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Technical Note

Could the Lacking Absorption Capacity of the Inflowing Capital Be the Real Cause of the Resource Curse?—A Case Study of Transition Economies

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Abstract: The present study proposes an alternative explanation for the negative natural-resource-growth nexus. Based on the theoretical analysis, the study shows that a balanced capital–labor ratio plays an essential role in the absorption of complex capital goods. It estimates the parameters of the constant elasticity of the substitution production function in Mathcad using nonlinear least squares, i.e., an approximate Marquardt method of optimization. The empirical analysis is based on the time-series data of these countries for the time interval between 2000 and 2020. We conducted analyses by calculating the elasticity of substitution between capital and labor. Specifically, for these countries, the elasticity of substitution of capital and labor appeared to be less than one, which indicates a lack of labor, or, more precisely, a qualified labor force. Each of these countries receives windfall profits from the exploitation of natural resources, which greatly influences the import of capital-intensive products of complex technologies—in other words, the import of capital. However, the lack of an adequate labor force that could utilize the increased capital led to a decrease in the elasticity of capital and labor substitution. A comparison of the optimal and the observed capital–labor ratio coefficient shows that this coefficient is significantly higher than optimal in all three countries. Therefore, while keeping the wage fund in balance with fixed capital costs, investments in the knowledge economy and human capital appear to be the preferred areas for the efficient allocation of oil revenues.

Keywords: natural resources; human capital; CES production function; Marquardt method

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1. Introduction

In the aftermath of the collapse of the former Soviet Union, Azerbaijani, Kazakh, and Russian economies have been heavily reliant on the exports of petroleum riches, and despite transforming the natural-resource wealth into accelerated growth and development they experienced a disproportional deindustrialization and the expected affluence and diversification failed to materialize. Contract of the Century on 20 September 1994 and commissioning the Baku–Tbilisi–Ceyhan oil pipeline in 2006 and the ongoing commodity super cycle lead to substantial commodity windfalls. The oil sector accounted for 29% of GDP in 2000, and this figure reached a peak of 56% in 2007, whereas in 2022 the share was equal to 47.8%. In 2001, 53% of goods exports were accounted for by the oil-and-gas sector, which reached a peak of 95% in 2011, and in 2022, this figure was 92.01%. Although the share of the non-oil sector in exports decreased during these periods, its share in imports increased significantly. In 2012, the share of imports in the trade turnover was 28.8%, and this figure was 34.5% in 2021. Products of the non-oil sector constituted the absolute majority in the structure of imports. Taking into account transfers from the Oil Fund, oil revenues make up more than half of the state budget revenues. In Kazakhstan, along with metal mining and coal mining, oil production accounts for 30% of the country's GDP. The oil sector accounts for 50% of total exports and 30% of tax revenues [1].

In Russia, which is one of the world's largest oil-producing countries, a slight decrease in oil production was observed in the 1990s. However, in the subsequent years, this indicator had a growth trend and peaked in 2018. Although the main socio-economic indicators of these three countries showed a growth trend, the indicators regarding the dependence of these economies on oil revenues, as well as the facts from the research related to Dutch Disease syndrome in these countries, increases the relevance of research in this direction.

As noted, natural resources have a significant impact on the economy of countries that are rich in them. There is a large corpus of empirical and theoretical literature on the nexus between natural resources and economic growth in commodity-abundant developing and transition economies [2–7]. There is a wealth of theoretical literature [8] and empirical evidence on the negative nexus between natural resources and economic growth [9–12].

In addition, country case studies that were based on country-specific time-series analyses and qualitative elaborations confirmed the negative growth and development effects of commodity abundance and dependence [13–17] However, there are some countries rich in natural resources that not only avoided the negative effects of these resources but also used natural-resource revenues for supporting the development of the economy. This makes it necessary to determine the causes of the resource curse and to study ways to eliminate its negative effects. Different approaches have been used in different studies to identify the mechanism of the negative impact of natural-resource abundance on the economy and to identify the symptoms of the resource curse in resource-rich countries. The follow-up studies showed the negative impact of natural-resource abundance on economic development in several directions—the Dutch disease, rent-seeking and degradation of institutions, and reduced incentives for human-capital development [18]. It is known that the exploitation and export of abundant natural resources create a surplus of foreign currency in the country, which increases the value of the national currency. The increase in the value of the national currency and the depreciation of the foreign currency stimulate imports. The flow of cheap capital into the country creates an incentive for capital-intensive modernization. Having considered that importing labor resources is not as easy as importing physical capital, cheap physical and financial capital lowers the demand for labor and human capital.

The study of Vasilieva [18] was devoted to the discussion of the results of theoretical and empirical studies on the influence of resource wealth on human-capital accumulation. It was shown that despite the existence of theoretical claims regarding the negative impact of resource abundance on human capital, empirical studies have not been sufficient to obtain consistent results. Our research is dedicated to filling this gap. Thus, this present inquiry is an attempt to assess the capability of resource-exporting transition economies to absorb the complex capital goods that require high-skilled technical staff to steer these technologies in a productive way. The lack of human capital can hinder the use and lead to underutilization of advanced means of production. Hence, under some conditions, it could be meaningful to import fewer or less complex technologies and develop less human-capital-intensive sectors.

To approach the research question empirically, we use production functions in the study. Thus, by estimating the dependence of the production volume on the main factors of production, we evaluate the balance between labor and capital factors, as well as the optimality of the capital–labor ratio, which allows us to evaluate the achievement of the optimal volume of production.

The study uses the CES function to determine the relationship between capital and labor, and regarding this, the corresponding output elasticities of the production function are estimated. The study is predicated on the statistical data for 2000–2020 for Azerbaijan, Kazakhstan, and Russia, which are rich in hydrocarbon resources. Our purpose is to investigate the impact of the exploitation of oil and gas resources on capital and labor resources in former Soviet republics such as Azerbaijan, Kazakhstan, and Russia using the CES production function and compare the obtained empirical results with existing theoretical results. Hasanli et. al. [19] evaluated the parameters of the CES function on the example of Azerbaijan, Kazakhstan, and Russia; calculated the elasticity of substitution between capital and labor; and obtained certain preliminary results. However, in that study, the coefficient characterizing the capital–labor ratio that yields the optimal level to GDP was not found and no generalization was made. In this study, this deficiency is overcome. It should be noted that the study of the impact of the abundance of natural resources on the economy with the application of the CES production function is a new approach.

Although the general aspect of all three countries is that they are rich in natural resources and gained independence and moved from the socialist system to market relations almost at the same time, the spending of the income from natural resources led to the formation of a different situation in the economies of these countries. From this point of view, the method used allows us to determine the problems caused by the wealth of natural resources in human capital in these countries and to evaluate the optimality of the capital–labor ratio. To review, the obtained results can give directions for optimal spending of oil revenues, which can be used when making policy decisions. In addition, with the proposed methodology, it is possible to conduct this type of research for other countries rich in natural resources.

2. Literature Review

As mentioned above, different approaches are used in the literature to study the causes and mechanisms of the negative impact of the revenues from natural resources on the economy. According to the Dutch disease, the exploitation and export of oil and gas resources lead to a large increase in the amount of foreign currency a country has, and the sale of foreign currency on the market leads to an increase in the value of the national currency. Consequently, in turn, it is associated with the loss of foreign products in the competition. As a result, development challenges arise in the non-oil sector. This situation is determined both by the effect of the Dutch disease and by rent-oriented behavior. An increase in rent income leads to an increase in the mining sector and the non-tradable goods and services sector, and a decrease in the manufacturing and agricultural sectors that produce tradable goods [8]. As a rule, the growth of the mining sector does not create sufficient demand for classified labor. A decline in the manufacturing and agricultural sectors leads to a decline in classified labor and more highly educated jobs. If the incomes of institutions that implement the redistribution of income (for example, those working in the public sector) are higher than those in production areas or entrepreneurial activities, then employees prefer to work in state bodies [20,21]. In the face of the fact, the public sector does not feel international competition. Thus, the public sector is less sensitive to the quality of human capital. Another reason is related to the policy of elites who use rent income to create inefficient jobs in sectors protected from international competition. Thus, in the state sector, for example, it is preferable to supply the consumption demand of the army and law-enforcement agencies (food, clothing, etc.) with the goods and services produced by local entrepreneurs. Here, the low level of competition also reduces the demand for the quality of labor resources. Another essential point is that entrepreneurs know that the state will protect even inefficient local production by raising customs tariffs or subsidies [18]. These studies show that natural-resource abundance has a negative impact on the economic development of a country. Subsequently, the mentioned factors also reduce the demand for human capital in the country. One reason for the decline in demand is the fact that human capital, in contradiction to physical capital, has fewer import opportunities. Thus, the increase in value of the domestic currency and the decrease in value of foreign currency stimulate the import of physical capital, which is the main production factor. Hence, the import of labor resources is not as easy as that of physical capital, so there is a tendency to use cheaper production factors in the production process, and production in capital-intensive areas becomes a priority direction. Therefore, the demand for human capital decreases.

The evidence shows that human capital is one of the main factors determining a country's development. Development of human capital determines the quality of management institutions [22]. In countries with high human capital, the probability of democratic governance increases and the inviolability of private property increases the level of protection and reduces corruption. From this point of view, the factors hindering the development of human capital lead to a delay in the development of the country.

But, what causes the wealth of natural resources to cause problems in human capital? It is well-established natural resources abundant countries invest less in education than countries resource-poor countries with an analogous level of income [6]. In other words, natural capital is crowding out human capital. In addition, high level of inequality is more severe in the resource-dependent countries, what also negatively affects human capital.

The empirical literature of the past two decades on the nexus between natural resource abundance and human capital development offers a rather mixed picture. Besides studies that confirm the negative resources-human capital development association there are also studies that show that there is no statistically significant, or even negative nexus between commodity abundance and human capital development [23,24]. Recently, much research have been conducted on the phenomenon of the "resource curse" and human capital development nexus in Russia [18,25,26]. These studies show that commodity windfalls lead to relatively low level of incentives to invest in human capital development in Russia.

Based on survey data conducted in Kazakhstan in 2018, Papyrakis and Parcero [27] assessed the impact of the psychological factor on the misuse of natural-resource income in countries with a wealth of natural resources. The study's finds that rising population expectations of the availability of natural resources and the discovery of new reserves had a detrimental effect on the growth of the nation by limiting the allocation of natural-resource revenues to priority areas.

Vakulchuk and Overland [28] investigated the role of civil society in Kazakhstan's management of natural-resource revenues. Because the country's social and economic performance has significantly improved since the post-independence collapse, the use of natural-resource revenues has been successful to some extent, and the population prefers stability in the country, the state's decisions are typically tacitly accepted by society. Czech and Niftiev [16] employ a structural vector autoregressive (SVAR) model to analyze the relationship between exchange rates and crude-oil price volatility and discovered a negative impact of oil-price increases on the USD/AZN and USD/KZT exchange rates, which is interpreted as the Dutch-disease effect in these countries.

By examining the short- and long-term impacts of oil prices and production on non-oil exports using an autoregressive distributed lag-model bounds test and a fully modified ordinary least-squares method for the period from 2001Q1 to 2019Q4, a recent study examined the presence of Dutch-disease symptoms in Azerbaijan. The survey shows that, in the long run oil prices have a favorable impact on non-oil real exports, a negative link has been observed between non-oil real exports and oil production, which can be related to resource-movement effects [29].

Bayramov and Abbas [30] examined the economic impact of the 2014 oil-price shocks on the Caspian Basin's oil-exporting nations of Russia, Kazakhstan, and Azerbaijan. By analyzing the main causes of the current crisis, the article comes to the conclusion that the economies of these countries are "subsidized economies," or rentier states that rely almost entirely on resource windfalls. Prior to the crisis, the non-resource industries in these countries were underdeveloped and unable to serve as a means of diversification since they lacked the capacity to be sustainable and export-oriented. The paper also emphasizes the significance of carrying out numerous changes to help the diversification of the economy, including liberal measures like removing obstacles to entry into the market and fostering competition.

Mohsen [31] examined whether there is a threshold impact depending on natural-resource revenues and output in oil-exporting countries. Empirical findings strongly imply the existence of a threshold. Exceeding this threshold in terms of the share of resource export revenues in gross GDP have negative repercussions on the pace of economic growth. The findings indicate that the impact on economic growth diminishes after a certain level of growth rate in oil income in these countries. Ignoring non-linearity, as demonstrated by other studies, hides the resource curse in these countries, particularly during oil booms.

Pelzman et. al. [32] investigated the case of Kazakhstan and concluded that institutional quality is not a determinant of the resource curse, and claimed that the resource curse in the country is driven by the volatility of commodity prices on the basis of empirical panel data of the country's regions. Gritsenko and Efimova [33] examined the resources-development nexus for seven regions of Russian Arctic and found that economic vulnerabilities and unfavorable economic trends were present in Russia's Arctic regions However, it was concluded that this is caused not only by resource abundance but also by other factors, including the socioeconomic-development level of the regions.

Thus, we can conclude that if the income from natural resources entering a country's economy is not regulated, it does not motivate the policy in the direction of reducing the demand for human capital and increasing the costs allocated to the development of human capital, but the planned use of these revenues can help to create a positive impact on the economic development of the country. In this regard, we evaluate the optimality of spending oil-and-gas revenues on the main production factors for Azerbaijan, Russia, and Kazakhstan using production functions.

3. Theoretical Framework and Empirical Methodology

3.1. CES Production Function

Production functions represent mathematically the relationship between production factors and output, and the estimated parameters of these functions can be used for various purposes [34,35]. Among production functions, the more general function is the constant elasticity of substitution (CES) production function. CES is based on the neoclassical theory and has a constant elasticity of substitution [36,37]. The general form of the CES production function is formulated in Equation (1).

$$Y = A_0 \cdot \left(\delta K^{-\rho} + (1-\delta) L^{-\rho}\right)^{-\frac{\nu}{\rho}} \tag{1}$$

where Y stands for the volume of production or gross domestic product, K stands for the capital, and L is the labor force. A_0—is the scale factor ($A_0 > 0$). δ is the distribution coefficient $0 < \delta < 1$, ν is the degree of homogeneity ($\nu > 0$), and ρ ($\rho > -1$) is an intermediate parameter that is used to calculate the elasticity of substitution between capital and labor (σ) in accordance with Equation (2).

$$\sigma = \frac{1}{1+\rho} \tag{2}$$

Within the framework of the CES function, it is assumed that the marginal rate of substitution of capital and labor is constantly decreasing. In this regard, the CES approach is analogous to the Cobb–Douglas approach. However, the CES function is more general [38,39] Therefore, if $\rho \to o$, then $\sigma \to 1$—that is, the elasticity of substitution of capital and labor is equal to unity, in which case the CES function coincides with the Cobb–Douglas production function. If $\rho \to \infty$, then $\sigma \to 0$—that is, the elasticity of substitution of capital and labor is equal to unity, and in this case, the CES function coincides with the Leontiev production function. That is, it is impossible to achieve the same level of production if we increase capital as much as possible and reduce labor consumption at the same time. On the contrary, it is impossible to achieve the same level of production by reducing the amount of capital and increasing labor consumption as much as possible. It should be noted that in the Leontiev production function, a certain minimum level of capital and labor consumption is required to produce one unit of goods or services. In other words, it is assumed that the direct-cost coefficients of the technological matrix remain constant. If $\rho \to -1$, then $\sigma \to \infty$, the elasticity of substitution of capital and labor is equal to infinity, and in this case, the CES function coincides with the linear-production function. That is, it is possible to achieve a stable level of production by increasing capital and reducing labor consumption.

Note that the elasticity of substitution of capital with labor (σ or σ_{KL}) in the production function $Y = Y(K, L)$ is defined as follows:

$$\sigma_{KL} = -\frac{dln\left(\frac{K}{L}\right)}{dln(MY_K/MY_L)} \tag{3}$$

Here, MY_K and MY_L represent the marginal rate of substitution of output (GDP) for capital and labor. It can be seen from Equation (3) that the elasticity of substitution between capital and labor is equal to the percentage change in their ratio divided by the percentage change in the ratio of marginal products of capital and labor.

It is clear from here that if $\sigma < 1$, it means that the percentage change of the ratio between capital and labor has been slower than the percentage change of the ratio of their marginal products. Capital and labor cannot fully replace each other. For example, the increased amount of capital cannot be fully met by labor (lack of skilled labor). If $\sigma > 1$, it means that the percentage change in the ratio between capital and labor was faster than the percentage change in the ratio of their marginal products.

$$Y(K, L) = constant \tag{4}$$

If we differentiate each side of Equation (4),

$$\partial \mathrm{Y} \partial K dK + \partial \mathrm{Y} \partial \mathrm{L} \frac{\partial Y}{\partial K} dK + \frac{\partial Y}{\partial L} dL = 0,$$

$$MY_K dK + MY_L dL = 0$$

or,

$$Y'_K dK + Y'_L dL = 0$$

Here, the notations Y'_K and Y'_L are partial derivatives of the function $Y(K, L)$ with respect to K and L, respectively.

In the special case when the degree of homogeneity ν is equal to unity, the elasticity of substitution σ is more simply:

$$\sigma = \frac{Y'_K Y'_L}{YY''_{KL}} \tag{5}$$

Using Expression (5), it can be shown that Equation (2), that is, $\sigma = \frac{1}{1+\rho}$, is true.

Equation (6) is an augmentation of the CES production function by the Hicks-neutral technical progress, where A_0 is the constant that stands for the constant level of technical progress in $t = 0$, and λ is the parameter that determines the annual growth rate of the level of technology.

$$Y = A_0 \cdot e^{\lambda t} \left(\delta K^{-\rho} + (1-\delta) L^{-\rho}\right)^{-\frac{\nu}{\rho}} \tag{6}$$

The CES function is nonlinear in terms of parameters and has a complex structure. Note that it is possible to log functions that are linear according to parameters but nonlinear according to variables and bring them into linear form by simple substitution. In this case, the problem is greatly simplified, the parameters can be estimated, and the adequacy of the model can be tested by means of arbitrary software packages applied in econometric modeling. However, even after taking the log, the CES function remains non-linear with respect to parameters. Therefore, the nonlinear least-squares method is used to estimate this production function [40].

The general nonlinear least-squares method is as follows:

Let us assume that the theoretical picture of the nonlinear function F characterizing the dependence of the variable Y (dependent) on the variables $X_1, X_2, \ldots, X_n$ (independent) is known.

$$Y = F\,(X_1, X_2, \ldots, X_n)$$

However, the values of the parameters $a_1, a_2, \ldots, a_n$ corresponding to the explanatory variables $X_1, X_2, \ldots, X_n$ are unknown. Here, the parameter $\mathrm{a_i}$ characterizes the influence of the explanatory variable X_i on the explained variable Y. An evaluation of these parameters is required. For this purpose, m number of observations is made. As a result of the conducted m number of observations, the values of explanatory variables ($X_{i1}, X_{i2}, \ldots, X_{in}$) ($i = 1, 2, \ldots, m$) are obtained based on each Y_i value of the explained variable. In other words,

$$Y_i = F_i(a_1, a_2, \ldots, a_n; X_{i1}, X_{i2}, \ldots, X_{in}) + U_i, i = \overline{1, m} \tag{7}$$

Here, U_i is the statistical deviation. In Equation (7), it is necessary to find the values of the parameters $a_1, a_2, \ldots, a_n$ in such a way that the values of the explained variable obtained from the observations are the closest to the theoretical values. In other words, U_i deviations should be the smallest. The parameters $a_1, a_2, \ldots, a_n$ satisfying this condition are found by the method of least squares. More precisely, the following function is minimized.

$$S(a_1,\ a_2,\ \ldots,\ a_n) = U_1^2 + U_2^2 + \ldots + U_n^2 = \sum_{i=1}^{n} U_i^2 \ \rightarrow min$$

The application of Ferma's theorem to finding its minimum creates certain difficulties since the objective function S is non-linear with respect to parameters $a_1, a_2, \ldots, a_n$.

Thus, taking the partial derivatives of the function S with respect to the parameters a_1, $a_2, \ldots, a_n$ and solving the system equations by making these partial derivatives equal to zero becomes much more difficult, and sometimes it is impossible. Therefore, this minimization problem is solved by approximate and numerical methods. Numerical methods of minimizing S include the Marquardt method, which is a modification of the Newton–Gauss method; the Pauelov version of the least-squares method; the Haybred method; and others. We used the Marquardt method [41] in this research, which is considered a modification of the Newton–Gauss method [42]; the LSM method by Powelov; the Haybred method; and the Levenberg method [43].

Let us include the following vectors:

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y_m \end{bmatrix}, F = \begin{bmatrix} F_1 \\ F_2 \\ \cdot \\ \cdot \\ \cdot \\ F_m \end{bmatrix}, U = \begin{bmatrix} U_1 \\ U_2 \\ \cdot \\ \cdot \\ \cdot \\ U_m \end{bmatrix}, a = \begin{bmatrix} a_1 \\ a_2 \\ \cdot \\ \cdot \\ \cdot \\ a_n \end{bmatrix}$$

Now we can state our problem as follows:

It is necessary to find a point a^* such that when $U = Y - F$, the objective function $S = U^T U$ takes a minimum value.

Here, the vector U^T—is the transpose of the vector U.

The a^k—approximate value obtained in the kth step of the iterative process and the subsequent a^{k+1}—approximate value are related to each other by the correction vector Δa.

$$a^{k+1} = a^k + \Delta a$$

The formula for the correction vector Δa is found by solving the following system of equations according to the minimization condition.

$$(A^T A)\Delta a = (-A^T U) \tag{8}$$

Here, $\Delta a = -(A^T A)^{-1} A^T U)$. The matrix A is the matrix formed by the first-order partial derivatives of U. That is, it is a Jacobian matrix.

$$A = \begin{bmatrix} \frac{\partial U_1}{\partial a_1}, & \frac{\partial U_1}{\partial a_2}, \ldots, & \frac{\partial U_1}{\partial a_n} \\ \frac{\partial U_2}{\partial a_1}, & \frac{\partial U_2}{\partial a_2}, \ldots, & \frac{\partial U_2}{\partial a_n} \\ & \cdots & \\ \frac{\partial U_i}{\partial a_1}, & \frac{\partial U_i}{\partial a_2}, \ldots, & \frac{\partial U_i}{\partial a_n} \\ & \cdots & \\ \frac{\partial U_m}{\partial a_1}, & \frac{\partial U_m}{\partial a_2}, \ldots, & \frac{\partial U_m}{\partial a_n} \end{bmatrix}$$

The value of the elements of the matrix A is calculated at the point $a = a^k$.

This formula is the basic formula of the Newton–Gauss iteration. When using the Newton–Gauss method, if the degree of non-linearity of $F(x)$ is high and the starting value a^0 is far from the minimum value, then there is a high probability for deviation of Δa and a divergence of the iterative process.

Historically, the earliest method of minimizing a multivariate function is gradient descent. The essence of this method is the selection of the direction vector of the movement. This direction vector is the antigradient vector.

$$d = -\nabla S$$

Here,

$$\nabla S = \frac{\partial S}{\partial a} = 2A^T U$$

However, it is possible that the direction chosen by the gradient-descent method is far from optimal. At this time, Δa often gives poor convergence. Lebenberg and Marquardt introduced a non-negative element next to the diagonal matrix of Equation (8) and proposed to find the specified vector Δa from the following equation in the Newton–Gauss procedure.

$$\left(A^T A + m^2 I\right)\Delta a = -A^T U \tag{9}$$

Here, the I is a unit matrix with an nxn dimension. m—is any number (can be equal to zero) and is called the Marquardt number.

This method overcomes the noted shortcoming of gradient descent and the Newton–Gauss method.

Thus,

$$\Delta a = -\left(A^T A + m^2 I\right)^{-1} A^T U$$

When $m = 0$, we get the Newton–Gauss method, and for sufficiently large values of m, we get the gradient descent method:

$$\Delta a \approx -\left(m^2\right)^{-1} A^T U$$

Thus, we can say that this method combines the Newton–Gauss method and the gradient-descent method. The main idea is that at a high level of non-linearity (as long as the dispersion between the iterative and the sought solution is large enough), a sufficiently large value of m is used (gradient-descent method), whereas when approaching the sought solution, the value of m is reduced. This process allows us to quickly reach the desired minimum.

This described method is called the Marquardt method. The following simple algorithm is proposed for choosing m—the Marquardt number:

(1) The initial value is accepted as $m = \sqrt{0.001}$, $(m^2 = 0.001)$;
(2) The m-number is increased by $\sqrt{10}$ times (m^2—10 times) at each step until S starts to decrease;
(3) The value of m is increased by $\sqrt{0.1}$ times (m^2—0.1 times) and the obtained expression is accepted as a new initial value.

Steps (1)–(3) are the main iteration of this method (the increase or decrease of the value of S depends on the level of nonlinearity).

In order to reduce the limit (volume) of the calculation, it is recommended not to use the Marquardt primary system of equations but rather to use the following system equivalent to it:

$$(\widetilde{A^T} A^T + m^2 I)\Delta a = -\widetilde{A^T}\widetilde{U} \tag{10}$$

Here,

$$\widetilde{A} = [A \; vI\,], \;\; \widetilde{U} = [U \; 0\,].$$

Note that the difference between the system equations leads to the following two cases:

(a) $\widetilde{A}$—the expanded Jacobian matrix is obtained by adding mI matrix of nxn size to the lower row of the A—Jacobian matrix;
(b) An expanded vector of residuals $\widetilde{U}$ is obtained by adding zero components of length n to the vector of initial residuals U.

Therefore, the CES function can be estimated using this method.

3.2. Estimating the Optimality of the Capital–Labor Ratio

In the article "Mathematical analysis of neoclassical production functions," Yankovyi [44] investigated the problem of finding the optimal ratio of capital and labor, which determines the optimal volume of production in the Cobb–Douglas and CES functions. More precisely, a possible optimization of the dependence of output and capital–labor ratio was studied using the CES function. The optimal level of capital–labor ratio was determined, which yielded the maximum volume of production. In addition, the marginal substitution rate of resources was interpreted.

In the article, the optimal ratio of capital and labor depending on the parameters of the CES function is as follows: $\frac{K}{L} = \left(\frac{\delta}{1-\delta}\right)^{\frac{1}{\rho+1}}$. If we denote the sum of capital and labor with $C = K + L$, then $L = C - K$. Consider the issue of maximizing production taking into account the expression for CES function (1):

$$Y = A_0 \cdot \left(\delta K^{-\rho} + (1-\delta)(C-K)^{-\rho}\right)^{-\frac{v}{\rho}} \to max$$

To find the points of crisis, we find the derivative of the function and equate it to 0:

$$\begin{aligned} Y' = -A_0 \tfrac{v}{\rho}\left(\delta K^{-\rho} + (1-\delta)(C-K)^{-\rho}\right)^{-\frac{v}{\rho}-1} \times \left(-\rho\delta K^{-\rho-1} + \rho(1-\delta)(C-K)^{-\rho-1}\right) = \\ vA_0\left[\delta K^{-\rho} + (1-\delta)(C-K)^{-\rho}\right]^{-\frac{V}{\rho}-1} \times \left[\delta K^{-\rho-1} - (1-\delta)(C-K)^{-\rho-1}\right]. \end{aligned} \tag{11}$$

It is obvious that for the condition $Y' = 0$ to be satisfied, any of the factors in Equation (11) must be equal to 0:

$$\delta K^{-\rho} + (1-\delta)(C-K)^{-\rho} = 0 \tag{12}$$

$$\delta K^{-\rho-1} - (1-\delta)(C-K)^{-\rho-1} = 0$$

Solving the first equation, we have:

$$\left(\frac{K}{C-K}\right)^{\rho} = -\frac{\delta}{1-\delta} \Rightarrow \frac{K}{C-K} = \left(-\frac{\delta}{1-\delta}\right)^{\frac{1}{\rho}} \tag{13}$$

Considering that $C - K = L$:

$$\left(\frac{K}{L}\right)_1 = \left(-\frac{\delta}{1-\delta}\right)^{\frac{1}{\rho}} \tag{14}$$

From here,

$$K = L\left(-\frac{\delta}{1-\delta}\right)^{\frac{1}{\rho}} \tag{15}$$

Then, $Y_{\max} = A_0 \cdot \left(\delta()^{-\rho} + (1-\delta)L^{-\rho}\right)^{-\frac{v}{\rho}}$

The maximum production cannot be zero. Therefore, the point expressed in Equation (15) cannot be the extremum of this function.

Now, let us solve the second equation from Equation (12):

$$\left(\frac{K}{C-K}\right)^{-\rho-1} = \frac{1-\delta}{\delta} \Rightarrow \frac{K}{C-K} = \left(\frac{\delta}{1-\delta}\right)^{\frac{1}{\rho+1}} \tag{16}$$

$$\left(\frac{K}{L}\right)_2 = \left(\frac{\delta}{1-\delta}\right)^{\frac{1}{\rho+1}} \tag{17}$$

$$K = L\left(\frac{\delta}{1-\delta}\right)^{\frac{1}{\rho+1}} \tag{18}$$

$$\max Y = A_0\left(\delta\left(L\frac{K}{L}\right)^{-\rho} + (1-\delta)L^{-\rho}\right)^{-\frac{v}{\rho}} = A_0\left[\delta L^{-\rho}\left(\left(\frac{\delta}{1-\delta}\right)^{-\frac{\rho}{\rho+1}} + (1-\delta)\right)\right]^{-\frac{v}{\rho}} =$$
$$A_0\left[L^{-\rho}\left((1-\delta)\frac{\delta}{1-\delta}\left(\frac{\delta}{1-\delta}\right)^{-\frac{\rho}{\rho+1}} + (1-\delta)\right)\right]^{-\frac{v}{\rho}} = A_0 L^{v}\left[(1-\delta)\left(\frac{\delta}{1-\delta}\right)^{\frac{1}{1+\rho}} + 1\right]^{-\frac{v}{\rho}} = A_0 L^{v}\left[(1-\delta)\left[\left(\frac{K}{L}\right)_2 + 1\right]\right]^{-\frac{v}{\rho}}$$

Thus, Ratio (17) represents the optimal ratio of capital and labor to achieve the maximum volume of production. To determine the optimization of the ratio of capital and labor, we introduce the coefficient h as follows:

$$h = \frac{1-\delta}{\delta}\left(\frac{K}{L}\right)^{1+\rho}$$

If the ratio of capital and labor is determined by Equation (9), we get:

$$h = \frac{1-\delta}{\delta}\left(\frac{K}{L}\right)^{1+\rho} = \frac{1-\delta}{\delta}\left(\left(\frac{\delta}{1-\delta}\right)^{\frac{1}{\rho+1}}\right)^{1+\rho} = 1$$

If $h > 1$, the actual capital–labor ratio is higher than the optimal level, meaning that the costs of increasing fixed assets exceed wages. In this case, it is necessary to reduce fixed assets or increase the wage bill. If $h < 1$, the amount of fixed assets is lower than the wages fund. In this case, the cost of raising fixed assets must be higher or the wage must be reduced. The fact that $h = 1$ indicates that the ratio of capital and labor is at the optimal level, and at this time the level of production is maximal.

We estimated the parameters of the CES production function using the Marquardt method in the Mathcad software package using the World Bank indicators for 2000–2020 for Azerbaijan, Kazakhstan, and Russia. First, the statistical characteristics of the parameters were analyzed, and then a comparative analysis of the results was carried out. Then, using the parameters of the CES function obtained for the countries, the optimal capital–labor ratio was found for the optimization of the production volume.

4. Empirical Results

Now let us estimate the parameters of the CES production function using the aggregate country statistics. The respective data were deflated to reflect the statistical indices of countries in real prices. The models are based on the program written by the authors in Mathcad using the method proposed by the Japanese scholars, and the coefficients of determination and Darbin–Watson statistics were calculated in the program [44].

In addition, the F-test was performed, which shows the overall significance of the explanatory variables. The hypothesis test results showed that the effect of these variables jointly is significant. Moreover, we checked the stationarity of the indicators and residuals of the models using the augmented Dickey–Fuller test in EViews and they were all stationary at least at the second levels.

The following results were obtained as a result of evaluating the CES function for the Azerbaijani economy using the Marquardt method based on indicators from 2000–2020 (Table 1).

$$Y = 0.875e^{0.047t}\left(0.871K^{-2.163} + 0.129L^{-2.163}\right)^{-0.462}$$
$$R^2 = 0.86\ \sigma = 0.32$$
$$F = 55.3\ p = 0.0001$$

Table 1. Statistic indicators of Azerbaijan.

Year	GDP (Constant 2015 Million USD)	Gross Capital Formation (Current Million USD)	Labor Force (Total)
2000	11,918.02	1090.076	4,274,824
2001	13,097.9	1180.178	4,256,140
2002	14,334.2	2156.141	4,237,050
2003	15,797.48	3869.158	4,221,419
2004	17,259.35	5033.784	4,206,541
2005	22,085.33	5501.587	4,234,446
2006	29,704.76	6265.391	4,237,901
2007	37,130.96	7114.089	4,335,205
2008	41,125.87	9132.303	4,424,004
2009	44,949.08	8392.635	4,466,497
2010	47,218.53	9555.196	4,528,109
2011	47,265.75	13,366.97	4,572,791
2012	48,289.17	15,551.17	4,627,324
2013	51,094.67	19,029.06	4,702,401
2014	52,500.03	20,699.73	4,791,071
2015	53,074.37	14,814.95	4,876,104
2016	51,429.07	9724.886	4,969,576
2017	51,531.92	9962.584	5,033,710
2018	52,304.9	9483.588	5,091,128
2019	53,612.52	9783.118	5,103,475
2020	51,307.19	10346.53	4,846,887

Source: World Bank (2021) [45].

This analysis of the CES function for Azerbaijan's economy reveals that the elasticity of labor and capital substitution for one another was less than one, namely, 0.32. This once again demonstrates how using the Cobb–Douglas production function to analyze the economy of a country can generate inaccurate conclusions because the flexibility of the mutual substitution of capital and labor is assumed as a precondition in the Cobb–Douglas production function. The model's statistical properties demonstrated the reliability of the results. That is, the annual change in capital volume and labor use in the analyzed years explains 86% of the annual change in GDP volume, according to the coefficient of determination (R^2). The reliability of the coefficient of determination was verified by Fisher's F-test. Thus, the probability of rejecting this hypothesis (p) is almost zero.

The following results were obtained as a result of evaluating the CES function for the Kazakhstan economy using the Marquardt method based on indicators from 2000–2020 (Table 2).

$$Y = 0.968e^{0.048t}\left(0.569K^{-1.321} + 0.431L^{-1.321}\right)^{-0.757}$$
$$R^2 = 0.99\ \sigma = 0.43$$
$$F = 891\ p = 0.0001$$

Table 2. Statistic indicators of Kazakhstan.

Year	GDP (Constant 2015 Million USD)	Gross Capital Formation (Constant 2015 Million USD)	Labor (Total)
2000	66,179.34	9294.084	7,642,391
2001	75,113.55	13,058.19	7,658,645
2002	82,474.67	14,494.59	7,700,930
2003	90,144.82	15,422.24	7,783,698
2004	98,798.72	17,751	7,876,506
2005	108,382.2	23,963.85	7,943,998
2006	119,979.1	31,560.39	8,079,537
2007	130,657.2	38,945.52	8,274,942
2008	134,968.9	33,960.5	8,533,075
2009	136,588.5	34,741.59	8,573,098
2010	146,559.5	35,436.42	8,721,578
2011	157,404.9	37,349.99	8,816,456
2012	164,960.4	42,093.44	8,899,357
2013	174,858	44,913.7	8,972,219
2014	182,202	48,776.27	9,045,894
2015	184,388.4	51,458.97	9,115,881
2016	186,416.7	52,745.44	9,064,290
2017	194,059.8	54,380.55	9,004,270
2018	202,016.2	55,957.59	9,169,408
2019	211,107	62,784.41	9,227,219
2020	205,829.3	61,528.72	9,195,720

Source: World Bank (2021) [45].

Statistical evaluations show that the models are adequate. This result of the evaluation of the CES function for the economy of Kazakhstan also showed that the elasticity of mutual substitution of capital and labor was less than unity and was 0.43. The coefficient of determination (R^2) of 0.99 indicates that 99% of the variation of GDP in Kazakhstan over the studied years can be explained by the variation of capital and labor. The quality of this result was shown by the F-test. Thus, the probability of rejecting this hypothesis (p) is almost zero.

The following results were obtained as a result of evaluating the CES function for the Russian economy using the Marquardt method based on indicators from 2000–2020 (Table 3).

$$Y = 0.987e^{0.017t}\left(0.634K^{-2.469} + 0.366L^{-2.469}\right)^{-0.405}$$
$$R^2 = 0.98\ \sigma = 0.29$$
$$F = 441\ p = 0.0001$$

Statistical evaluations show that the models are adequate. This results of assessment of the CES function for the Russian economy also indicates that the elasticity of labor and capital substitution was less than one, at 0.29. According to the coefficient of determination (R^2) of 0.98, changes in capital and labor may explain 99% of the change in GDP in Russia over the research period. The F-test demonstrated the reliability of this result. Thus, the probability of rejecting this hypothesis (p) is almost zero.

Table 3. Statistics for Russia.

Years	GDP (Constant 2015 Million USD)	Gross Capital Formation (Constant 2015 Million USD)	Labor Force (Total)
2000	780,432.2	157,160.3	73,312,709
2001	820,234.7	183,405.4	72,007,910
2002	858,785.6	178,637.4	72,965,301
2003	921,476.6	204,182.6	72,845,412
2004	987,822.4	229,093.4	73,570,472
2005	1,051,043	250,857.1	74,140,578
2006	1,137,229	295,258.9	74,432,744
2007	1,233,893	360,215.3	75,462,934
2008	1,298,055	398,037.7	76,004,239
2009	1,196,807	234,842.1	76,014,195
2010	1,250,663	301,771.4	75,880,787
2011	1,304,442	365,143.4	76,029,232
2012	1,356,934	385,379.4	75,820,112
2013	1,380,754	365,513.6	75,450,406
2014	1,390,920	342,175.8	75,248,204
2015	1,363,481	301,993.7	75,016,902
2016	1,366,122	300,063.4	74,937,521
2017	1,391,065	319,296.3	74,694,581
2018	1,430,115	314,215.7	74,549,433
2019	1,459,189	324,442.2	73,525,633
2020	1,416,124	318,039.8	72,809,444

Source: World Bank (2021) [45].

The study of the CES production function's parameters for all three oil-rich countries reveals that the balance between capital and labor was disrupted in each of these three countries. In Russia, there was more imbalance. The brain drain resulting from the recent socioeconomic circumstances in Russia is another factor contributing to this.

Let us calculate the value of the parameter h to determine the optimal level of the balance of capital and labor:

$$h = \frac{1-\delta}{\delta}\left(\frac{K}{L}\right)^{1+\rho}$$

For the Azerbaijan economy, δ = 0.871 and ρ = 2.163. The capital for 2020 was AZN 234.2 billion (fixed assets in the economy at the end of the year) with a labor force of 4,876,600 people. The average salary was AZN 708. Therefore, $L = 708 \times 4876600 \times 12$ = AZN 41.43 billion. In this case,

$$h = \frac{1-0.871}{0.871}(\frac{234.2}{41.43})^{1+2.163} = 0.15 \times 5.65^{3.163} = 0.15 \times 239.2 = 35 > 1$$

For the economy of Kazakhstan, δ = 0.569 and ρ = 1.321. The capital for 2017 was USD 257 billion, with a labor force of 9,253,298 people. The average salary was USD 485. Therefore, $L = 485 \times 9253298 \times 12$ = USD 52.38 billion. In this case,

$$h = \frac{1-0.569}{0.569}(\frac{257}{52.38})^{1+1.321} = 0.76 \times 4.91^{2.321} = 0.76 \times 40.2 = 30.5 > 1$$

For the economy of Russia, δ = 0.634 and ρ = 2.469. The capital for 2019 was RUR 349 trillion, with a labor force of 73,525,633 people. The average salary was RUR 51,344 rubles. Therefore, $L = 51344 \times 73525633 \times 12$ = USD 45 trillion. In this case,

$$h = \frac{1-0.634}{0.634}(\frac{349}{45})^{1+2.469} = 0.577 \times 7.8^{3.469} = 0.577 \times 1243 = 717 > 1$$

Thus, we can summarize the obtained results as in the Table 4.

Table 4. Parameters of CES and optimal capital–labor ratio.

Year	h	σ	δK	$(1-\delta)L$	A_0	ρ	λ
Azerbaijan	35	0.32	0.871	0.129	0.875	2.163	0.047
Kazakhstan	30.5	0.43	0.569	0.431	0.968	1.321	0.048
Russia	717	0.29	0.634	0.02	0.96	1.9	−0.007

The results illustrate an imbalance between the capital and labor markets as well as an imbalance compared to the previous years.

Let us take a look at the interpretation of the results obtained by the researchers who evaluated the parameters of the CES function. Weitzman [46] estimated the parameters of the CES function of the Soviet economy for the period 1950–1969. The evaluation was carried out with the algorithm proposed by MIT (Massachusetts Institute of Technology) professor M. Weitzman himself ("Least Squares Estimates of Non-Linear Parameters") and concluded that the elasticity of substitution is much smaller than unity ($\sigma = 0.4031043$). Weitzman explained the obtained result with the lack of manpower. This situation is associated with the fact that the Soviet Union, which suffered a significant loss of manpower from the Second World War, is still unable to restore its labor resources. Granberg [47] estimated the parameters of the CES function based on the data of the Soviet Union for the years 1960–1985 and found the elasticity of substitution of labor (labor) with capital to be σ =0.25 and concluded that there was a labor shortage.

In this study, for Russia, the elasticity coefficient was less than one and the coefficient for the capital–labor ratio was higher than one. In other words, along with the lack of qualified labor, the optimal capital–labor ratio for achieving the maximum volume of GDP did not exist. This situation suggests that the decrease in the import of capital goods in Russia will deepen in the coming years and that the GDP volume will decrease. It should be noted that this result obtained for Russia was obtained with data covering the period before Russia's war with Ukraine. The conflict between Russia and Ukraine deepens the result.

It should be noted that in the research conducted by Hasanli [48], a elasticity coefficient of 3 was obtained for the economy of Azerbaijan with the data of 1990–1996. Thus, after the collapse of the former Soviet Union, the termination of economic relations with the former Soviet states, and the failure to establish new foreign relations as a result of the aging of the existing main funds in the economy and the failure to renew them due to the economic decline, the labor force remained unemployed, which caused the elasticity of substitution to be greater than unity—that is, labor abundance. The result of the study of the parameters of the CES production function with the data of 1994–2000 showed that the elasticity of substitution of labor and capital was 1.0003. An elasticity close to 1 indicates a balance between labor and capital. This means that the qualification level of the existing labor force at that time was sufficient to mobilize the available capital. This was due to the large amount of investment made in the country with the contracts concluded in 1994 and the increase in the capital volume and the balance with the available labor.

In our example, this coefficient was equal to approximately 0.32 for the years 2000–2020. The reason for this is that the income from oil was directed to the import of capital created with modern technologies, which was not met by the existing labor force, and a situation of skilled labor shortage arose. The coefficient of optimality for Azerbaijan was much higher than optimal—that is, the amount of the wage fund was lower than the level that could give the optimal level to the GDP. The main reason for this is the import of capital products, which are not used at full capacity, as mentioned above, and at the same time, the low wage bill—that is, the low level of qualification, which forces people to work in low-paid jobs. This situation increases the possibility that the elasticity of substitution of the capital and labor ratio in Azerbaijan will remain below unity in the coming years.

For Kazakhstan, the elasticity of substitution (σ) is less than unity, and the coefficient (h) characterizing capital–labor ratio that can give the optimal level to the GDP is greater than unity. Although this situation is positive compared to Azerbaijan and Russia, it is beyond the level of balance and optimality. Thus, in Kazakhstan, there is a lack of qualified labor force that can use the capital (fixed assets) to its full potential, and the volume of the wage fund that can give an optimal level to the GDP is low and the volume of the capital (fixed assets) is high.

5. Discussion

The elasticity of substitution estimated in the CES production function was found to be less than unity for all three countries. It can be concluded that this situation is related to the lack of labor in the current capital–labor ratio in all three countries rich in natural resources. This means that the potential of existing capital (fixed funds) is not used. Rather, labor lacks taking advantage of capital potential. In the current period, the main assets (capital) in the economy consist of machines, devices, equipment, etc. made with advanced technologies. In order to activate these basic funds and involve them in the production process with full power, the presence of qualified personnel and labor force is necessary.

The obtained values of elasticities of substitution also indicate that there is a complex labor shortage. Thus, in countries rich in oil and gas resources, the exploitation and export of these resources causes a large amount of foreign currency to enter the country. These foreign-exchange reserves allow for the quick import of capital products produced with the most advanced technologies from abroad. However, the training of qualified personnel who can handle these basic funds is delayed. Bringing qualified labor force from foreign countries to these countries has not happened either. The training of qualified personnel takes place by increasing the costs and raising the quality of science and education. The process of training qualified personnel takes a long time. The main reason for this process is the complex capital structure from oil revenues and the low level of specialization of the existing labor force to launch this capital. Thus, the imbalance between science and education and capital is obvious. On the other hand, capital is more mobile than labor.

The rapid import of modern capital, created using advanced technology, innovation, and nanotechnology, creates a shortage of qualified personnel to mobilize this capital. This is typical for countries rich in natural resources. Although liberal market relations in the economy create incentives for the imbalance of capital and labor, there are other examples. For example, Norway, despite being a country rich in natural resources, did not have an imbalance in the ratio of capital and labor. A total of 100% of shares of the Norwegian Stotoil Oil Company belong to the state. This does not allow the oil-export revenues to be liberally sold on the currency market. The revenues are collected in the Oil Fund and used for future generations and to improve the quality of science and education.

The optimal capital–labor-ratio coefficients show that these coefficients are significantly higher than optimal, meaning that, compared to the wage fund, the value of the fixed capital is greater than the amount that can give the optimal level to the volume of GDP. One of the reasons for this may be the low level of specialization that makes people work in low-wage jobs.

It should be noted that the optimal capital–labor ratio for all three countries was calculated with data from recent years.

In general, the lack of skilled labor appears to be a challenge for all three countries to achieve their potential GDP. Therefore, in these resource-rich countries, while keeping the wage fund in balance with fixed capital expenditures, directing oil revenues to human capital and education could be an impetus for the development of the non-oil sector, especially in the current uncertain situation.

6. Concluding Remarks

In contrast to the existing literature that is dominated by non-theoretical or cursory elaborations, this study conducts a rigorous, i.e., theory-based analysis of the petroleum-exporting economies and decisively changes the perspective on the problem. We find that the human-capital shortage is also a relevant problem for the transition economies that are deemed to be formally human-capital rich.

Thus, the estimation of the elasticity of capital–labor substitution and its juxtaposition with the optimal level of the capital–labor ratio indicates that there is a strong divergence between two values. This kind of disequilibrium exhibits grave repercussions for the growth perspectives of petroleum-exporting countries. The impressive amount capital imports is the direct result of oil windfalls. Without the compliance of a trained working force, however, capital accumulation does not translate into economic growth. The present inquiry is the first step in testing the significance of the lack of human capital as the primary cause of the resource curse in the natural-resource-abundant settings.

Follow-up studies with a special focus on developing countries will show whether the findings of this study can be generalized for the case of the Global South. Against the backdrop of the relatively high level of human-capital development in post-communist areas, the effects for developing countries could be even more proliferated. The success of the UAE could also emanate from the fact that over the past three decades the massive capital inflow into the UAE has been accompanied by a remarkable level of immigration of a qualified labor force.

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