internal development of academic research groups as quasi-firms based on a system of competitive research funding. The second stage relates to participation of scientists in a transfer of technology to enterprises through intermediary mechanisms established for this purpose. At the third stage, scientists actively participate in business and the creation of firms. Establishing an entrepreneurial university or reorganising an existing university is becoming an increasingly popular regional development strategy.

The dynamic business environment encourages academic researchers to manage risk by raising funds from multiple sources, bringing an entrepreneurial element to the role of educators as a matter of academic survival. There is also a shift in the focus of academic attention away from the departments of individual scholars to networks of research groups and centres to attract larger funds, often only available for such collaboration. The aim is to encourage universities to play a creative role in economic and social development from an independent point of view, while not losing focus on government and industry priorities. Just as the university has become the key to regional development, regional development has become the backbone of the university's development strategy (Etzkowitz, 2017).

The triple helix can work well in strong regions with numerous world-class universities and knowledge-based firms. However, there are fewer of these in the weaker regions, so other options need to be explored for policies linking universities to regional development (Harrison and Turok, 2017). For example, the triple helix approach was unsuccessful in Wales, where two major challenges for Welsh triple helix programs were identified:

1 a gap between design and implementation

2 a supply/demand mismatch with too much emphasis on pushing innovation out of universities instead of increasing absorptive capacity and business opportunity, which leads to insufficient business involvement in many programs (Pugh, 2017).

The triple helix approach assumes that government and industry will be willing to pay for a privileged access to university knowledge and innovation. In a weaker region with a higher proportion of firms engaged in traditional or non-knowledge-based activities, the demand for university knowledge and services may be lower. Pugh (2017) makes two main policy recommendations:

1 to take a broader and more interactive approach to university-industry interactions

2 to build the strength and capacity of the business sector to absorb and use the knowledge and innovation from universities.

Often, existing business support systems, which act as surrogates for regional innovation systems in non-competitive regions, are poorly linked to the higher education system, and special policies are required to fulfil this role. This policy should ensure an appropriate balance of support for both network and market transfer of knowledge. Regional policymaking in this area should seek to create more open and interconnected networked systems that highlight the potential role of universities in functioning as nodes in knowledge networks linking regions and their participants with international knowledge sources, rather than as a purely regional domestic knowledge provider (Huggins et al., 2008).

It may seem that the triple helix model does not work well in weak regions where science does not have good international connections, but the authors of this paper believe that this is not the case. The main mechanism underlying the interactions of the triple helix model as an optimal condition for innovation is 'to take on the role of another' (Etzkowitz, 2008), performing both new roles and their traditional functions. Organisations playing non-traditional roles are seen as the main potential source of innovation in innovation field (Cai and Etzkowitz, 2020). In regions where absorptive capacity is weak, the Technology Transfer Office (a government-created technology modernisation support body) may take the lead in facilitating the creation of an external support structure and may also have to fill in internal gaps when the interest of inventors is limited. Conversely, the office can take a relatively passive stance when the regional absorptive capacity and interest of inventors are high, but this can lead to untapped potential among moderately entrepreneurial educators (Etzkowitz, 2017).

2.2 Technology upgrading approach

The former socialist world, to which Kazakhstan belongs, is a multi-level Eurasian region, which includes Central Europe, the Baltic countries and Southeast Europe, Eastern Europe, Caucasus and Central Asia. Although the developmental approach of this region is still dominated by the economic theory approach of markets with institutional change, a number of researchers have lately adhered to the idea of technology upgrading playing a central role in economic growth and an evolutionary view of economic development (Radosevic, 2022).

Technology upgrading is a multidimensional process, and existing indicators that are overly R&D oriented do not reflect this multidimensionality. In particular, the existing indicators do not reflect the specifics of the technological modernisation of middle-income countries. They are either a theoretical or not based on stylised evidence of technology upgrading and therefore not relevant to low/middle income countries (Radosevic and Yoruk, 2018).

Radosevic and Yoruk (2014, 2018) developed a conceptual framework for the phenomenon of technological modernisation as a three-dimensional process, which includes intensity and types of technology renewal, expansion of technological modernisation through various forms of technology and knowledge diversification, and interaction with the global economy through various forms of imports, adoption and knowledge sharing. The technology modernisation measurement models (Radosevic and

Yoruk, 2018) are based on 35 indicators of both 'hard' (objective) and 'soft' (subjective) nature, and they are applied to a balanced sample of 42 countries ranging from lower-middle to high incomes. Indicators are selected based on their conceptual relevance, accessibility, and relationship to income levels. The three-component composite indicator of technological modernisation focuses on metrics that are important for the growth of middle-income economies in the broadest sense.

Post-socialist transformation is a process of institutional changes towards the dominant role of markets. It is also a process that requires a serious change in the role of enterprises as carriers of opportunities and a source of innovation. Their transformation from production units to business units entailed not only a change of ownership, that is, corporate governance, but also a transformation of their technical and economic profile (Radosevic, 2022).

A key feature of dynamic innovation systems is the 'interactive dynamic opportunity' that arises from firms' interactions with their R&D networks, as well as with foreign technology sources and market access. In the post-socialist period, this interaction was weak. Their relationships were either with weak organisational capacity (firms), or unreformed organisational capacity (research organisations), or with external players (especially foreign direct investment). Increased efficiency at any of these nodes, which is not complemented by synergy and complementarity between the nodes of innovation ecosystems, cannot provide sustainable income and economic growth (Radosevic, 2022).

Universities have an important role to play in the process of modernising technology. Universities are gradually increasing their focus on fulfilling their third mission and becoming drivers of regional development (Compagnucci and Spigarelli, 2020). The transfer of knowledge and technology can occur between any stages of the R&D spectrum: basic research, applied research, exploration, development for production, engineering and manufacturing capability (Amsden and Tschang, 2003).

2.3 Conceptual frameworks

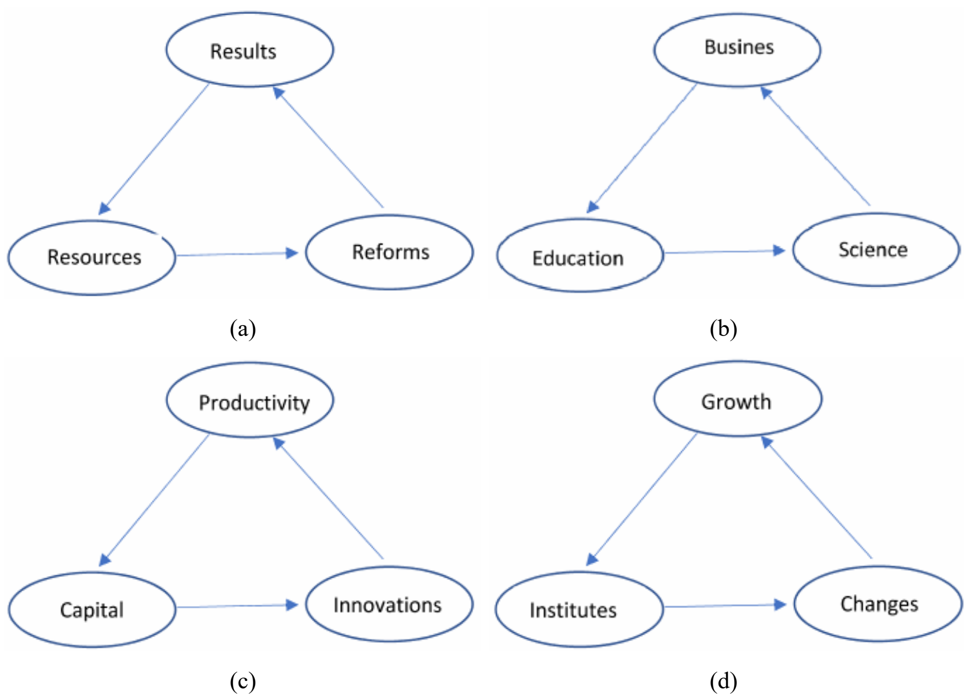
One of the most effective ways to build an innovative economy in industrial regions is, in our opinion, the creation of innovative territorial clusters around regional universities. It will be possible to involve industrial enterprises in such clusters and initiate close interaction between the university and business for the exchange of knowledge and the formation of technology diffusion chains.

In this paper, we use the triple helix model to analyse the interaction of various actors (Figure 1).

Since in some cases we consider interaction at the micro level (enterprises, universities), in another case – at the meso level (regions), we consider it expedient to unify our approach, which we conditionally called the principle of three Rs (resources-reforms-result) [Figure 1(a)]. These three categories are related to each other in the following way: resources enable reforms, reforms lead to results, and results strengthen resources. All three of these categories twist into a triple helix, mutually reinforcing each other.

In the case of universities, this is education-science-business [Figure 1(b)], in the case of enterprises – capital-innovation-productivity [Figure 1(c)], in the case of regions – institutions-change-growth [Figure 1(d)]. That is, the category 'resources' refers to education in the case of universities, capital in the case of enterprises, and institutions in the case of regions. The category ‘reform’ is science in the case of universities, innovation in the case of enterprises, and change in the case of regions. Finally, the category ‘outcome’ is business in the case of universities, productivity in the case of enterprises and growth in the case of regions. All these categories make up latent (hidden variables), which will be used in our analysis as constructs – composite constructs of measurable indicators. Indicators reflecting latent variables are presented in Tables A1 (universities), A2 (enterprises) and A3 (regions) in Appendix.

Figure 1 Three R principle and three triple helix models, (a) three R principle on base on triple helix approach (b) triple helix for universities (c) triple helix for firms (d) triple helix for regions (see online version for colours)



3 Data and methods

This paper examines universities with educational programs in mining specialties, mining enterprises, and regions with a developed mining industry. Regions with the developed mining industry, regional universities and mining enterprises were previously studied (Myrzakhmet et al., 2021). Since all data was re-extracted and recalculated for each region, considerable amount of data series emerged, which we combined into samples. Table 1 shows all surveyed regions and universities.

The main data for the analysis was obtained by the webometric method (Myrzakhmet et al., 2018b), where the frequency of a keyword is defined as the number of pages opened on the university (enterprise, region) website. The webometric method is convenient for researching universities which closely interact with their environment and develop and maintain their websites (Sarwar et al., 2021). The activities of universities are divided into three main types: education, science and business. This is similar to the three elements, state-science-business, in the concept of the triple helix, as well as the three missions of the university (education, research, and contribution to the territorial economy) (Compagnucci and Spigarelli, 2020). The governmental functions in the triple helix scheme in the innovation process at the university level are performed by education – departments, schools and other educational units; science is represented by research institutes, scientific laboratories, research centres and other research units; while business is represented by institutes, centres, and other units that manufacture products or provide services (Myrzakhmet, 2012).

Table 1 Research objects

N	*University*	*City*	*Region*
1	Karaganda Industrial University	Karagandy	Karagandy
2	Karaganda State Technical University	Karagandy	Karagandy
3	L.N. Gumilyov Eurasian National University	Nur-Sultan	Akmola
4	Qorqyt Ata University	Kyzylorda	Kyzylorda
5	Rudny Industrial Institute	Rudny	Kostanay
6	Satbayev University	Almaty	Almaty
7	Sh. Ualikhanov Kokshetau State University	Kokshetau	Akmola
8	Toraigyrov University	Pavlodar	Pavlodar
9	Zhezkazgan Baikonurov University	Zhezkazgan	Karagandy

The types of activities (addressed here as factors) are circles, the area of which is equal to the number of pages found (*N*), the diameter (circle size) is proportional to the square root of the circle area, and the intersections of the circles of two factors are found by counting the number of pages opened when searching for pages where both factors are mentioned (search string 'Factor_1 Factor_2 site:[university site]'). Here, a simplified version is used, where education (E – education), science (S – science) and business (B – business) are represented by keywords (Myrzakhmet, 2018): education, science and business. Such a limited number of keywords – one per factor – simplifies the model and allows comparison of objects of the same industry (universities to universities, enterprises to enterprises and regions to regions).

The data was obtained from the Internet using the Google Chrome browser. The following distribution was usually encountered: (E, S, B) > (ES, EB, SB) > (ESB). However, due to the peculiarity of the Google search engine's work, in some cases, this ratio was not achieved. In such cases, it was necessary to reduce the values of those data to the maximum possible value.

For research objects including universities, enterprises and regions, we use two types of potential – innovation potential and production potential. Innovation potential characterises the facility's ability to change and production potential – to productivity. The production potential in the case of universities turns into educational potential, and in the case of the regions – into the resource potential. In addition, within the limits of potential, we use the concepts of activity and cooperation. By activity, we mean the number of pages opened in the browser when searching for one keyword; under cooperation – the number of pages opened in the browser when searching for two or more keywords.

The list of mining enterprises can be found on the e-government website (E-Government of Kazakhstan: Open Data, 2021), and the financial indicators of enterprises – on the website of the depository of the Ministry of Finance of the Republic of Kazakhstan (2021). Calculations and graphical constructions in previous works were performed using R language for data analysis and visualisation (Kabacoff, 2015).

This paper uses structural equation modelling (PLS-SEM) to analyse the data and validate the results, which is capable of simulating multiple exogenous latent variables along with other endogenous latent variables in a pathway analysis model, establishing losses and mediating effects of the variables (Monecke and Leisch, 2012). In addition, as a variance-based approach, PLS-SEM can handle small sample sizes and provide reliable results without multivariate normality as a precondition. Moreover, PLS-SEM can consider measurement errors of indicator variables in the model. The webometric data obtained in previous works are used in this work as indicators of latent variables. The WarpPLS algorithm used in this study can model nonlinear data, unlike other programs that are based on either variance or covariance (Kock, 2014). This method is becoming more popular in research on the interaction of enterprises and universities (see, for example, Abdulai et al., 2015).

4 Results

4.1 Universities

Tables 2–4 and A4 of Appendix present the results of the PLS-SEM study of universities. Empirically obtained indicators are webometric data, to which data from the financial statements of universities are added, and variables (also called latent, since they are composite, i.e., constructs) are science, education and business. Data from previous studies were used (Myrzakhmet et al., 2021).

Evaluating the created models, we will obtain empirical measurements of the relationships between indicators and constructs (a measuring model, in our case, reflective, since constructs do not form indicators, but reflect them), as well as between different constructs (structural model). Empirical measurements allow one to compare theoretically established measurement models and structural models with the reality represented by sample data (Hair et al., 2014). In other words, one can determine how well a theory fits the data. The models were analysed using partial least squares (PLS) regression in the WarpPLS v7.0 statistical package to test the hypothesised relationships between the hidden variables (Chin, 2010). Table 2 shows the combined loads (magnitude of the relationship between the construct variable and reflective indicators) and cross-loads (magnitude of the relationship between the construct variable and foreign indicators).

Measurement model assessment (indicators – construct) includes composite reliability for assessing internal consistency reliability, reliability of individual measures, and an average variance extracted (AVE) for assessing convergent reliability. In addition, the Fornell-Larcker test and cross-loadings are used to assess discriminant validity (Hair et al., 2014).

Table 2 Combined loading and cross-loadings with standard errors, *p*-values and VIFs

Indicator	*Variables*			*SE*	*p-value*
	Educati	*Science*	*Busines*		
S	–0.084	*0.855*	–0.076	0.117	< 0.001
ES	–0.329	*0.887*	0.056	0.115	< 0.001
EB	0.030	*0.939*	0.010	0.113	< 0.001
SB	0.285	*0.900*	–0.047	0.115	< 0.001
E	–0.323	*0.822*	0.132	0.119	< 0.001
B	0.375	*0.901*	–0.077	0.115	< 0.001
ESB	0.007	*0.953*	0.010	0.112	< 0.001
D	*0.732*	0.359	–0.088	0.124	< 0.001
S_	*0.701*	0.575	0.035	0.126	< 0.001
R	*0.513*	–0.340	–0.026	0.138	< 0.001
DS	*0.851*	0.367	0.181	0.117	< 0.001
DR	*0.896*	–0.377	–0.131	0.115	< 0.001
SR	*0.924*	–0.237	0.041	0.113	< 0.001
DSR	*0.921*	–0.268	–0.023	0.114	< 0.001
Income	–0.068	0.106	*0.876*	0.116	< 0.001
N_IP	0.097	–0.142	*0.893*	0.115	< 0.001
N_EP	0.091	–0.134	*0.892*	0.115	< 0.001
Workers	–0.123	0.174	0.882	0.116	< 0.001
α	0.901	0.958	0.909		
VIF	2.103	2.387	1.233		

Note: Educati = education, Science = science and Busines = business.

A common internal consistency checker is Cronbach's alpha, which performs reliability checks based on the cross-correlation of measured indicators. If Cronbach's alpha is in the range of 0.60–0.70, then the indicators have approximately equal external loads on the structure, i.e., are equally reliable. The PLS-SEM program arranges the indicators in order of magnitude for their individual reliability. On the other hand, Cronbach's alpha depends on the number of elements in the scale, and accordingly, underestimates the reliability of internal consistency. Therefore, another measure of reliability – composite reliability – may be a more acceptable criterion here.

Composite reliability, like Cronbach's alpha, in the 0.60–0.90 range can be considered acceptable (Hair et al., 2014). If the value of composite reliability exceeds 0.90, then the indicators measure virtually the same, and therefore such an indicator becomes unreliable, values below 0.60 indicate a lack of confidence in internal consistency. According to Table A4, this indicator is higher than 0.90, which indicates that the model indicators are too consistent, and the data should be checked for multicollinearity.

Convergent validity is a degree to which one dimension is positively correlated with alternative dimensions of the same construct. The construct indicators should be close in size or their variance should be significant. To determine the converged confidence, external indicator loads must be used together with the AVE. Large values of external loads show a close relationship of indicators and determine the indicator reliability. The statistical significance of the external loads of all indicators is demonstrated by the probability of error p, which must be below the critical threshold. The construct must explain at least 50% of the variance of each indicator, therefore the standardised external loads must exceed 0.708, which is equal to the root of 0.50. This means that the outer load of the indicator should exceed 0.708, since the square of this number is 0.50 (in practice, 0.70 is acceptable). According to Table 2, the outer loads are higher than 0.70 for all constructs (except for the R indicator for the E construct), which indicates that the outer loads of the indicators are quite high. At the same time, the statistical significance is very high ($p < 0.001$, which is significantly less than the 5% significance level). When the probability of measurement error p is less than the significance level, the result is significant since the measurement cannot be neglected in this case.

A common measure for establishing convergent confidence at the model building level is the AVE, which can be defined as the sum of the squares of the loads divided by the number of indicators. Therefore, AVE is tantamount to generality of construction. According to Table A4, the AVE converged confidence exceeds 0.50 for all three constructs (0.803, 0.895 and 0.886).

Discriminant validity demonstrates the differences of this construct from other constructs. Three dimensions of discriminant confidence can be used. The first method for assessing discriminant validity is the heterotrait-to-monotrait (HTMT) ratios. These ratios are proposed for assessing discriminant validity using modern algorithms that evaluate various factors. If the calculated indicator is less than 0.85, then we can assert about the discriminant reliability of the measurement. According to row 3 of Table A4, this criterion is met, except for the relationship between S and E, which is not significant from measurement error perspective (the 5% significance level is exceeded). The second approach is to study the cross-loadings of indicators. In particular, the combined outer load of the indicator on the associated construct should be greater than all of its loads on other constructs (i.e., cross-loads). According to Table 2, the combined outer load for all structural indicators exceeds the cross-load. The third method is the Fornell-Larcker test, which compares the square root of AVE values with the correlations of other latent variables. The square root of the AVE of each construct must exceed the correlation with any other construct since the construct shares more of the variance with its associated indicators than with the indicators of other constructs. According to Table 3, the diagonal elements of the matrix (square roots from the AVE) do outperform correlations with any other construct.

Table 3 Correlations and its *p*-values among latent variables

Correlations (p-values)	*Educati*	*Science*	*Busines*
Educati	0.803 (1.000)	0.723 (< 0.001)	–0.276 (0.126)
Science	0.723 (< 0.001)	0.895 (1.000)	–0.432 (0.014)
Busines	–0.276 (0.126)	–0.432 (0.014)	0.886 (1.000)

Note: Square root of AVEs shown on diagonal.

If the level of collinearity is high (as indicated by a VIF value > 5), consider removing one of the corresponding indicators. However, this requires that the remaining indicators adequately reflect the content of the construct from a theoretical point of view. Building a higher-order construct or combining collinear indicators into one (new) composite indicator, for example, using their means, weighted average, or factor estimates, are other options for solving collinearity problems. According to Table A4, the VIF values do not exceed the critical value 5 (2.103, 2.387 and 1.233).

The estimates of the structural relationships of the model (path coefficients β) represent the assumed relationships between the constructs. Path coefficients have standardised values from –1 to +1. Values close to +1 represent strong positive relationships (and vice versa for negative values). The closer the estimated coefficients are to 0, the weaker the relationship. An assessment of the significance of the relationship of constructs E and S with the path coefficient for sample sizes over 30 is given by the following formula:

$$t = \frac{p_{ES}}{se^{*}_{p_{ES}}}$$

where the original travel coefficient estimate (p_{ES}) and the bootstrap standard error $se^{*}_{p_{ES}}$ are used. The bootstrap method refers to the methods of numerical enumeration of the sample, the purpose of which is to construct the distribution of the sample estimate of the desired parameter and refine its properties. It is a further development of the so-called jack-knife method, which is named so because, as a universal method, it replaced many of the private methods that existed at that time (Turkey, 1958). The idea behind the bootstrap is to analyse many phantom samples (up to 5,000 or more), randomly selected from the available sample (Efron, 1979). Bootstrap is a modification of the Monte Carlo method. When the empirical value of t is greater than the critical value, we say that the coefficient is significant at a certain probability of error (i.e., at the level of significance). Bootstrap calculations are performed for a certain level of significance (for example, $\alpha = 5\%$). Additionally, there are p-values that are path measurement errors. If $p < \alpha$, then the value of the path is significant since the measurement error is less than the significance level. If the path measurement error is less than the significance level, the null hypothesis cannot be rejected, which assumes that the computed paths are significant. If the measurement error p is greater than the significance level α, then these measurements should not be trusted.

Commonly used critical values for two-sided tests are 1.65 (10% significance level), 1.96 (5% significance level) and 2.57 (1% significance level). The choice of significance level depends on the field of study and the purpose of the study. Instead of t values, p-values are often reported, which correspond to the probability of erroneously rejecting the null hypothesis given the available data. In addition to calculating the t and p-values, the bootstrap t-confidence interval for a predetermined error probability can be determined. The confidence interval for p_{ES} is given by:

$$p_{ES} \pm z_{1-\alpha/2} \cdot se^{*}_{p_{ES}}$$

where $z_{1-\alpha/2}$ is found from the normal (z) distribution table. For example, when the probability of error is 5% (i.e., $\alpha = 0.05$), $z_{1-\alpha/2} = z_{0.975} = 1.96$. Thus, the lower bound of the confidence interval is $\overline{p}_{ES} - 1.96 \cdot se^{*}_{p_{ES}}$ and the upper bound is $\overline{p}_{ES} + 1.96 \cdot se^{*}_{p_{ES}}$. When interpreting the results of the path model, it is necessary to check the significance of all relationships of the structural model. When reporting the results, the empirical t-value, the p-value, or the bootstrap t-confidence interval is checked. It is often unnecessary to report all three types of significance test results as they all lead to the same conclusion. Indeed, according to Table A4 (line 9):

- *t*-values are 5.807 (E → S), –3.293 (S → B), and –3.969 (B → E): All values are significant because their modules exceed the critical value of the two-sided test 1.96.
- The values of the path coefficients of the structural model p_{ES} and p_{BE} are significant, since their error probabilities are less than 0.001, which does not exceed the significance level of 0.05.
- Confidence intervals (0.480, 0.969) (E → S), (–0.742, –0.188) (S → *B*) and (–0.808, –0.274) (B → E) with an error probability $\alpha < 5\%$: Values of all coefficients paths of the structural model are significant, since zero does not fall within the confidence interval at the 5% significance level.

A sample size of 32 (> 30) allows this criterion to be trusted.

The path coefficients of the structural model can be interpreted relative to each other. If one path coefficient is greater than the other, its effect on the endogenous latent variable is greater. If the path coefficient is statistically significant ($p < \alpha = 5\%$), its value indicates the degree to which the exogenous construct is associated with the endogenous construct. According to Table 4, $p_{ES} = 0.725$, $p_{BE} = -0.541$, $p_{SB} = -0.465$, which means the effect of education on science is very large and positive, while the effect of business on education is noticeable and negative, and the influence of science on business is also noticeable and negative. Thus, business in this system is an alien element and its development only oppresses education and science.

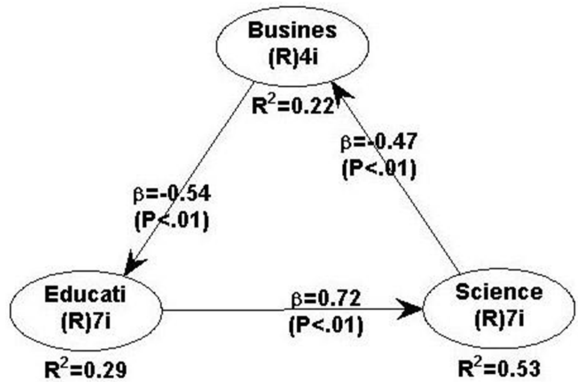
Table 4 Path coefficients for latent variables

Path coef.	*Educati*	*Science*	*Busines*	*se*	R^2
Educati			–0.541	0.136	0.293
Science	0.725			0.125	0.525
Busines		–0.465		0.141	0.217
p	< 0.001	0.001	< 0.001		

Note: APC = 0.577 ($p < 0.001$), ARS = 0.345 ($p = 0.007$), AARS = 0.323 ($p = 0.010$) and AFVIF = 1.908.

The most used indicator when evaluating a structural model is called the coefficient of determination (R^2 values). This coefficient is a measure of the predictive accuracy of the model and is calculated as the square of the correlation between the actual and predicted values of a particular endogenous construct. The coefficient is the cumulative effect of exogenous latency variables on endogenous latent variables. Since the coefficient is the square of the correlation between actual and predicted values, it represents the amount of variance in an endogenous construct attributable to all exogenous constructs associated with it. The R^2 value ranges from 0 to 1, with higher levels indicating higher levels of forecast accuracy. An $R^2 = 0.20$ is considered high in disciplines such as consumer behaviour, while much higher values are expected in research on success factors: 0.75 and above. For example, in marketing literature, R^2 values of 0.75, 0.50, or 0.25 for endogenous latency variables can, as a rough rule of thumb, be respectively described as substantial, medium, or weak (Hair et al., 2014). In Figure 2, we see that for education the forecast accuracy of the model $R^2 = 0.29$ is estimated as weak, for science $R^2 = 0.53$ – medium, and for business $R^2 = 0.22$ – weak.

Figure 2 Model of university



Note: Educati – education, Science – science and Busines – business.

As with multiple regression, the adjusted R^2_{adj} helps to avoid bias against complex models. This criterion varies depending on the number of exogenous constructs relative to the sample size. The quantity R^2_{adj} is formally defined as

$$R^2_{adj} = 1 - (1 - R^2) \cdot \frac{n-1}{n-k-1}$$

where n is the sample size and k is the number of exogenous latent variables used to predict the endogenous latent variable under consideration. The value of R^2_{adj} reduces the value of R^2 by the number of predictor constructs and the sample size, and thus systematically compensates for the addition of non-essential exogenous constructs simply to increase the explained variance of R^2. In Table A4, for education, the forecast accuracy of the model $R^2_{adj} = 0.269$ is estimated as weak, for science $R^2_{adj} = 0.509$ – medium, for business $R^2_{adj} = 0.190$ – weak, which confirms the estimates of the forecast accuracy for R^2.

In addition to estimating the value of R^2 values, Q^2, an indicator of the predictive relevance of the model, can be used as a criterion for forecast accuracy (Hair et al., 2014). In the structural model, Q^2 values greater than zero for reflecting endogenous latent variable indicate the predictive value of the pathway model for this construct. The Q^2 value is obtained using a blind check procedure, a sample reuse technique that skips every pre-set data point in endogenous construct indicators and estimates parameters with the remaining data points (Hair et al., 2014). This is an iterative process that repeats until every data point is skipped and the model is revaluated. The blinded procedure applies only to endogenous constructs of the reflective dimension model, as well as to endogenous single-element constructs. The Q^2 values estimated using the blind test procedure is a measure of how well the track model can predict the initially observed values. In Table A4, we see that for education, the forecast accuracy of the model

$Q^2 = 0.277$ is estimated as weak, for science $Q^2 = 0.533$ – medium, for business $Q^2 = 0.214$ – weak. On the other hand, all values are positive, which indicates a generally satisfactory forecast accuracy.

Model fit indicators are satisfactory according to the following indices: average path coefficient (APC) = 0.577 ($p < 0.001$), average R-squared (ARS) = 0.345 ($p = 0.007$), average adjusted R-squared (AARS) = 0.323 ($p = 0.010$), and average full collinearity VIF (AFVIF) = 1.908. The internal models were analysed using the Warp3 nonlinearity algorithm.

4.2 Mining enterprises

The main factor influencing the innovative activity of enterprises is not only the amount of attracted investments and the use of new technologies in industry, but also human capital. An innovative way of development requires the preparation of better-quality labour resources, new approaches to the training of personnel, both working specialties and management personnel, capable of introducing advanced experience, increasing the competitiveness of the economy of the region and Kazakhstan. Universities play a key role in training and retraining of personnel for enterprises. In addition, the scientific sphere of educational institutions contributes to innovative developments and their implementation in production activities.

The state and universities, of course, are making efforts to bring education, science and business closer together. One of these activities is the Atlas of New Professions Initiative (2021), which, along with other sectors of the economy, studied the country's mining and metallurgical complex, including geological exploration, mining, beneficiation, and production of primary products of ferrous and non-ferrous metallurgy. The issues of ecology and waste processing of the extractive industry were also considered.

The biggest changes are taking place in the field of equipment maintenance. Businesses strive to minimise breakdowns and equipment downtime. Businesses are adopting predictive analytics and lean repair and maintenance practices. Approaches to managing the economy of full cycle equipment are introduced. Enterprises are actively implementing digital solutions: the transition to remote control, the use of drones, as well as the work of collecting and processing big data. The eyes of workers will be sensors installed in mines and production halls, and engineers will be assisted in making decisions by data scientists and machine learning specialists. Robots and machines will work in difficult and dangerous areas, which will be controlled by operators from a safe office.

According to the Atlas, the specialists of the future will have to solve many problems to reduce the harmful effects of mining and smelting metals. Waste from the mining and metallurgical complex contains precious metals and other useful materials and can become a raw material for manufacturing. Careers that have exhausted their potential, waste heaps, empty industrial premises of closed mines and workshops will turn into objects of industrial tourism, recreation centres, storage facilities, will become scenery for films and will perform a lot of other useful functions. Companies will have to actively create internal social networks at enterprises, introduce elements of gamification in building individual career plans for employees. The concept of designing single-industry towns, where mining and metallurgical enterprises usually operate, will also change.

Considering the activity of enterprises in the mining industry in Kazakhstan, we studied enterprises engaged in exploration and mining in the regions of Kazakhstan from Table 1. The aggregate sample consisted of 41 datasets, which is more than 30, and allowed for a full analysis.

Composite reliability is higher than 0.87 according to Table A5. Composite reliability scores in Table A5 do not exceed 0.95, suggesting that multicollinearity is not a concern for these constructs.

As for the convergent validity, i.e., the degree of positive correlation of one dimension with alternative dimensions of the same construct, then, according to Table 7, the AVE values are higher than 0.70 for all constructs, which indicates that the outer loadings of the indicators are quite high. At the same time, the statistical significance is very high ($p < 0.001$).

According to Table 5, the combined outer load for the structural indicators (indicated in italic) exceeds the cross-load. According to Table 6, the diagonal elements of the matrix (square roots of the AVE) exceed correlations with any other construct except the correlation between P and C (0.809), which exceeds the AVE for C (0.755).

Table 5 Combined loading and cross-loadings with standard errors, *p*-values and VIFs (firms)

Indicator	*Variables*			*SE*	*p-value*
	Capital	*Innovat*	*Product*		
Innovat	0.136	*0.947*	–0.253	0.104	< 0.001
N_F_Uni	–0.203	*0.735*	–0.008	0.114	< 0.001
IP	0.023	*0.890*	0.276	0.107	< 0.001
Workers	*0.874*	–0.405	0.247	0.108	< 0.001
N_F	*0.364*	–0.768	–0.347	0.134	0.005
Distanc	*0.893*	0.517	0.099	0.107	< 0.001
N_Reg	*0.497*	0.166	–0.765	0.126	< 0.001
Mine	*0.954*	0.094	0.212	0.104	< 0.001
N_Reg_F	–0.277	0.082	*0.860*	0.108	< 0.001
N_Uni_F	0.080	0.205	*0.921*	0.106	< 0.001
Project	0.282	0.573	*0.770*	0.113	< 0.001
Income	–0.051	–0.347	*0.939*	0.105	< 0.001
Taxes	–0.005	–0.426	*0.879*	0.108	< 0.001
α	0.777	0.822	0.923		
VIF	1.092	1.026	1.105		

Notes: Capital = capital, Innovat = innovations and Product = productivity.

Table 6 Correlations among latent variables (firms)

Correlations (p-values)	*Capital*	*Innovat*	*Product*
Capital	0.755 (1.000)	0.713 (< 0.001)	0.809 (< 0.001)
Innovat	0.713 (< 0.001)	0.862 (1.000)	0.787 (< 0.001)
Product	0.809 (< 0.001)	0.687 (< 0.001)	0.876 (1.000)

Note: Square root of AVEs shown on diagonal.

Table 7 Path coefficients for latent variables

Path coef.	*Capital*	*Innovat*	*Product*	*se*	R^2
Capital			0.852	0.109	0.726
Innovat	0.789			0.112	0.622
Product		0.825		0.110	0.681
p	< 0.001	< 0.001	< 0.001		

Notes: APC = 0.822 ($p < 0.001$), ARS = 0.676 ($p < 0.001$), AARS = 0.668 ($p < 0.001$) and AFVIF = 2.885.

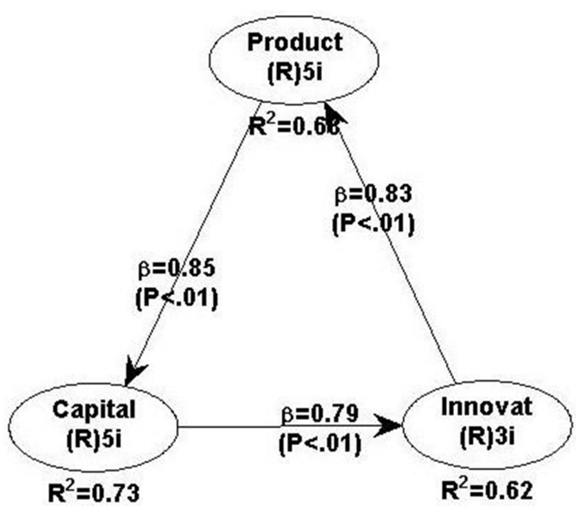
Regarding the level of collinearity, Table A5 for all three constructs gives satisfactory VIF values (3.348, 2.188, 3.317), which indicates the absence of multicollinearity.

According to Table A5, *t*-values are 7.058 (to I), 7.504 (to P), 7.831 (to C), confidence intervals are (0.570, 1.088), (0.610, 1.041) and (0.639, 1.065), respectively for constructs C, I, P at a significance level of $\alpha < 5\%$. Since the boundaries of the confidence intervals are positive, 0 does not fall within the confidence intervals, hence all path coefficients are significant.

The path coefficients of the structural model can be interpreted relative to each other. According to Table 7, $p_{PC} = 0.852$, $p_{CI} = 0.789$, $p_{IP} = 0.825$, i.e., productivity has the maximum impact on capital, and capital has the minimum impact on innovation. Nevertheless, the absolute values of the coefficients are quite high.

Figure 3 shows that for productivity, the estimate of the forecast accuracy of the model is $R^2 = 0.68$ (substantial), for capital $R^2 = 0.73$ (substantial), for innovation $R^2 = 0.62$ (medium).

Figure 3 Model of firm



Note: Capital – capital, Innovat – innovations and Product – productivity.

As with multiple regression, the adjusted R^2_{adj} can be used as a criterion to avoid bias against complex models. In Table A5, for productivity, the estimate of the forecast accuracy of the model is $R^2_{adj} = 0.673$ (substantial), for capital $R^2_{adj} = 0.719$ (substantial), for innovation $R^2_{adj} = 0.612$ (medium), which is the same as the data for R^2.

In Table A5, we see that for productivity the estimate of the forecast accuracy of the model is $Q^2 = 0.633$ (substantial), for capital $Q^2 = 0.713$ (substantial), for innovation $Q^2 = 0.621$ (medium). On the other hand, all values are positive, which indicates a generally satisfactory forecast accuracy.

4.3 Region

The economic development of the region is influenced not only by specialisation, economic activity of enterprises and government bodies, but also by investment attractiveness and innovative development. The innovation potential of the region was calculated using the following keywords: budget/'local government', project, services. In addition to innovative activity, the development of the regional economy is influenced by the effective use of resource potential: minerals, labour resources, operating enterprises, introduction of innovative technologies and scientific developments in the production process, the level of qualifications of workers involved in the industry, and the adequacy of financial capital. To calculate the resource potential, we used the following keywords: technology, capital and personnel.

Composite reliability is higher than 0.88 according to Table A6. In the case of growth, this value exceeds 0.95 (0.978), which suggests that the indicators of this construct are overly consistent. This is true since the N_IP and N_RP indicators are essentially the same thing.

Convergent validity: AVE in Table A6 above 0.50 – for G is 0.929, for I is 0.808, and for C is 0.669. Thus, the outer loads of indicators are quite large.

According to Table 8, the combined outer load for the structural indicators (indicated in italic) exceeds the cross-loads. Fornell-Lancker test: according to Table 9, the diagonal elements of the matrix (square roots of the AVE) outperform correlations with any other construct.

According to Table A6, VIF indices do not exceed the critical value 5 (1.245, 1.438, 1.205), which indicates that there is no multicollinearity.

The coefficients of the paths of the structural model are statistically significant ($p < \alpha = 5\%$), and according to Table 10 $p_{IC} = 0.520$, $p_{CG} = -0.586$, $p_{GI} = 0.585$, i.e., changes for growth. The absolute values of the coefficients are large enough and approximately the same.

In Figure 4, we see that all constructs are characterised by poor model prediction accuracy: for growth $R^2 = 0.34$, for institutions $R^2 = 0.34$, and for innovation $R^2 = 0.27$.

As with multiple regression, the adjusted R^2_{adj} can be used as a criterion to avoid bias against complex models. In Table A6, the estimate of the predictive accuracy of the model for growth is $R^2_{adj} = 0.303$ (weak), for institutions $R^2_{adj} = 0.302$ (weak), for changes $R^2_{adj} = 0.225$ (weak), which practically repeats the data for R^2.

In Table A6, we also observe weak forecast accuracy: the estimate of the model's predictive accuracy for growth is $Q^2 = 0.342$, for institutions $Q^2 = 0.344$, and for changes $Q^2 = 0.275$. All values are greater than zero, which indicates, albeit weak, but quite acceptable overall forecast accuracy.

Table 8 Combined loading and cross-loadings with standard errors, *p*-values and VIFs (regions)

Indicator	*Variables*			*SE*	*p-value*
	Institu	*Changes*	*Growth*		
S	–0.367	*0.651*	–0.223	0.155	< 0.001
GS	0.427	*0.525*	0.003	0.168	0.003
SB	–0.169	*0.489*	–0.229	0.172	0.006
GSB	0.307	*0.816*	0.279	0.140	< 0.001
G	–0.049	*0.576*	–0.107	0.163	0.001
B	–0.143	*0.864*	0.104	0.136	< 0.001
N_IP	0.100	–0.159	*0.979*	0.126	< 0.001
N_RP	–0.100	0.159	*0.979*	0.126	< 0.001
L	*0.723*	–0.178	0.261	0.148	< 0.001
TC	*0.628*	–0.251	–0.545	0.158	< 0.001
CL	*0.918*	0.048	–0.058	0.131	< 0.001
TCL	*0.921*	0.263	0.224	0.131	< 0.001
α	0.812	0.737	0.956		
VIF	1.245	1.438	1.205		

Note: Institu = institutes, Changes = Changes and Growth = growth.

Table 9 Correlations among latent variables (regions)

Correlations (p-values)	*Institu*	*Changes*	*Growth*
Institu	*0.808* (1.000)	0.404 (0.097)	0.024 (0.925)
Changes	0.404 (0.097)	*0.669* (1.000)	–0.367 (0.134)
Growth	0.024 (0.925)	–0.367 (0.134)	*0.979* (1.000)

Note: Square root of AVEs shown on diagonal.

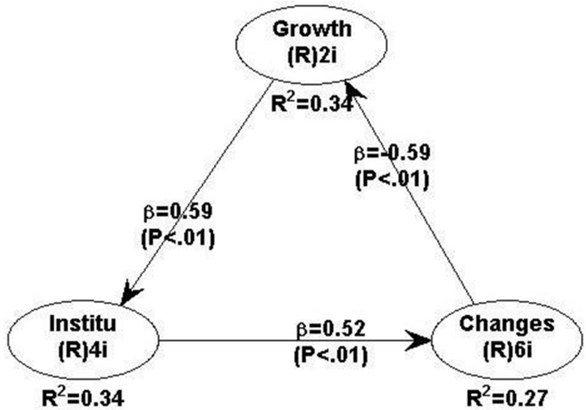
Table 10 Path coefficients for latent variables (regions)

Path coef.	*Institu*	*Changes*	*Growth*	*se*	R^2
Institu			0.585	0.129	0.626
Changes	0.520			0.123	0.766
Growth		–0.586		0.124	0.732
p	0.003	0.001	0.001		

Note: APC = 0.584 ($p < 0.001$), ARS = 0.319 ($p = 0.029$), AARS = 0.276 ($p < 0.045$) and AFVIF = 1.296.

We are not discussing compliance with the t-value criteria here, since the sample size (18) is significantly less than 30 and these data do not allow us to draw reliable conclusions.

Figure 4 Model of regions



Note: Institu – institutes, Changes – changes and Growth – growth.

5 Discussion

There is some scepticism about webometric data, since the number of pages opened on websites is not constant. Search engines at different times can give different results, although our experience in webometric research suggests that this technique provides interesting and characteristic data for a particular research object. Structural equation modelling provides an excellent opportunity to test the webometric approach for the reliability of internal consistency, convergent validity, discriminant validity, multicollinearity, path significance, and predictiveness of the model. Table 11 summarises the results presented in Tables A4–A6.

Table 11 Sum results of models' testing

	Composite reliability	*Convergent validity*	*Discriminant validity*	*Collinearity*	*Significance of path coefficients*	*Predictive relevance (validity)*
Universities	4/6	19/20	8/9	6/6	3/3	3/9
Firms	6/6	12/14	5/9	6/6	3/3	9/9
Regions	4/6	9/14	9/9	6/6	3/3	0/9

The results show a generally good quality of the models, except for the weak predictability of the structural model of the regions (Table A6, lines 6–8). There is also a slightly reduced reliability of the internal consistency (composite reliability) of the structural model of universities and regions, which may be cause by indicator variables measuring the same phenomenon. On the other hand, this does not lead to collinearity.

Figures 2–4 display that the constructs are related to each other. Path coefficients β are essentially multivariate regression coefficients calculated by the least square's method. The meaning of the coefficient is how the construct changes under the influence of the neighbouring construct from which the arrow (path) is drawn. Since the values are standardised, the coefficients do not exceed 1. The negative sign of the coefficient indicates that the impact weakens the construct, while the positive sign enhances it.

Using our modification of the triple helix model – the principle of three Rs (resources-reforms-result) – we can assess the overall effect of the interaction of the three constructs for each of the research subjects.

Table 12 Sum effect of 3R

	Resource-reform	*Reform-result*	*Result-resource*	*Sum effect*
Universities	0.72	–0.47	–0.54	–0.29
Firms	0.79	0.83	0.85	2.47
Regions	0.52	–0.59	0.59	0.52

In the case of universities, there is a positive relationship between resources and reform. Resources strengthen the reforms, and significantly (0.72). Reforms weaken the result (–0.54). Result affects resources to the same extent (–0.47). The overall effect is negative (–0.29). There is no synergy between constructs. It also reflects the fact why universities in Kazakhstan need continuing state support. Our results are in part consistent with the findings reported by García-Aracil and Palomares-Montero (2012) and De La Torre et al. (2017), who suggested that there is a negative relationship between learning (resources) and entrepreneurship (result), but there is a positive relationship between research (reforms) and entrepreneurial initiatives (result).

Result is the third mission of the university. Compagnucci and Spigarelli (2020) noted that any coherent methodology for assessing the third mission of the university and its impact on external stakeholders are absent, because the measurement systems are inadequate, underdeveloped, and usually do not allow to assess the success of the university in implementing the third mission initiatives. Our result assessment methodology shows a possible way to assess the third mission of the university.

In the case of firms, we see a much more mutually reinforcing relationship between constructs. The greatest effect is demonstrated by the impact of result on resources (0.85), the smallest (however significant) effect is the impact of resources on reforms. At the same time, firms have a large sum effect (2.47).

Regions have an intermediate cumulative effect (0.53). In this case, the maximum impact occurs along the line result-resources (0.59), which is completely neutralised by the negative impact of the reforms on result (–0.59). The positive influence of resources on reforms is approximately the same in absolute value (0.52).

Why is the situation for universities so dramatically different from that of firms and regions? Firms are in a competitive environment and problems with the profitability of their work often lead them to bankruptcy. Universities are mostly (especially in countries like Kazakhstan) supported by government funding and are more stable in this regard. Accordingly, the construct result (in the case of universities, this is business) is not natural for our universities and is supported by universities often formally as a response to the modern requirements of the state and society. Therefore, extraordinary approaches are needed to stimulate the transition of universities to modern forms of activity.

One of such mechanisms functioning in the country is the territorial cluster. A cluster, according to the definition of Porter (1998), is a group of interconnected companies, specialised suppliers, service organisations, firms from related industries and associated institutions in a particular area, concentrated in a certain area, which both compete and cooperate with each other. In Kazakhstan, the cluster approach is carried out in accordance with the Concept for the Formation of Promising National Clusters (Resolution of the Government of the Republic of Kazakhstan, 2013). The concept says that "… universities become the nucleus of new generation clusters, around which a belt of small innovative enterprises and start-ups is being formed."

The university alone can hardly become an important element of the ecosystem of the region; for this to occur it needs to cooperate effectively with other actors of the ecosystem. The creation of a mining cluster around a university with mining majors can help multiply collaborative efforts. Public-private partnership, which is often used in Kazakhstan, can be used as one of the effective mechanisms for this (see, for example, Sadykov and Myrzakhmet, 2012; Tastulekov et al., 2019).

Nowadays, the situation in the technology and economic appraisal of the mining industry offers many opportunities for challenging and interesting research and improvement across the entire spectrum of mining (Runge, 2017). Currently, the mining industry is entering the efficiency and cost reduction regime from the previous period of expansion. Smart use of technology, coupled with more robust assessment processes, can make a large difference in this environment. Small changes can lead to efficiency gains that lead to large economic improvements. Revising all aspects of mine operations to regulate operations (often referred to as debottlenecking) can yield high margins for relatively little additional investment. Connecting universities to mining and the accompanying processes within the framework of the creation of regional clusters can significantly change the type and role of the mining industry.

6 Conclusions

We have explored universities, businesses, and regions from the perspective of the triple helix model. The triple helix arises from interactions between representatives of different institutional spheres, each of which contributes to solving a common problem by inventing a new organisational format. The triple helix as a methodology works at the macro level of the region as well as at the micro level in relation to specific topics such as sustainability (Zhou and Etzkowitz, 2021).

The weakest link in Kazakhstan's university-enterprise-region chain is the universities. This chain is poorly balanced in relation to business: though to a smaller extent, science does cooperate with education, while business in universities remains an alien element and does not generate income on its own. The university is still a dependent part of the region's economy and needs a substantial support from the public. Consequently, in a triple helix, the state, represented by regional authorities, and business, represented by large enterprises, can act in an appropriate organisational format to gradually strengthen local universities so that they become a stronger and more stable institutional sphere.

Regional universities should strengthen their structural flexibility including cooperation of their divisions and establish broad collaborations to train professional personnel for the mining industry. The training of such personnel with systemic knowledge in the field of innovative development and skills in the commercialisation of technologies is not yet sufficiently developed. Moreover, regional universities, enterprises, and regional authorities should consider establishing closer ties within the framework of dual education and creation of regional clusters around universities. The supporting centres of regional clusters in the mining industry can be universities with mining specialties, which have trained personnel for the region's enterprises for several decades. The involvement of universities in mining and the accompanying processes within such a cluster will significantly change the type and role of the regional industry, which, as a result, will become a factor in the economic growth of the region.

In the case of firms, we see a much more mutually reinforcing relationship between constructs. Firms are in a competitive environment and problems with profitability often lead them to bankruptcy. Smart use of technology, coupled with more robust assessment processes, can make a big difference in this environment. Small changes can lead to efficiency gains that translate into economic improvement.

Revising all aspects of mine operations to regulate operations can yield high margins for relatively little additional investment. Connecting universities to mining and the accompanying processes within the framework of the creation of regional clusters can significantly change the type and role of the mining industry.

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Appendix

Tables A1–A3 show latent variables (constructs) and indicators reflecting them. Indicators represent numerically the number of pages opened for a given set of keywords, or data from sources (e.g., national statistics).

Table A1 Universities: keywords

Indicator	*Variables*		
	Educati	*Science*	*Busines*
S (science)		*Science*	
ES		*Education + science*	
EB		*Education + business*	
SB		*Science + busivess*	
E (education)		*Education*	
B (business)		*Business*	
ESB		*Education + science + business*	
D (degree)	*Master's*		
S_(staff)	*Professor*		
R (room)	*Faculty*		
DS	*Master's + professor*		
DR	*Master's + faculty*		
SR	*Professor + faculty*		
DSR	*Master's + professor + faculty*		
Income			(From national statistics)
N_IP			Total pages on website (when IP is measured)
N_EP			Total pages on website (when EP is measured)
Workers			(From national statistics)

Note: Keywords in italic.

Table A2 Firms: keywords

Indicator	*Variables*		
	Capital	*Innovat*	*Product*
Innovat		*Innovation*	
N_F_Uni		Popularity of university on firm website	
IP		Innovation potential	
Workers	(From national statistics)		
N_F	Number of pages on firm website		

Note: Keywords in italic.

Table A2 Firms: keywords (continued)

Indicator	Variables		
	Capital	*Innovat*	*Product*
Distanc	*Distance*		
N_Reg	Number of pages on region website		
Mine	*Mine*		
N_Reg_F			Popularity of firm on region website
N_Uni_F			Popularity of firm on university website
Project			*Project*
Income			(From national statistics)
Taxes			(From national statistics)

Note: Keywords in italic.

Table A3 Regions: keywords

Indicator	Variables		
	Institu	*Changes*	*Growth*
S (science)		*Project*	
GS		*Local government + services*	
SB		*Project + services*	
GSB		*Local government + project + services*	
G (local government)		*Local government*	
B (business)		*Services*	
N_IP			Total pages on website (when IP is measured)
N_RP			Total pages on website (when RP is measured)
L(labour)	*Personnel*		
TC	*Technology + capital*		
CL	*Capital + labour*		
TCL	*Technology + capital + labour*		

Note: Keywords in italic.

Tables A4–A6 contain the results of simulations carried out using the WarpPLS software package.

Table A4 Results of calculation for universities and their compliance with criteria

N	*Index*	*Criterion*	*Latent variables*		
			E	*S*	*B*
1	Composite reliability	> 0.708	0.925	0.966	0.936
	Cronbach's alpha	0.70–0.90; < 0.95	0.901	0.958	0.909
2	Indicator's outer loadings	> 0.708	Yes for 6 from 7 (except for R)	Yes for 7	Yes for 4
	Convergent validity AVE	> 0.50	0.803	0.895	0.886
3	Discriminant validity	HTMT ratios (good if < 0.90, best if < 0.85)	0.311 ($p < 0.001$; to B)	0.783 ($p = 0.092$; to E)	0.462 ($p < 0.001$; to B)
	Indicator's outer (combined) loadings	> Cross-loadings	Yes	Yes	Yes
	Fornell-Larcker criterion	$\sqrt{AVE} >$ correlation with other constructs	Yes	Yes	Yes
4	Collinearity	Predictor construct's tolerance TOL = 1 / VIF > 0.20	0.48	0.42	0.81
	Full collinearity VIFs	VIF < 5	2.103	2.387	1.233
5	Path coefficients		0.725 (to S)	–0.465 (to B)	–0.541 (to E)
	Significance of path coefficients	$p < \alpha = 5\%$	< 0.001 (to S)	= 0.001 (to B)	< 0.001 (to E)
6	R^2-coefficients	0.75, 0.50 or 0.25 (significant, moderate and weak)	0.293	0.525	0.217
7	R^2_{adj} -coefficients	0.75, 0.50 or 0.25 (significant, moderate and weak)	0.269	0.509	0.190
8	Predictive relevance (validity)	$Q^2 > 0$	0.277	0.533	0.214
9	T ratios for path coefficients	The critical value (two-tailed test) is 1.960 for confidence level 0.95 ($\alpha = 5\%$)	5.807 (to S)	–3.293 (to B)	–3.969 (to E)
	p for confidence	$p < \alpha = 5\%$	< 0.001 (to S)	< 0.001 (to B)	< 0.001 (to E)
	Confidence intervals	If 0 falls into the interval, then the corresponding path coefficient is insignificant	[0.480, 0.969] (to S)	[–0.742, –0.188] (to B)	[–0.808, –0.274] (to E)
	Composite reliability	> 0.708	0.925	0.966	0.936

Notes: Sample size is 32.
E – education, S – science and B – business.

Table A5 Results of calculation for firms and their compliance with criteria

N	*Index*	*Criterion*	*Latent variables*		
			C	*I*	*P*
1	Composite reliability	> 0.708	0.856	0.896	0.942
	Cronbach's alpha	0.70–0.90; < 0.95	0.777	0.822	0.923
2	Indicator's outer loadings	> 0.708	Yes for 5	Yes for 2 from 3 (except for P)	Yes for 2 from 3 (except for I)
	Convergent validity AVE	> 0.50	0.755	0.862	0.876
3	Discriminant validity	HTMT ratios (good if < 0.90, best if < 0.85)	0.893 (to P) $p = 0.239$	0.869 (to C) $p = 0.189$	0.789 (to P) $p = 0.074$
	Indicator's outer (combined) loadings	> Cross-loadings	Yes	Yes	Yes
	Fornell-Larcker criterion	$\sqrt{AVE} >$ correlation with other constructs	No	Yes	Yes
4	Collinearity	Predictor construct's tolerance TOL = 1 / VIF > 0.20	0.299	0.457	0.301
	Full collinearity VIFs	VIF < 5	3.348	2.188	3.317
5	Path coefficients		0.789 (to I)	0.825 (to P)	0.852 (to C)
	Significance of path coefficients	$p < \alpha = 5\%$	< 0.001 (to I)	< 0.001 (to P)	< 0.001 (to C)
6	R^2-coefficients	0.75, 0.50 or 0.25 (significant, moderate and weak)	0.726	0.622	0.681
7	R^2_{adj} -coefficients	0.75, 0.50 or 0.25 (significant, moderate and weak)	0.719	0.612	0.673
8	Predictive relevance (validity)	$Q^2 > 0$	0.713	0.621	0.633
9	T ratios for path coefficients	The critical value (two-tailed test) is 1.960 for confidence level 0.95 ($\alpha = 5\%$)	7.058 (to I)	7.504 (to P)	7.831 (to C)
	p for confidence	$p < \alpha = 5\%$	< 0.001 (to I)	< 0.001 (to P)	< 0.001 (to C)
	Confidence intervals	If 0 falls into the interval, then the corresponding path coefficient is insignificant	[0.570, 1.088] (to I)	[0.610, 1.041] (to P)	[0.639, 1.065] (to C)

Notes: Sample size is 41.
C – capital, I – innovations and P – productivity.

Table A6 Results of calculation for regions and their compliance with criteria

N	*Index*	*Criterion*	*Latent variables*		
			I	*C*	*G*
1	Composite reliability	> 0.708	0.880	0.822	0.978
	Cronbach's alpha	0.70–0.90; < 0.95	0.812	0.737	0.956
2	Indicator's outer loadings	> 0.708	Yes for 3 from 4	Yes for 2 from 6	Yes
	Convergent validity AVE	> 0.50	0.808	0.669	0.929
3	Discriminant validity	HTMT ratios (good if < 0.90, best if < 0.85)	0.459 (to G) $p = 0.002$	0.561 (to I) $p = 0.012$	0.290 (to G) $p < 0.001$
	Indicator's outer (combined) loadings	> Cross-loadings	Yes	Yes	Yes
	Fornell-Larcker criterion	$\sqrt{AVE} >$ correlation with other constructs	Yes	Yes	Yes
4	Collinearity	Predictor construct's tolerance TOL = 1 / VIF > 0.20	0.80	0.70	0.83
	Full collinearity VIFs	VIF < 5	1.245	1.438	1.205
5	Path coefficients		0.520 (to C)	–0.586 (to G)	0.585 (to I)
	Significance of path coefficients	$p < \alpha = 5\%$	0.003 (to C)	0.001 (to G)	0.001 (to I)
6	R^2-coefficients	0.75, 0.50 or 0.25 (significant, moderate and weak)	0.343	0.270	0.344
7	R^2_{adj} -coefficients	0.75, 0.50 or 0.25 (significant, moderate and weak)	0.302	0.225	0.303
8	Predictive relevance (validity)	$Q^2 > 0$	0.344	0.275	0.342
9	T ratios for path coefficients	The critical value (two-tailed test) is 1.960 for confidence level 0.95 ($\alpha = 5\%$)	3.078 (to C)	–3.623 (to G)	3.614 (to I)
	p for confidence	$p < \alpha = 5\%$	0.003 (to C)	0.001 (to G)	0.001 (to I)
	Confidence intervals	If 0 falls into the interval, then the corresponding path coefficient is insignificant	[0.189, 0.851] (to C)	[–0.904, –0.269] (to G)	[0.268, 0.903] (to I)

Notes: Sample size is 18.
I – institutes, C – changes and G – growth.