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Economic Effects of Innovation Diffusion and Knowledge Spillover in a Digital Society

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ABSTRACT

In the context of increasing regional differentiation and the digital transformation of the economy, there is a growing need to quantify the factors driving regional economic growth. The purpose of the study is to quantify the impact of human capital, innovation activity, social conditions, and the dynamics of world oil prices on the economic growth of Kazakhstan's regions. The methodological basis of the study is a panel model with fixed effects within the catch-up growth framework, along with spatial econometric methods to account for interregional spillovers. The assessment results show that the most significant growth factors are oil prices and innovation activity. The simulation results show that a 1% increase in world oil prices raises the GRP growth rate by an average of 0.48%, with an effect of 0.54% for oil-producing regions and 0.44% for other regions. Expenditures on technological innovations have a positive and statistically significant impact of $\beta = 2.15$ ($p < 0.01$), with interregional innovation spillovers of $\beta = 11.8$ ($p < 0.01$). The contribution of healthcare is also significant (($\beta = 5.66$, $p < 0.05$), whereas expenditures on R&D, education and investments in fixed assets did not show a statistically significant short-term effect. A high correlation has been established between the dynamics of world oil prices and the average growth of regional GRP ($r = 0.87$). At the same time, expenditures on R&D, education, and fixed capital investments do not show a statistically significant short-term effect. The results obtained confirm the dominant role of the oil factor and the importance of innovative spillovers as key drivers of regional economic growth.

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Қазақстан өңірлеріндегі инновациялар диффузиясы, білімнің таралуы және экономикалық өсу

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ТҮЙІН

Аймақтық дифференциацияның күшеюі және экономиканың цифрлық трансформациясы жағдайында өңірлердің экономикалық өсу факторларын сандық тұрғыдан бағалау қажеттілігі артып отыр. Зерттеудің мақсаты – Қазақстан өңірлерінің экономикалық өсуіне адами капиталдың, инновациялық белсенділіктің, әлеуметтік жағдайлардың және әлемдік мұнай бағасының динамикасының әсерін сандық тұрғыдан бағалау. Зерттеудің әдіснамалық негізін догоняющий өсу моделінің шеңберіндегі бекітілген әсерлері бар панельдік модель, сондай-ақ өңіраралық спилловерлерді есепке алу үшін кеңістіктік эконометрика әдістері құрайды. Бағалау нәтижелері көрсеткендей, экономикалық өсудің ең маңызды факторлары – мұнай бағасы мен инновациялық белсенділік. Модельдеу нәтижелері бойынша әлемдік мұнай бағасының 1%-ға өсуі жалпы өңірлік өнімнің (ЖӨӨ) өсу қарқынын орта есеппен 0,48%-ға арттырады, бұл әсер мұнай өндіруші өңірлерде 0,54%, ал қалған өңірлерде 0,44% құрайды. Технологиялық инновацияларға жұмсалатын шығындар оң және статистикалық тұрғыдан мәнді әсер көрсетеді ($\beta = 2.15$, $p < 0.01$), ал инновациялардың өңіраралық спилловерлік әсері жоғары ($\beta = 11.8$, $p < 0.01$). Денсаулық сақтау саласының үлесі де маңызды ($\beta = 5.66$, $p < 0.05$), ал ҒЗТКЖ-ға, білім беруге және негізгі капиталға инвестицияларға жұмсалатын шығындар қысқа мерзімде статистикалық тұрғыдан мәнді әсер көрсетпеді. Әлемдік мұнай бағасының динамикасы мен өңірлердің орташа ЖӨӨ өсуі арасында жоғары корреляция анықталды ($r = 0.87$). Сонымен қатар, ҒЗТКЖ, білім беру және негізгі капиталға инвестициялар қысқа мерзімді кезеңде статистикалық тұрғыдан мәнді әсер көрсетпейді. Алынған нәтижелер мұнай факторының басым рөлін және инновациялық спилловерлердің өңірлік экономикалық өсудің негізгі драйверлері ретіндегі маңыздылығын растайды.

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Диффузия инноваций, перетоки знаний и региональный экономический рост в Казахстане

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АННОТАЦИЯ

В условиях усиления региональной дифференциации и цифровой трансформации экономики возрастает необходимость количественной оценки факторов экономического роста регионов. Цель исследования заключается в количественной оценке влияния человеческого капитала, инновационной активности, социальных условий и динамики мировых цен на нефть на экономический рост регионов Казахстана. Методологическую основу исследования составляют панельная модель с фиксированными эффектами в рамках модели догоняющего роста, а также методы пространственной эконометрики для учета межрегиональных спилловеров. Результаты оценки показывают, что наиболее значимыми факторами роста являются цены на нефть и инновационная активность. Результаты моделирования показывают, что рост мировых цен на нефть на 1% увеличивает темпы роста ВРП в среднем на 0.48%, при этом эффект составляет 0.54% для нефтедобывающих регионов и 0.44% для остальных. Расходы на технологические инновации оказывают положительное и статистически значимое влияние $\beta = 2.15$ ($p < 0.01$), при межрегиональных спилловерах инноваций составляет $\beta = 11.8$ ($p < 0.01$). Вклад здравоохранения также значим (($\beta = 5.66$, $p < 0.05$), тогда как расходы на НИОКР, образование и инвестиции в основной капитал не показали статистически значимого краткосрочного эффекта. Установлена высокая корреляция между динамикой мировых цен на нефть и средним ростом ВРП регионов ($r = 0.87$). В то же время расходы на НИОКР, образование и инвестиции в основной капитал не демонстрируют статистически значимого краткосрочного эффекта. Полученные результаты подтверждают доминирующую роль нефтяного фактора и значимость инновационных спилловеров как ключевых драйверов регионального экономического роста.

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1. Introduction

Human capital has been widely considered one of the factors in economic growth in the second half of the 20th century (Hanushek & Woessmann, 2008; Pelinescu, 2015; Wang & Liu, 2016; Laskowska & Dańska-Borsiak, 2016). With the increasing level of digitalization of the economy, technological innovations, and the development of artificial intelligence, the level of human capital development is becoming a driver of regional economic growth, a factor in the implementation of new solutions and increased competitiveness (Luo et al., 2023; Brey & van der Marel, 2024). High-quality human capital allows for increased labor productivity, the introduction of new technologies, the development of science, an improvement in the investment climate, economic transformation, increased social sustainability, etc. (Salike, 2016; Zheng et al., 2017; Diebolt & Hippe, 2019; Simões et al., 2023; Zhang et al., 2023). It is worth noting that the effect of human capital may depend on regional development and other related factors (Agasisti & Bertoletti, 2022; Shaban & Khan, 2023). The role of education is invaluable in the development of human capital, while the impact of education expenditures on regional economic growth can be both positive and insignificant (Woo et al., 2017; Köktaş et al., 2022; Zhang & Liu, 2022; Zuo & Huang, 2025). Education spillover can have both positive and negative effects (Ramos et al., 2010; Valero & Van Reenen, 2019). The negative effect may be associated with the outflow of human resources to regions with greater investment in education (Ma et al., 2023).

Technological innovation expenditures typically have a positive impact on regional economic growth. The effect may depend on the level of expenditure; a significant increase in expenditures can contribute to economic growth (Hall & Sena, 2017; Tuncel & Oktay, 2022). The effect may be nonlinear, and increased expenditures do not always lead to increased efficiency; efficiency largely depends on the level of regional innovation development (Hou et al., 2019). Depending on the country's level of economic development and the selected innovation indicators, the impact can be both positive and negative (Hammar & Belarbi, 2021). Depending on barriers to market entry, the structure, and conditions of resource reallocation, the effect of increased expenditures on technological innovations may be limited (Di Mauro et al., 2020). In many ways, the effectiveness of increasing expenditure on technological innovation depends on the availability of trained personnel, the quality of the organization of innovation processes, the level of infrastructure development, the readiness of businesses to implement and apply new technologies, as well as the general level of economic development (Aguirre, 2022; Roth et al., 2023; Ciaffi et al., 2024).

Innovation spillover generally has a beneficial effect on neighbouring regions (Peng et al., 2021), with the magnitude of the effect depending on regional distance: the closer a region is to the innovation, the stronger the effect (Rodríguez-Pose & Crescenzi, 2008; Bottazzi & Peri, 2003). The effect is strongly influenced by the technological similarity of regions; if regions have different technological orientations, innovation spillover is almost insignificant (Deltas & Karkalakos, 2013). Innovation spillover will also have a negative effect if neighbouring regions have a weak ability to absorb innovations, if a stronger, innovative region attracts personnel, firms, and resources from a weaker region, or if firms from a strong region displace firms from a weak region (Song & Zhang, 2017). Thus, the positive or negative impact of innovation spillover to neighbouring regions depends on many factors, for example, with the presence of high-speed railways between regions, positive effects are observed (Cui, 2025), while with the concentration of high-quality human

capital in strong regions, the innovative potential of neighbouring regions may decrease (Wen et al., 2023).

Healthcare expenditures often have a positive impact on regional economic growth (Rivera & Currais, 2004; Zhang et al., 2020; Tang et al., 2020). Healthcare expenditures may have a threshold value above which they positively impact economic growth. For example, using 30 provinces in China as an example, a threshold expenditure level of 8.755% was determined; financing below this threshold hurt economic growth (Han, 2018). It is worth noting that with higher-quality public institutions in regions and better governance, healthcare expenditures have a positive impact on economic development (Balani et al., 2023). The social filter is often positively and statistically significantly associated with regional economic growth (Rodríguez-Pose & Crescenzi, 2008; Rodríguez-Pose & Villarreal Peralta, 2015). In regions where it is difficult to find the necessary personnel and workers lack the necessary knowledge and skills, the social filter hurts economic performance (Xiong et al., 2020). In most cases, spillover of socioeconomic conditions between regions has a positive effect on regional economic growth (Schubert & Kroll, 2016). In cases of significant regional differences, human resource spillover, and institutional weakness, a negative effect can be observed (Ma et al., 2023). It is worth noting that the characteristics of regional divergence and convergence also influence regional economic growth (Lau, 2010; Aristizábal & García, 2021).

Rising oil prices on world markets can contribute to increased economic growth in regions, especially in oil-producing regions (Munasib & Rickman, 2015; Baimaganbetov et al., 2019). In oil-importing countries, rising oil prices hurt regional economic growth (Park et al., 2011). In the long run, rising prices may have a negative impact and may not lead to sustainable economic growth (Pellegrini et al., 2021). The oil effect can be cyclical and unsustainable, especially during periods of price decline (Abboud & Betz, 2021). In an oil region, rising prices may have a positive impact on economic growth in the long run, while in a non-oil region, the impact is negative (Alyammahi et al., 2025).

Investments in fixed assets can promote economic growth in regions (Psycharis et al., 2022; Li et al., 2025), but their effects depend on various factors, including the regional economic environment and the efficiency of invested funds. Therefore, investment in fixed assets may have a mixed or negative impact on regional economic growth (Chen & Wu, 2005; Guo et al., 2023). R&D expenditures have a similar impact on regional economic growth; in regions with opportunities for commercialization and knowledge retention, a positive effect is observed (Koo & Kim, 2009). In regions with a higher concentration of low-tech sectors, R&D expenditures have a weak or negative effect, whereas in regions with high-tech and medium-tech industries, they have a positive effect (Pyo & Choi, 2025). The impact of R&D expenditures on regional economic growth is determined by the region's availability of qualified specialists, strong firms, effective institutions, and entrepreneurs capable of innovating (Celli et al., 2024). R&D spillovers often have a positive impact on the regional economic growth of neighbouring regions (Furková & Chocholatá, 2017), while a negative effect can be observed in weaker regions due to their inability to compete with stronger ones (Li et al., 2024).

Thus, given the relevance of the research topic and the limited research on this subject in Kazakhstan's scientific literature, the goal was to identify and quantify the influence of the factors discussed above on regional economic growth in Kazakhstan. The purpose of the study is to quantify the impact of human capital, innovation activity, social conditions, and the dynamics of

world oil prices on the economic growth of Kazakhstan's regions. The following two hypotheses are checked in the research:

H1. Expenditures on R&D, technological innovation, human capital, socio-economic conditions, investments in fixed capital, and the dynamics of the world oil price have a significant positive impact on the region's economic growth.

H2. Spillovers from expenditures on human capital, technological innovation, and R&D, as well as from socio-economic conditions, have a substantial and positive impact on the region's growth.

2. Literature review

The forerunners of modern studies of regional economic growth were the works of the 1950-1960s, in which innovations were measured by indirect indicators: the number of patents, companies' expenditures on research and development, and others. These studies laid the foundations of linear models of innovation activity, which later transformed into multifactor growth models emphasizing the role of population, investments, and the increase in savings with income growth.

Exogenous growth models in early empirical works identified two key drivers of economic growth: the expansion of labor use and the formation of knowledge-based capital. With the emergence of spatial econometrics, human capital gained recognition as a driving force of growth, and knowledge and learning by doing began to be considered as sources of non-decreasing returns to capital.

In the second half of the twentieth century, research actively developed that viewed knowledge as a factor of economic growth. Within the framework of the modification of the Solow-Swan model, Mankiw et al. (1992) showed that human capital is an important element of the production function and explains cross-country differences in income levels. In addition, Andrade et al. (2018) found that migration processes contribute to the convergence of countries through the exchange of ideas.

The concept of the knowledge production function (KPF), proposed by Griliches (1979), explains the "innovation – regional growth" relationship through investments in R&D. Grossman and Helpman (1991) confirmed the necessity of innovations for ensuring long-term economic growth. Acs and Varga (2002a) investigated the U-shaped relationship between innovation activity and the level of competition and indicated that the maximum level of innovation is achieved not under conditions of perfect, but of moderate competition. They also proposed the first theoretical provisions on knowledge spillovers as social processes of information transfer between economic agents. In subsequent works by Acs and Varga (2002b), as well as Marrocu et al. (2013), the concept of knowledge spillovers received further development within the framework of the spatial econometrics of innovations.

In the knowledge economy, knowledge spillovers are the basis of innovation activity and a source of positive externalities. In the conditions of a digital society, the mechanisms of these spillovers are radically changing: digital communication networks, platform solutions, systems for storing and processing big data, electronic government, and digital business services expand the space of interaction between regions. This reduces information barriers and strengthens the role of human capital, R&D, and digital innovations as drivers of economic growth.

At the same time, international and interregional empirical evidence is expanding: Snieska and Valodkiene (2009) showed that in transition economies economic growth is determined not by

exports, but by the stimulation of consumer spending. Kaneva and Untura (2019) investigated the innovation activity of the regions of Russia and confirmed the importance of socio-economic conditions for the diffusion of innovations. Lv et al. (2017) identified spatial spillover effects of education factors in the provinces of China in 1996-2010. Moreno et al. (2005) and Acs and Varga (2002b) applied spatial methods to assess the contribution of innovation activity to the regional growth of European countries and the USA. As the literature review shows, studies confirm the presence of an indirect relationship between R&D, human capital, innovations, and regional economic growth through the mechanism of technological progress.

3. Research methodology

The study is based on annual data from 2005 to 2016 for all 14 regions and two major cities of Kazakhstan. The analyzed data extended up to and including 2016 and did not cover later years due to the administrative-territorial structure of Kazakhstan's regions. Therefore, extending the panel without harmonizing regional boundaries creates a problem of regional comparability over time. Given this, this article uses the pre-reform period as the most homogeneous for econometric assessment.

To estimate the factors driving regional growth, we used a fixed-effects panel catch-up growth model, including both within-region factors and between-region spillover effects. The basic model specification is presented in formula (1):

$$\begin{aligned} growth_{it} = \alpha + \beta_1 \ln(y_{it-1}) + \beta_2 R\&D + \beta_3 Spill\_R\&D_{it} + \beta_4 Inno_{it} + \beta_5 Spill_{Inno\,it} \\ + \beta_6 HEDU_{it} + \beta_7 Spill_{HEDU\,it} + \beta_8 Health_{it} + \beta_9 SocFilter_{it} \\ + \beta_{10} ExtSocFilter_{it} + \beta_{11} FixInv_{it} + \beta_{12} rPoil_t + u_i + \varepsilon_{it} \end{aligned} \quad (1)$$

where:

i – region index;

t – period of time; dependent variable;

$growth_{it}$ – growth rate of gross regional product per capita, %;

$\ln(y_{it-1})$ – natural logarithm of GRP per capita with a 1-year lag.

The lag for this variable allows us to test the convergence hypothesis, according to which lagging regions grow at a higher rate; $R\&D_{i,t}$ – R&D costs as a percentage of the region's GRP; $Spill\_R\&D_{it}$ – flow of R&D costs to region i from other regions; $Inno_{i,t}$ – expenditures on technological innovations as a percentage of the region's GRP; $Spill\_Inno_{it}$ – flow of expenditures on technological innovations to region i from other regions; $SocFilter_{it}$ – index of socio-economic conditions in this region; $ExtSocFilter_{it}$ – influence of socio-economic conditions of all other regions on this region or "flow of socio-economic conditions"; $HEDU_{it}$ – education costs as a percentage of the region's GRP; $Spill\_HEDU_{it}$ – flow of education costs to region i from other regions; $Health_{it}$ – healthcare costs as a percentage of the region's GRP; $FixInv_{it}$ – share of fixed capital investment as a percentage of the region's GRP; $rPoil_t$ – rate of change in the real oil price; u_i – individual effect of region i; ε_{it} – random model error (Mukhamediyev & Spankulova, 2020).

The social filter was calculated using principal component analysis based on a set of demographic and socioeconomic indicators. Figure 1 shows the list of indicators included in the factor analysis. Two alternative versions of this index are tested: one accounting for employment

in the industrial sector and one accounting for employment in the agricultural sector. Spatial spillover variables are calculated using the interregional accessibility index approach of Kaneva and Untura (2016).

Figure 1. Indicators included in the factor analysis for constructing the social filter index.

In order to separately identify the impact of changes in oil prices on growth in the regions in which oil is extracted or processed, and in other regions in the model instead of $rPoil_t$ included two variables $rPoil_t * Oil_i$ and $rPoil_t * (1 - Oil_i)$. Here Oil_i is a dummy variable equal to 1 for the regions of Atyrau, West Kazakhstan, Mangistau, South Kazakhstan, and Pavlodar associated with oil production or processing, and equal to 0 for the rest of the regions.

4. Research results

Before presenting the results of the regression analysis, it is advisable to summarize the key quantitative estimates of the impact of regional economic growth factors. The estimates obtained reflect the contribution of innovation activity, social conditions, investments and the dynamics of world oil prices to the formation of GRP growth rates. Table 1 shows the results of a panel regression with fixed effects, which makes it possible to assess the importance of both internal factors of regional development and interregional spillovers.

Table 1. Panel regression with fixed effects based on the catch-up growth model.

Independent variable	**Equations**			
	I	**II**	**III**	**IV**
$\ln(y_{it-1})$	-2.37 (9.63)	-8.56 (12.3)	-5.68 (10.36)	-10.75 (11.87)
$R\&D_{i,t}$	-8.31 (17.0)	-7.89 (13.8)	-8.20 (16.2)	-7.29 (13.3)
$Spill\_R\&D_{it}$	-32.7 (32.1)	-36.1 (32.3)	-38.1 (32.7)	-39.2 (34.9)
$Inno_{i,t}$	2.15*** (0.60)	2.19*** (0.65)	2.14*** (0.59)	2.20*** (0.65)
$Spill_{Inno\,it}$	11.8*** (1.9)	11.0*** (2.0)	11.6*** (1.9)	10.9*** (2.0)
$HEDU_{it}$	1.27 (2.27)	2.13 (2.35)	1.36 (2.36)	2.33 (2.42)
$Spill_{HEDU_{it}}$	-5.19 (4.03)	-5.30 (4.11)	-4.43 (3.85)	-4.35 (4.02)
$Health_{it}$	5.66** (2.57)	5.66** (2.45)	5.51** (2.61)	5.37** (2.53)

$SocFilter_{it}$	0.93** (0.32)	12.23 (10.63)	0.83** (0.34)	12.75 (10.7)
$IndustrExtSocFilter_{it}$	-1.37 (1.12)		-1.51 (1.09)	
$AgricultExtSocFilter_{it}$	–	-16.43 (13.58)	–	-17.9 (13.4)
$FixInv_{it}$	0.20* (0.11)	0.14 (0.11)	0.19* (0.11)	0.12 (0.10)
$rPoil_t * (1 - Oil_i)$	0.48*** (0.04)	0.47*** (0.04)	–	–
$rPoil_t * Oil_i$	–	–	0.53*** (0.09)	0.54*** (0.08)
$rPoil_t$	–	–	0.45*** (0.04)	0.43*** (0.04)
Constant	24.1 (79.4)	68.8 (94.4)	51.0 (86.0)	83.4 (91.0)
Fixed effect	Yes	Yes	Yes	Yes
Number of observations	175	175	175	175
R^2	0.66	0.65	0.66	0.65
Fisher test	F(12, 15) = 26.83 [0.0000]	F(12,15) = 50.61 [0.0000]	F(13,15) = 44.65 [0.0000]	F(13,15) = 105.7 [0.0000]

Note: compiled by the authors.

The negative signs of the coefficients for the variable "Logarithm of GRP per capita" in Table 1 are consistent with the neoclassical theory of growth regarding the catching-up development of lagging regions (Kaneva and Untura, 2019). However, the coefficients for this variable in Table 1 are statistically insignificant, and the hypothesis of the convergence of Kazakhstan's regions is not confirmed.

The growth of the world oil price significantly increased the economic growth rate of the regions of Kazakhstan, and this influence was stronger for the oil-producing regions. This is one of the explanations for the absence of confirmed convergence of the regions of Kazakhstan: oil-producing territories grew faster, increasing interregional disparities. The positive influence of world oil prices on the growth of regions that do not produce oil is explained by the close production interconnections within the country and the increase in demand for their products from the oil-producing regions, which expand economic activity during periods of high oil prices.

This study shows the influence of innovative and other factors in combination with the dynamics of the world oil price on the economic development of the regions of Kazakhstan. It is revealed that expenditures on technological innovations and their spillovers between regions significantly influence the economic growth of the regions of Kazakhstan. A key finding of the study is that the spatial impact of technological innovation is almost comparable to the impact of global oil prices. The spatial impact of technological innovation can be a key driver of growth: the economic impact is not confined to the region where innovation growth originates, but spreads to neighboring regions through production chains, infrastructure links, and institutional interactions.

At the same time, R&D expenditures, as well as their flows between regions, did not provide significant support for the economic growth of the regions. This means that research and development activities conducted in the country's regions do not yield immediate returns, and their impact is expected over a longer period. Similarly, there is no significant positive impact on the rate of regional growth in education spending or its transfers between regions. This can be explained by the fact that the return on investment in education occurs with a significant lag, and its effects are not apparent after a one-year lag. The same can be said for investments in fixed capital. For a digital society, this is interpreted as a need for closer alignment between investments in education and R&D with the development of digital competencies, digital infrastructure, and the practical use of digital technologies in the regional economies.

Socio-economic conditions assessed taking into account employment in industry significantly contributed to increasing the economic growth rate of the region, while those assessed taking into account employment in agriculture did not have a significant influence. In addition, no influence of the spillovers of socio-economic conditions between regions was identified either when accounting for employment in industry or when accounting for employment in agriculture.

As expected, there is a direct connection between changes in the world oil price and the economic growth rates of the regions. This is illustrated in Figure 2, where rPoil is the growth rate of the world oil price, and *growth_avr* is the average of GRP growth rates across all regions of Kazakhstan (Mukhamediyev & Spankulova, 2020).

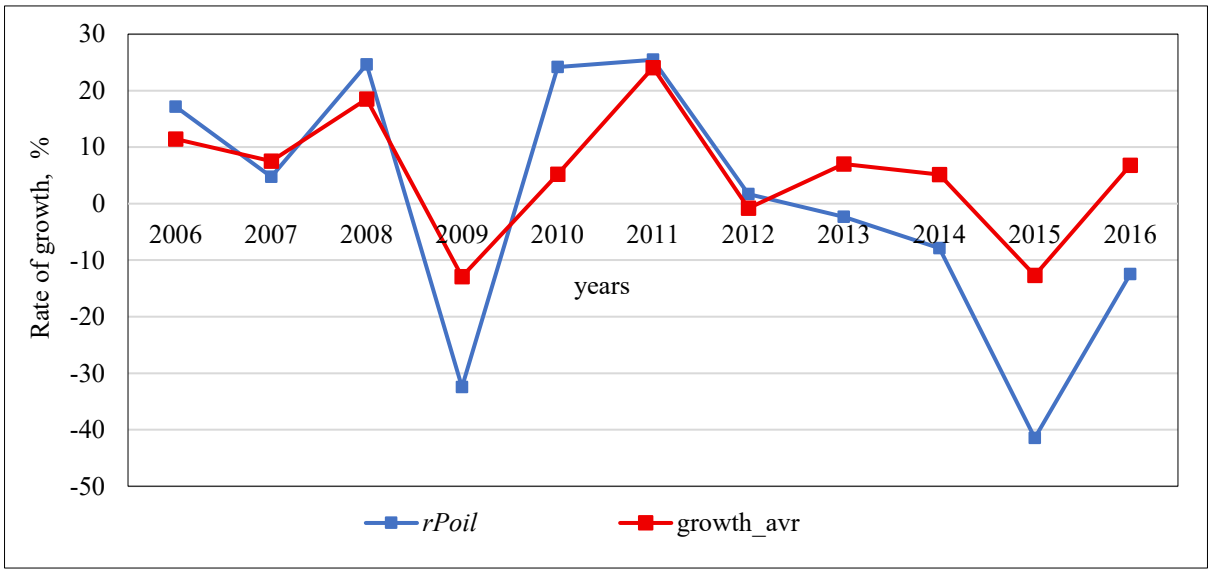

Figure 2. World oil price growth rate and average GRP growth rate the regions of Kazakhstan.

The correlation coefficient between these variables is 0.87. It is hardly possible to expect the emergence of an endogeneity problem here and to assume that the GRP of the regions of Kazakhstan can influence the world oil price. According to the data in Table 1, an increase in the world oil price by 1% increases the GRP growth rate on average by approximately 0.48%. Moreover, the increase in the GRP growth rate in the regions that extract or process oil amounts to approximately 0.54%, whereas in the remaining regions it averages 0.44%.

Thus, innovation (especially the impact of innovation on neighboring regions), public health, and the oil sector have the most positive impact on GRP growth. It's worth noting that investment supports moderate growth, while R&D and education do not yield statistically reliable results. The social filter and catch-up growth show insufficient statistical robustness.

It is of interest to compare the influence of changes in the world oil price and the factors of innovative development on the growth rates of GRP. Table 2 shows the estimates of the influence on the GRP growth rate of those variables in Table 1 whose coefficients are significant at least at the 5% level. The second column contains these coefficients. The third column shows the mean standard deviations of the variables. The fourth column contains the products of the corresponding values from the second and third columns.

As can be seen in the last column of Table 2, the influence of changes in technological innovations and their spillovers between regions on GRP growth is quite comparable to the influence of changes in the oil price. The impact of healthcare spending and the influence of regional socioeconomic conditions are more moderate. It is worth noting that the estimated specifications did not reveal a statistically significant short-term effect of education and R&D spending, nor interregional "spillover" effects. Therefore, the model under consideration confirms the significance of technological innovation and its spillover effects, healthcare, the social filter, and the oil sector. It is likely that the impact of R&D and education is indirect and delayed.

Table 2. Comparison of the impact of various factors on GRP growth

Independent variable	Coefficient	The average standard deviations	Assessing the effect of a variable on GRP growth
The oil price growth, %	0.48	22.7	10.90
The technological innovation costs as a percentage of GRP with a lag of 1 year	2.15	1.43	3.07
The spillover of technological innovation costs between regions with a lag of 1 year	11.8	0.83	9.80
Health expenditures as a percentage of GRP with a lag of 1 year	5.66	0.30	1.70
Social filter based on employment in industry with a lag of 1 year	0.93	2.26	2.10

Note: compiled by the authors

Comparing the standardized effects, it can be noted that, against the dominant factor of oil (10.90), the spillover effects of technological innovation (9.80) are the most powerful non-commodity driver of growth. Based on this, it can be concluded that not only are a region's own innovation expenditures important for a country, but also its active participation in interregional knowledge and technology exchange. As for expenditures on technological innovation, they have a more moderate impact (3.07), indicating that their effectiveness depends on the regional economy's ability to absorb and scale new solutions. The effects of healthcare (1.70) and the social filter (2.10) are significantly lower, but statistically significant, confirming the complementary role of human capital and the quality of the socioeconomic environment in ensuring regional growth.

5. Conclusion

This study demonstrates that long-term regional economic growth cannot be achieved solely through resource allocation or innovation. A combination of factors is necessary to ensure growth. While the oil sector continues to drive economic growth in Kazakhstan, technological innovation, particularly artificial intelligence, is becoming an increasingly important driver of development and growth. For Kazakhstan and its regions, not only is the scale of expenditures important, but also the ability to translate them into tangible economic results. In the study, R&D and education expenditures, their interregional flows, and fixed capital investment did not show statistically significant short-term effects in the specification used. However, the global experience examined in the study shows that R&D and education expenditures may not immediately yield the desired effect, so this does not mean they are useless. The impact of these factors may manifest itself over the longer term, through various mechanisms, such as commercialization, training, high-quality institutionalization, digital infrastructure development, and so on. It is important to understand that with a better organization of interactions between science, education, industry, and regional

policy, expenditures will be more effective and will more quickly benefit not only the regions but also society. Along with increasing investment volumes, it is necessary to improve the efficiency of the return mechanism. Regions that invest more actively in technological (including digital) innovations and have a more favorable social filter gain an additional advantage in access to knowledge and technology, which strengthens their ability to adapt to the digital transformation of the economy. In this context, regional development policy should focus not only on mitigating the impact of oil price shocks but also on accelerating the transition to a digital society by supporting digital infrastructure, the population's digital competencies, and digital innovation. To ensure long-term sustainable economic growth in the regions, it is necessary to implement a range of measures that include strengthening technological innovation, closer interregional integration, developing high-quality human capital, and deliberately reducing dependence on raw materials and vulnerability to global price shocks.

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