2/2025, mart-aprel (№ 00076)

TFP ESTIMATION: EVIDENCE FROM SILK ROAD REGION

Ataev Farrukh Rakhimjanovich
Lecturer and PhD candidate at School of Business and Economics, Westminster International University in Tashkent, Uzbekistan, 100047, Tashkent, Istiqbol Street, 12.
Email: fataev@wiut.uz
DOI: *https://doi.org/10.55439/EIT/vol13_iss2/665*

Abstract
The paper estimates the total factor productivity (TFP) of 86 countries along the ancient Silk Road region from 1991 to 2019, employing the growth accounting (GA) method and the generalized OLS (GOLS) model. Unlike many studies, it considers three factors of production: capital, labor, and natural resources. The findings indicate average TFP contributions to economic growth of 0.52 for high-income, 1.55 for upper-middle-income, 0.73 for lower-middle-income, and -0.23 for low-income countries. The TFP estimates for the income group samples are more accurate than those derived from the total sample of countries. Natural resources significantly contribute to economic growth. This TFP analysis offers valuable insights for policymakers, researchers, and businesses, helping them understand productivity dynamics, identify the areas for improvement, and develop policies and strategies to enhance productivity and economic growth. The study enriches literature on TFP estimation in Silk Road countries.
Keywords: Total factor productivity, Growth theory, Growth accounting, Silk Road region, GOLS.

1. Introduction

The concept of productivity has deep historical roots, beginning with early human civilizations focused on agricultural output. Early farmers enhanced productivity through effective practices like crop rotation, irrigation, and domestication of animals. The Industrial Revolution in the 18th century marked a major shift, introducing steam power, mechanization, and mass production, which were crucial for economic growth. This era emphasized efficiency, waste reduction, and process optimization in factories.

Economists such as Smith (1776), Ricardo (1817), and Malthus (1798) developed classical growth theory, highlighting the significance of capital accumulation, division of labor, specialization, and the role of free markets and competition in economic growth. While this theory does not explicitly address technological progress, it acknowledges that advancements in technology can boost economic growth by increasing productivity and efficiency. The spread of new ideas, innovation, and the collection of knowledge can all lead to technological advancements. In the late 19th and early 20th centuries, Taylor (1911) introduced the principles of scientific management, or Taylorism, aimed at enhancing employee productivity and efficiency by standardizing and assessing their work, providing proper tools and training, and rewarding them when they do well.

Economists Solow (1956, 1957) and Swan (1956) independently developed neoclassical growth theory, emphasizing capital accumulation, technological advancement, and the efficient use of available resources to drive economic growth. They introduced total factor productivity (TFP), which measures the portion of output growth not explained by changes in input quantities (such as labor and capital) alone. It captures technological progress, innovation, and improvements in resource allocation efficiency. Solow (1957) estimated the parameters of his model and tested predictions using historical data from the United States. He discovered that capital accumulation accounts for only 12.5% of output per worker growth, while technical progress contributes 87.5%. Solow's groundbreaking work on TFP has significantly influenced economic research and policymaking. As TFP growth is recognized as the primary driver of long-term economic growth, governments, corporations, and enterprises worldwide concentrate on fostering it through investments in R&D, education, and infrastructure.

The ancient Silk Road was a vast network of trade routes, stretching thousands of miles over land and sea, which connected Asia, Europe, and Africa. It significantly impacted the societies and economies of the regions it linked. It fostered economic growth, encouraged cultural diversity, and facilitated the emergence of powerful empires and trading cities. However, by the 15th century, its importance declined due to political instability and the discovery of new sea routes during the Age of Exploration.

In recent years, the term "Silk Road" has been revived to describe modern initiatives aimed at promoting economic connectivity and cultural exchange along these historic routes, notably China's Belt and Road Initiative (BRI). Launched in 2013, the BRI is the largest infrastructure and development project in history, presenting both risks and opportunities for ecosystems, economies, and communities (Hughes et al., 2020). The initiative seeks to improve connectivity and promote economic cooperation between China and countries across Asia, Europe, Africa, and beyond.

The initiative encompasses a wide range of projects, including the construction of roads, railways, ports, pipelines and other infrastructure facilities. According to Nedopil (2024), by December 2023, 150 countries had signed cooperation agreements with China under the BRI framework. Over its first decade, cumulative BRI engagement exceeded $1.053 trillion, with about $634 billion in construction contracts and $419 billion in non-financial investments.

2. Literature review

Inspired by Solow's seminal work (1957), which introduced the GA method and estimated TFP (also known as Solow residual), economists have extended its application across various datasets at the firm, industry, and country levels. Utilizing cross-sectional, time-series, and panel data, this extension has led to the development of more refined TFP measures, as summarized in Figure 1 (see Mahadevan (2003), Kiani et al. (2008), See and Coelli (2014), Hu and Liu (2017)):

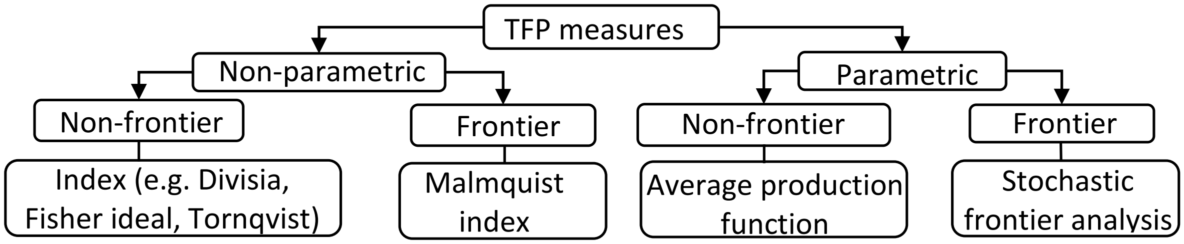


Figure 1. TFP measurement methods.

From its initial definition by Copeland (1937) to its codification by Solow (1957), Griliches (1995) examined the evolution of the term “residual”, outlining prior contributions from Tinbergen, Stigler, Schmookler, Fabricant, Kendrick, Abramovitz, and others. Bosworth and Collins (2003) applied both GA and growth regression methods to 84 countries from 1960 to 2000, concluding that both methods can yield consistent and useful results on cross-country differences in economic growth. However, Louwerse (2018) doubted in accuracy of the GA methodology, arguing that it relies on unrealistic assumptions of perfect competition, simultaneous expenditures, and revenues for labor and intermediaries. He concluded that when these assumptions fail, economic growth attributed to labor and intermediaries is underestimated, while that attributed to physical capital is overestimated. As a result, the economic growth attributed to productivity can be biased in both directions.

Senhadji (2000) conducted a GA exercise for 88 countries from 1960 to 1994 to observe the sources of cross-country differences in TFP levels. He estimated the production function in both levels and first differences for comparison. The author found unusually high output shares for capital (0.55 in levels and 0.53 in first differences), compared to typical values (ranging from 0.30 to 0.40) used in GA exercises.

Xiuwu *et al.* (2022) employed the DEA-Malmquist index method to measure TFP in 36 BRI countries from 2006 to 2015, empirically estimating two-way investments between China and BRI nations. They concluded that China’s direct investment in BRI countries effectively enhances TFP in each country and emphasized the need to focus on the quality of foreign investments in China. However, their study was limited by the selection of only 36 out of over 130 BRI countries due to data availability.

Qiu *et al.* (2022) demonstrated the positive impact of innovation investment and institutional quality (political, economic, and legal) on green TFP using panel data of 46 BRI countries between 2004 and 2016, and used Malmquist-Luenberger index to estimate green TFP.

Crafts and Woltjer (2021) noted that TFP is commonly treated as a measure of technology, capturing how intensively and efficiently inputs are utilized in production. However, they acknowledged that this broad interpretation of TFP raises several unresolved questions, particularly regarding the inclusion factors beyond labor and capital. They made a logical assumption that the discovery of new arable land or natural resources can significantly increase a country’s output without changing labor and capital. This can create a misleading impression of improved TFP or substantial technological change. This raises the paradoxical issue of the “resource curse”, a term first coined by Auty (1993), which describes how resource-rich countries often fail to use their wealth to boost their economies. Adika (2022) lists studies that observe a negative relationship between natural resource abundance and economic growth.

Malik and Masood (2020) investigated the variability of economic growth and productivity in Middle East and North Africa (MENA) countries from 1970 to 2014, using the GA method to decompose economic growth into contributions from factor accumulation and TFP. They found that the output growth in the region was due to factor inputs accumulation, with TFP playing a minor role, except in Iraq and Tunisia. They also noted significant variability in growth performance among oil-dependent countries, linked to fluctuations in oil prices, while non-oil countries showed higher and more consistent growth. Their model assumed constant returns to scale, using labor shares from PWT 9.0, which implies that the capital share equals one less labor share of output. However, several research gaps remain:

1) considering a non-constant returns to scale production function and estimating labor and capital shares of output through regression analysis.

2) classifying countries by income levels to gain insights into economic and TFP growth patterns.

3) treating natural resources as a separate factor of production could clarify growth performance differences between oil-dependent and independent countries.

N. Nordin and H. Nordin (2018) analyzed the role of economic freedom in mediating the impact of domestic and foreign R&D on productivity growth in 38 developing countries in 2000-2010. The researchers found mixed results. Notably, additional research gaps include:

1) clarifying the sampling of countries by income level (high-income (HIC), upper-middle-income (UMIC), lower-middle-income (LMIC), low-income (LIC)) to enhance the validity of findings, as HICs are typically classified as developed rather than developing.

2) the 10-11 year period allows for the examination of medium effects, including the accumulation of R&D, changes in economic freedom policies and potential impacts on technological progress and economic growth, but a longer timeframe could provide a more accurate reflection of these relationships.

In this research article, our primary objectives are to address several unresolved issues and research gaps related to the estimation of TFP. We aim to refine TFP measurement by incorporating natural resources as a third input alongside capital and labor. Furthermore, we seek to enhance the accuracy of TFP estimation by expanding our sample size to include 86 countries within the Silk Road region. Hence, this study contributes to the literature by providing empirical evidence on the significance of economic and TFP growth in the Silk Road region.

To achieve these objectives, we will investigate the following research questions:

1) What are the implications of incorporating natural resources into TFP measurement for assessing technological change and productivity growth in countries?

2) How do estimated TFP values differ when natural resources are included as a factor input compared to the traditional approach that considers only labor and capital?

3) What variations, patterns, and trends exist in TFP levels and growth rates across the 86 Silk Road countries, and what factors contribute to these differences?

4) What are the potential policy implications of the refined TFP estimates for promoting sustainable economic growth and development in the Silk Road countries?

By addressing these research questions, our study aims to fill the existing gaps in understanding TFP measurement and provide valuable insights into productivity growth and technological change in the Silk Road countries. As Hall and Jones (1999) noted, differences among countries can be attributed to variations in human capital, physical capital, and productivity.

3. Data and methodology

Solow (1957) defined the production function as follows:

$$Q(K,L) = A(t)f(K,L) \qquad (1)$$

where Q is output, K is capital, L is labor, $A(t)$ is cumulative effect of shifts (technical change or TFP).

Hamilton et al. (2019) extended this function to include natural resources:

$$Q(K,L,N) = A(t)f(K,L,N) \qquad (2)$$

where $N -$ natural resources.

We consider the Cobb-Douglas aggregate production function:

$$Y_{it}(K,L,N) = A_{it}K_{it}^{\alpha}L_{it}^{\beta}N_{it}^{\gamma} \qquad (3)$$

where i is country index, t is time index, α is share of capital and β is share of labor. For simplicity, indices are omitted in the subsequent content.

Taking the natural logarithm of (3) provides the econometric model for estimating α, β, and γ:

$$\ln Y = \ln A + \alpha \ln K + \beta \ln L + \gamma \ln N \qquad (4)$$

Next, we estimate the level of TFP with the formula:

$$A = Y/(K^{\alpha}L^{\beta}N^{\gamma}) \qquad (5)$$

To estimate TFP growth, we first take the total differential of (3) and then divide the result by Y:

$$g_A = g_Y - \alpha g_K - \beta g_L - \gamma g_N \qquad (6)$$

where g represents growth.

The study used data from the Penn World Table 10.0 (Feenstra *et al.*, 2015) for variables such as real GDP, capital stock, and labor force. Additionally, data for total natural resources was sourced from the World Bank (World Development Indicators, 2023). Below is a description of the variables:

rgdpna: Real GDP at constant 2017 national prices (in million 2017 USD). It represents the total value of goods and services produced in an economy, adjusted for inflation using 2017 as the base year.

rnna: Capital stock at constant 2017 national prices (in million 2017 USD). It refers to the total value of physical capital, such as machinery, equipment, and infrastructure, in an economy, adjusted for inflation using 2017 as the base year.

emp: Number of persons engaged (in millions). It represents the total number of individuals who are employed or actively involved in productive activities in the economy.

rtfpna: Total Factor Productivity (TFP) at constant national prices, with 2017 set as the reference year (2017=1). TFP measures the portion of output that cannot be explained by changes in inputs such as labor and capital. It provides an indication of technological progress, efficiency gains, and other factors affecting overall productivity.

totnatres: Total natural resources rents, the income generated from the extraction and use of natural resources (coal rents, forest rents, mineral rents, natural gas rents and oil rents expressed as percentage of GDP) in a country.

All calculations, and the generation of tables and figures, were performed using Stata 14 software.

4. Results and discussion

As illustrated in Table 1, most of the 86 countries included in the study experienced a progressive improvement in their income status over the 29-year period from 1991 to 2019.

Table 1

List of countries in samples (based on GNI per capita in US dollar, World Bank)

20 Low income ($635 or less in 1991) Bangladesh, Bhutan, Cambodia, China, Egypt, Ethiopia, India, Indonesia, Kenya, Lao PDR, Madagascar, Mozambique, Myanmar, Nepal, Pakistan, Sri Lanka, Sudan, Tanzania, Viet Nam, Yemen **27 Lower middle-income ($636 to $2,555 in 1991)** Albania, Algeria, Armenia, Azerbaijan, Bulgaria, Djibouti, Georgia, Iran, Iraq, Jordan, Kazakhstan, Kyrgyzstan, Lebanon, Malaysia, Moldova, Mongolia, Morocco, Philippines, Poland, Romania, Syria, Tajikistan, Thailand, Tunisia, Turkmenistan, Ukraine, Uzbekistan **12 Upper middle-income ($2,556 to $7,910 in 1991)** Bahrain, Belarus, Estonia, Greece, Hungary, Republic of Korea, Latvia, Lithuania, Oman, Portugal, Russian Federation, Saudi Arabia **18 High-income ($7,911 or more in 1991)** Austria, Belgium, Brunei Darussalam, Denmark, France, Germany, Israel, Italy, Japan, Kuwait, Luxembourg, Netherlands, Qatar, Singapore, Spain, Switzerland, United Arab Emirates, United Kingdom	**7 Low income ($1,035 or less in 2019)** Ethiopia, Madagascar, Mozambique, Sudan, Syria, Tajikistan, Yemen **23 Lower middle-income ($1,036 to $4,045 in 2019)** Algeria, Bangladesh, Bhutan, Cambodia, Djibouti, Egypt, India, Kenya, Kyrgyzstan, Lao PDR, Moldova, Mongolia, Morocco, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Tanzania, Tunisia, Ukraine, Uzbekistan, Viet Nam **22 Upper middle-income ($4,046 to $12,535 in 2019)** Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, China, Georgia, Indonesia, Iran, Iraq, Jordan, Kazakhstan, Lebanon, Malaysia, Montenegro, North Macedonia, Russian Federation, Serbia, Thailand, Turkiye, Turkmenistan **34 High-income ($12,535 or more in 2019)** Austria, Bahrain, Belgium, Brunei Darussalam, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Israel, Italy, Japan, Kuwait, Latvia, Lithuania, Luxembourg, Netherlands, Oman, Poland, Portugal, Qatar, Republic of Korea, Romania, Saudi Arabia, Singapore, Slovakia, Slovenia, Spain, Switzerland, United Arab Emirates, United Kingdom

For instance, of the 20 LICs, 13 transitioned to the lower middle-income group, and two – China and Indonesia – advanced to the upper middle-income group. Among the 27 LMICs, 13 moved up to the upper-middle income group, with Poland and Romania advancing to the high-income group.

Additionally, 10 of the 12 UMICs progressed to the HIC group. Our analysis of the TFPs of the countries indicates that these upward transitions reflect the economic growth and technological progress.

Table 2 presents the descriptive statistics of the factors of the log-linear production function (4).

Table 2

Descriptive statistics (T-total, H-high, U-upper-middle, LM-lower-middle, L-low)

	ln(Output)					ln(Capital)					ln(Labor)					ln(Totres)				
	T	H	U	LM	L	T	H	U	LM	L	T	H	U	LM	L	T	H	U	LM	L
n	2,494	986	638	667	203	2,494	986	638	667	203	2,494	986	638	667	203	2,437	962	612	661	202
Mean	12.0	12.6	11.9	11.5	10.8	13.8	14.2	13.3	12.6	12	1.7	1.3	1.6	2.1	1.9	7.7	7.3	8.1	7.9	7.9
SD	1.72	1.5	1.8	1.8	0.9	1.9	1.5	1.9	1.9	1.0	1.7	1.5	1.9	1.7	0.8	2.7	2.5	3.32	2.3	2.0
Min	6.9	9.7	8.4	6.9	8.7	7.2	11.3	10.1	7.2	9.9	-2.2	-2.2	-1.8	-1.7	0.6	-1.6	-0.4	-0.3	1.4	-1.6
Max	16.8	15.4	16.8	16.0	12.5	18.4	17.1	18.4	17.4	13.4	6.7	4.3	6.7	6.2	4.1	14.0	13.5	14	12.7	10.9

Note that while the averages of labor and total resources are rising, the averages of output and capital decline from HICs to LICs. This illustrates the theory that LICs may employ more labor and resources in their production processes, potentially due to limited access to capital, technology, and productivity-enhancing resources. In contrast, HICs likely benefit from advanced technology, higher capital intensity, and more efficient production processes, enabling them to produce more at higher levels while using comparatively less labor and resources.

By considering the intensity of factor employment, we can better understand the variations in resource allocation and production patterns among different income groups. Furthermore, the standard deviation statistics indicate that the data values for all variables in HICs are less volatile than those in middle-income countries. This suggests that over time, the economic performance of HICs may be more stable and predictable. Several factors may contribute to this stability:

Economic diversification: HICs often have more diversified economies, encompassing a wider range of sectors and industries. This diversity reduces overall volatility by lessening the impact of shocks in specific sectors.

Strong institutional frameworks: HICs typically possess robust institutions, including strong legal systems, stable political environments, and efficient regulatory frameworks. These institutions provide a steady and predictable business climates, reducing economic uncertainty and volatility.

Financial resource accessibility: Generally, HICs have easier access to both local and foreign capital markets. This accessibility enables them to manage economic fluctuations, smooth consumption patterns, and mitigate the effects of external shocks.

Effectiveness of policies: HICs often have well-established institutions and policy frameworks that allow them to implement countercyclical measures and effectively address economic difficulties. By lowering the volatility of key economic indicators, these policies contribute to a stable economic climate.

Table 3 displays the correlation between the variables.

Table 3

The correlation matrix

	Total				High				Upper middle				Lower middle				Low			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
ln(Output)	1				1				1				1				1			
ln(Capital)	0.95	1			0.97	1			0.97	1			0.95	1			0.51	1		
ln(Labor)	0.79	0.69	1		0.95	0.95	1		0.95	0.93	1		0.91	0.81	1		0.32	-0.33	1	
ln(Totres)	0.50	0.39	0.52	1	0.19	0.09	0.11	1	0.76	0.72	0.76	1	0.82	0.76	0.75	1	0.62	0.11	0.44	1

As expected, the dependent variable shows strong positive correlations with the independent variables, except for natural resources in HICs. Furthermore, in HICs, the labor and capital show weak positive correlation with the natural resources. There are several explanations for this:

Technology and innovation: HICs may rely less on natural resources as a source of output due to advancement in technology and innovation.

Economic diversification: To lessen sensitivity to fluctuations in specific industries and resources, HICs often diversify their economy. This diversification involves investing in sectors such as manufacturing, services, and technology, which contribute significantly to output growth.

Knowledge-based industries and human capital development: HICs may prioritize knowledge-based industries and human capital development over others. Sectors such as banking, research and development, and information technology, rely more on intellectual capital and skilled labor than on natural resources.

Sustainability and environmental considerations: Wealthy nations often recognize the importance of environmental sustainability. Consequently, they may implement regulations and practices to lessen resource exploitation and encourage ecologically sustainable production methods. This focus can lead to a weak link between output and natural resources.

Testing is conducted on four models: Fixed Effect, Random Effect, Pooled OLS, and GOLS. Table 4 provides the model selection for the entire sample and for different income groups.

Table 4

Generalized OLS model (GOLS is better than Pooled OLS, Random/Fixed effects)

	Total	High	Upper middle	Lower middle	Low
ln(Capital)	0.6825^{***} (0.006)	0.7290^{***} (0.02)	0.5738^{***} (0.025)	0.6307^{***} (0.011)	0.9114^{***} (0.049)
ln(Labor)	0.3021^{***} (0.008)	0.2926^{***} (0.021)	0.3949^{***} (0.025)	0.3362^{***} (0.015)	0.2025^{***} (0.074)
ln(Totres)	0.0131^{***} (0.002)	0.0144^{***} (0.002)	0.0132^{***} (0.003)	0.0210^{***} (0.004)	0.0136^{*} (0.008)
***p*-value**	0.000	0.000	0.000	0.000	0.000
n	2437	962	612	661	202
Note: $* p < 10\%$, $** p < 5\%$, $*** p < 1\%$. Standard errors in parentheses.					

Due to the presence of serial correlation and heteroskedasticity, the GOLS model is found the best among the four models. The findings show that the production function exhibits a nearly constant return to scale for all samples. In other words, the output shares of labor, capital, and natural resources add up to roughly one: $\alpha + \beta + \gamma \approx 1$. Moreover, the shares decrease in the order of $\alpha > \beta > \gamma$.

HICs show the highest output shares of capital and the lowest shares of labor. This is attributed to their more advanced industrial and service sectors, which require substantial investments in capital-intensive technologies and infrastructure. Consequently, their production functions have a larger capital share. Conversely, LICs tend to rely more on labor-intensive sectors such as agriculture, where labor accounts for a bigger portion of the production function.

UMICs exhibit the highest output share of labor, while LMICs have the highest output share of natural resources. Generally, the percentage of labor in the production function is greater in UMICs compared to other income groups. This can be attributed to a larger presence of labor-intensive sectors, lower levels of capital-intensive technologies, and a larger population. In contrast, LMICs often have a higher proportion of natural resources in their production functions due to their reliance on resource extraction and export-oriented industries.

Figure 2 displays the mean TFP levels and mean outputs for each nation from 1991 to 2019.

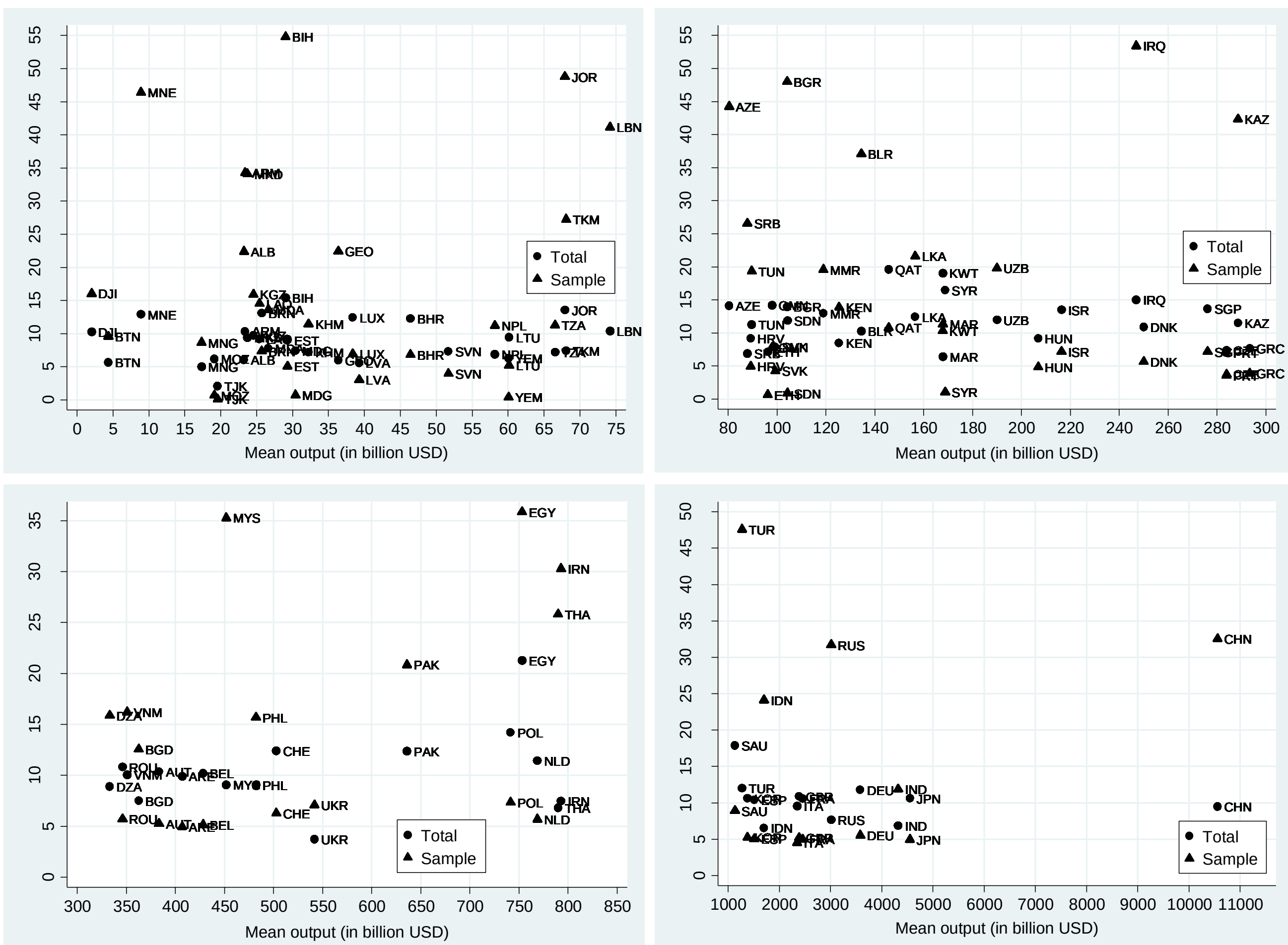


Figure 2. Mean TFP (total sample and income group sample) and mean output (real GDP) in 1991-2019.

Two types of Cobb-Douglas production functions are used to estimate the TFP figures:

1) Total sample (Total):

$$TFP = Y/(K^{0.6825}L^{0.3021}N^{0.0131}) \qquad (7)$$

2) Income group sample (Sample).

Since Saudi Arabia was classified as a HIC in 2019, the production function for estimating TFP is:

$$TFP = Y/(K^{0.7290}L^{0.2926}N^{0.0144}) \quad (8)$$

Similarly, as China was classified as an UMIC in 2019, TFP is derived from:

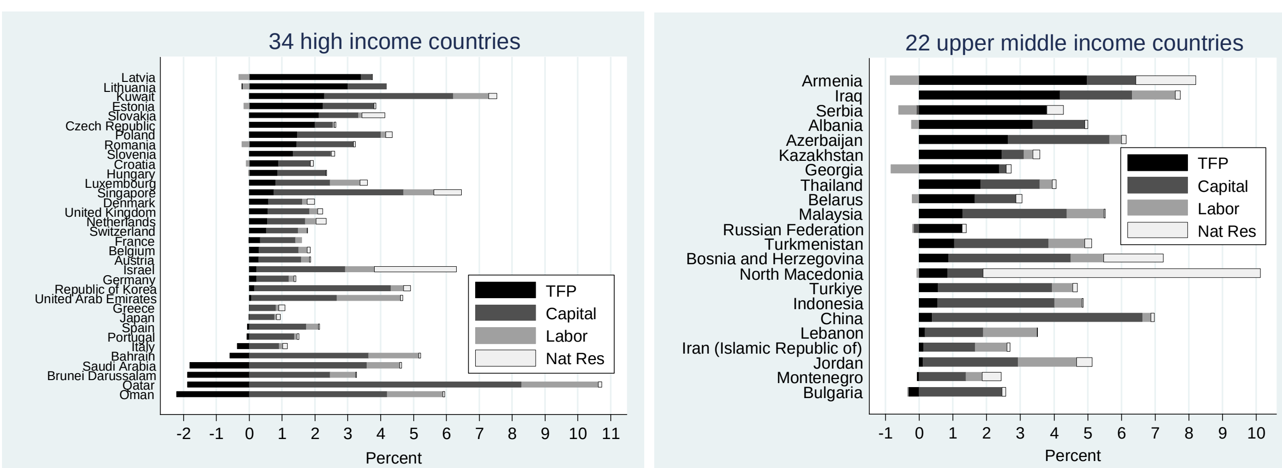
$$TFP = Y/(K^{0.5738}L^{0.3949}N^{0.0132}) \quad (9)$$

In general, the income group estimate of TFP is more accurate and reliable compared to the total sample estimate. The TFP levels for Saudi Arabia and China were 17.9 and 9.5 using the total sample formula (7), while the income group sample formulas (8) and (9) yielded 8.9 and 32.5, respectively.

During 1991-2019, China demonstrated significantly greater technological advancement than Saudi Arabia. China made remarkable progress across various technological sectors and emerged as a global leader in innovation. China’s focus on R&D, investments in education and infrastructure, and robust industrial policies contributed to its technological progress. Notable breakthroughs occurred in telecommunications, information technology, manufacturing, renewable energy, high-speed rail, and space exploration. Chinese companies became major players in sectors like telecommunications equipment, consumer electronics and e-commerce.

In contrast, while Saudi Arabia has invested in industries like gas and oil, it has not advanced technologically to the same extent as China during this period. Historically, Saudi Arabia’s economy has been more dependent on oil exports, resulting in less technical advancement. Nonetheless, since 2016, the country has initiated efforts to diversify its economy through programs like Vision 2030, which intends to advance technological innovation and transform various sectors, including digital transformation, artificial intelligence, and renewable energy.

Additionally, Figure 3 shows the mean contributions to TFP, capital, labor, and natural resources for countries at various income levels.



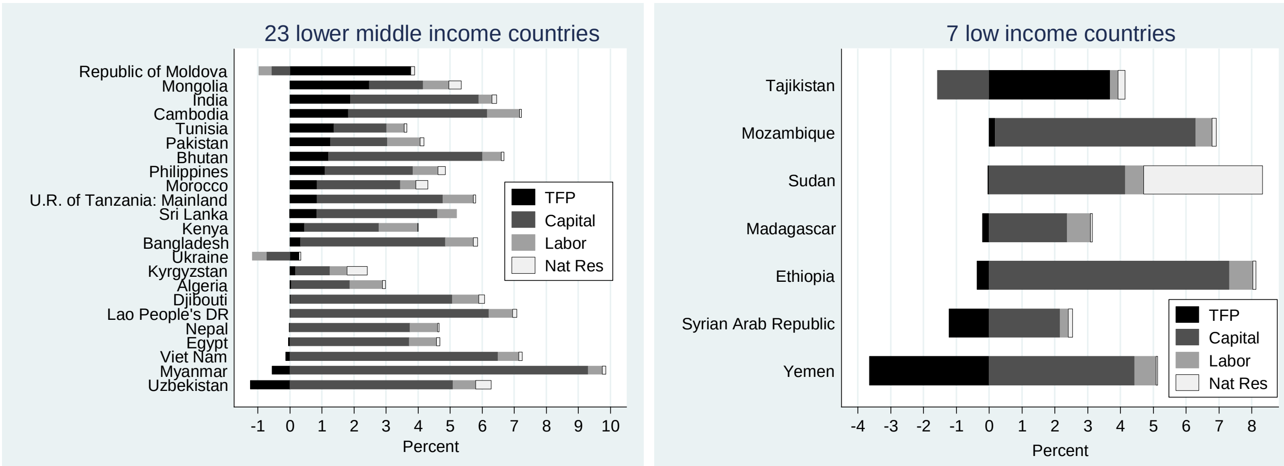


Figure 3. Mean contributions of TFP, capital, labor and natural resources in 1992-2019.

It is evident that China’s mean TFP growth was 0.38%, while Saudi Arabia’s TFP contribution was −1.8%. This notable contrast highlights the significant divergence in technological accomplishments between the two nations.

Table 5 presents the rankings of the nations based on mean TFP estimates for 10 regions within income group samples from 1991 to 2019.

Table 5

Ranking by mean TFP figures (income group sample) in 10 regions in 1991-2019.

Western Europe Luxembourg (6.9) Switzerland (6.3) Netherlands (5.7) Germany (5.5) Austria (5.3) Belgium (5.2) France (5.0) **Mean:** 5.7	**Northern Europe** Denmark (5.7) Lithuania (5.2) United Kingdom (5.2) Estonia (5.1) Latvia (3.0) **Mean:** 4.8	**Africa** Egypt (35.8) Tunisia (19.4) Djibouti (16.0) Algeria (15.9) Kenya (13.9) Morocco (11.3) Tanzania (11.3) Sudan (0.9) Madagascar (0.73) Mozambique (0.7) Ethiopia (0.7) **Mean:** 11.5	**East Asia** China (32.5) Mongolia (8.7) Republic of Korea (5.2) Japan (5.0) **Mean:** 12.9
Eastern Europe Bulgaria (48.0) Azerbaijan (44.2) Belarus (37.1) Armenia (34.3) Russian Federation (31.7) Georgia (22.4) Moldova (13.6) Czech Republic (3.8) Poland (7.3) Ukraine (7.1) Romania (5.7) Hungary (4.8) Slovakia (4.2) **Mean:** 20.3	**Southern Europe** Bosnia and Herzegovina (54.8) Turkiye (47.6) Montenegro (46.4) North Macedonia (34.1) Serbia (26.6) Albania (22.4) Spain (5.0) Croatia (5.0) Italy (4.5) Slovenia (4.0) Greece (3.9) Portugal (3.6) **Mean:** 21.5	**Middle East** Iraq (53.4) Jordan (48.8) Lebanon (41.2) Iran (30.3) Qatar (10.8) Kuwait (10.4) Saudi Arabia (8.9) Oman (7.8) Israel (7.2) Bahrain (6.8) United Arab Emirates (5.0) Syrian Arab Republic (1.1) Yemen (0.4) **Mean:** 17.84	**South Asia** Sri Lanka (21.6) Pakistan (2.8) Bangladesh (12.6) India (11.9) Nepal (11.2) Bhutan (9.6) **Mean:** 14.6
		Central Asia Kazakhstan (42.4) Turkmenistan (27.3) Uzbekistan (19.8) Kyrgyzstan (15.9) Tajikistan (0.1) **Mean:** 21.1	**Southeast Asia** Malaysia (35.3) Thailand (25.8) Indonesia (24.1) Myanmar (19.6) Viet Nam (16.2) Philippines (15.7) Lao People’s DR (14.5) Cambodia (11.4) Brunei Darussalam (7.3) Singapore (7.2) **Mean:** 17.7

Furthermore, Table 6 lists the nations according to their mean TFP values, calculated using income group samples for the period from 1991 to 2019.

Table 6

Ranking by mean TFP figures (income group sample) in 4 income groups in 1991-2019.

High income (34)	Upper middle income (22)	Lower middle income (23)	Low income (7)
Qatar (10.8) Kuwait (10.4) Saudi Arabia (8.9) Oman (7.8) Brunei Darussalam (7.3) Poland (7.3) Israel (7.2) Singapore (7.2) Luxembourg (6.9) Bahrain (6.8) Switzerland (6.3) Romania (5.7) Netherlands (5.7) Denmark (5.7) Germany (5.5) Austria (5.3) Republic of Korea (5.2) Lithuania (5.2) United Kingdom (5.2) Belgium (5.2) Estonia (5.1) Spain (5.0) France (5.0) Croatia (5.0) Japan (5.0) United Arab Emirates (5.0) Hungary (4.8) Italy (4.5) Slovakia (4.2) Slovenia (4.0) Greece (3.9) Czech Republic (3.8) Portugal (3.6) Latvia (3.0) **Mean:** 5.8	Bosnia and Herzegovina (54.8) Iraq (53.4) Jordan (48.8) Bulgaria (48.0) Turkiye (47.6) Montenegro (46.4) Azerbaijan (44.2) Kazakhstan (42.4) Lebanon (41.2) Belarus (37.1) Malaysia (35.3) Armenia (34.3) North Macedonia (34.1) China (32.5) Russian Federation (31.7) Iran (30.3) Turkmenistan (27.3) Serbia (26.6) Thailand (25.8) Indonesia (24.1) Georgia (22.4) Albania (22.4) **Mean:** 36.8	Egypt (35.8) Sri Lanka (21.6) Pakistan (20.8) Uzbekistan (19.8) Myanmar (19.6) Tunisia (19.4) Viet Nam (16.2) Djibouti (16.0) Kyrgyzstan (15.9) Algeria (15.9) Philippines (15.7) Lao People's DR (14.5) Kenya (13.9) Moldova (13.6) Bangladesh (12.6) India (11.9) Cambodia (11.4) Morocco (11.3) Tanzania (11.3) Nepal (11.2) Bhutan (9.6) Mongolia (8.7) Ukraine (7.0) **Mean:** 15.4	Syrian Arab Republic (1.0) Sudan (0.9) Madagascar (0.7) Mozambique (0.7) Ethiopia (0.7) Yemen (0.4) Tajikistan (0.1) **Mean:** 0.7

From the two tables, we observe significant differences among various income groups and geographical areas. The catch-up effect explains why TFP estimates in middle-income countries are comparatively greater than in HICs. According to the catch-up effect, countries that initially lag behind may eventually catch up and converge with more developed economies. In growth theory, this phenomenon refers to countries or regions with lower initial levels of economic development experiencing faster economic growth rates compared to those with higher initial levels. Several factors contribute to the catch-up effect:

Technological diffusion: Less developed economies can gain an advantage by absorbing and copying existing technologies and knowledge from more developed countries. Implementing these technologies can accelerate economic growth and boost productivity.

Investing in human and physical capital: Infrastructure, education, and skill development are key areas where less developed nations can make significant progress. By investing in both human and physical capital, they can narrow the productivity gap with more developed countries.

Capital deepening: Increasing the capital-to-labor ratio can lead to catch-up growth. Due to their lower initial capital stock, less developed nations may experience higher returns on investment, which spurs higher investment rates and faster economic growth.

Institutional reforms: Implementing measures like strengthening property rights, fostering market competition, and enhancing governance can create a favorable enviroment for economic growth. These reforms can boost investment, entrepreneurship, and innovation, aiding in catch-up growth.

The catch-up effect is a key mechanism behind the concept of convergence in growth theory. It implies that nations with lower starting levels of development may eventually grow faster and reduce the income gap with more developed economies. However, the extent and pace of catch-up growth can vary depending on various factors, including government policies, infrastructure, education, and access to technology and global markets. For instance, Hall and Jones (1999) showed that variations in government policies and institutions, or what they refer to as social infrastructure, lead to variations in capital accumulation, productivity, and, consequently, output per worker.

Note that the high TFP estimates of nations like Qatar, Kuwait, Iraq, Saudi Arabia, Azerbaijan, and Oman stem primarily from their rich natural resources rather than from technological progress.

The following Table 7 presents the average contributions of TFP, capital, labor, and natural resources to economic growth categorized by income groups, as depicted in Figure 3.

Table 7

Economic growth decomposition.

	TFP	Capital	Labor	Natural resources
High	0.52	2.01	0.45	0.22
Upper-middle	1.55	2.06	0.41	0.70
Lower-middle	0.73	3.45	0.65	0.17
Low	-0.23	3.57	0.52	0.62

Source: Author's own calculations.

The table indicates a catch-up effect, showing that middle-income countries have achieved higher TFP contributions to economic growth than HICs. These contribution figures align with the data in descriptive Table 2 and the associated analysis discussed earlier.

Let us compare the TFP values of Uzbekistan, a LMIC, and the United Kingdom, a HIC, to illustrate the catch-up impact while maintaining generality. The significant disparity in mean TFP figures between the United Kingdom and Uzbekistan can be attributed to multiple factors:

Strong State Support: Since gaining independence in 1991, Uzbekistan has undergone significant economic reforms while still retaining a notable level of state involvement in key sectors. The government has made significant investments in technological development, scientific research, and fostering business-friendly environment, resulting in advancements in sectors like manufacturing, energy, and agriculture. In contrast, the United Kingdom functions as a developed market economy, where the government plays a less significant role in supporting industry and technology. Recent cuts in government funding for scientific research and technology development may have slowed the rate of technological progress.

Education Reforms: Uzbekistan has initiated crucial reforms in its educational system aimed at improving educational quality and producing highly qualified professionals in STEM fields,. These reforms have led to a growing pool of qualified workers and specialists in the country.

Resource Access: Uzbekistan benefits from rich natural resources, including oil, gas, and minerals, which offer opportunities for the development of new technologies for their extraction and processing.

In contrast, the United Kingdom encounters challenges that impede its technological progress, including an aging population, declining worker productivity, and intensified competition from countries like China and India.

It’s critical to recognize that TFP is a complex metric, and that additional context is necessary for accurate interpretation. Here are some key considerations:

Sectoral excellence: Uzbekistan’s TFP may be high in some sectors due to substantial state investments in resource extraction and infrastructure development,. However, this does not imply the same level of technological maturity as the UK, which has made more significant advancements across diverse fields.

Disparities in economic structures: Developed nations such as the UK tend to focus more on knowledge-based and service-oriented businesses, which can be more challenging to account for in TFP estimates than resource-intensive businesses.

Figure 4 displays the mean TFP values derived from two formulas for the countries within the four income groups:

$$A_1 = Y/(K^{\alpha}L^{\beta}) \text{ and } A_2 = Y/(K^{\alpha}L^{\beta}N^{\gamma}) .$$

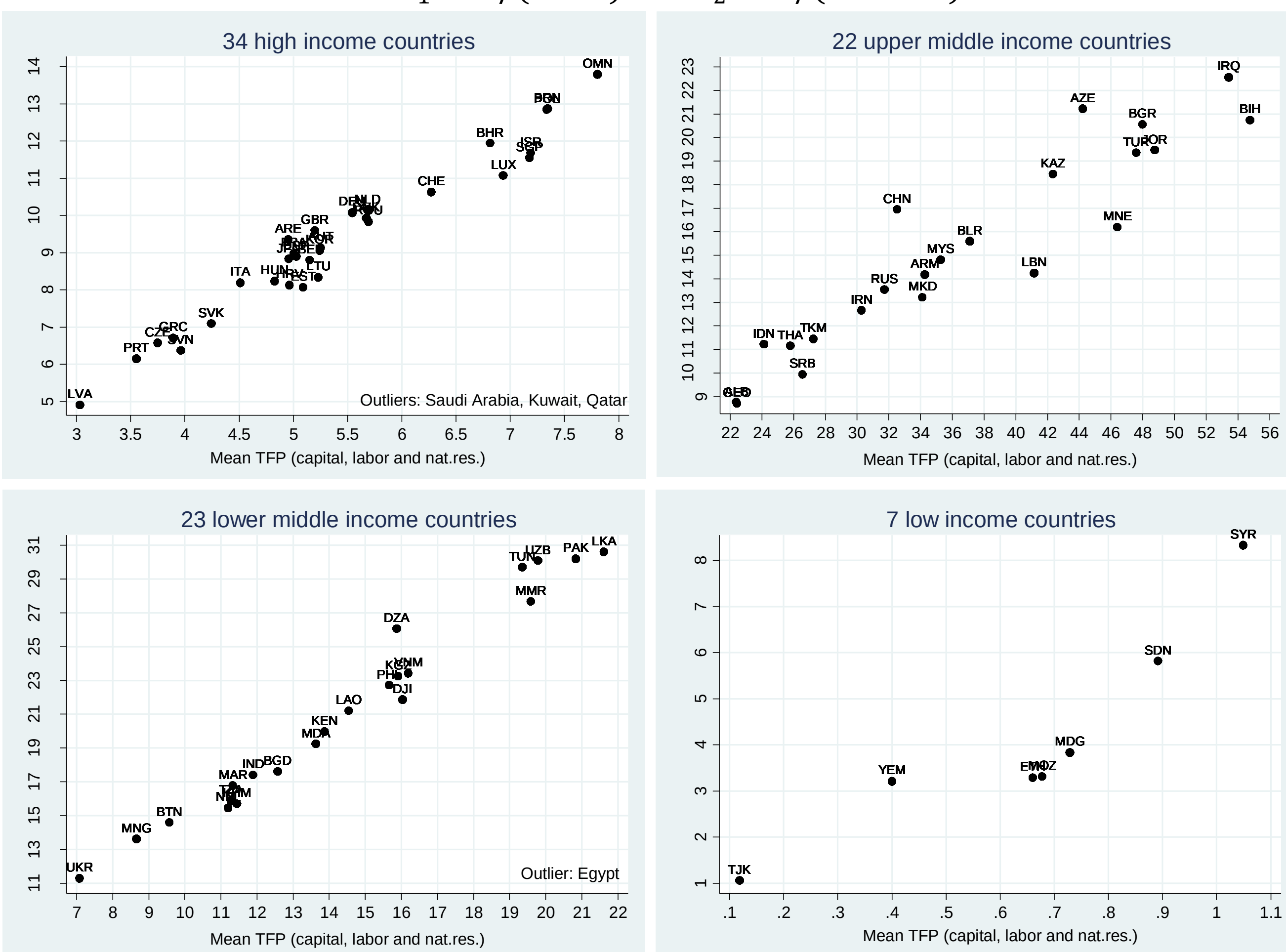


Figure 4. Mean TFP (capital, labor and nat. res.) and Mean TFP (capital and labor) in 1991-2019

Ataev (2022) estimated TFP figures using the first formula A_1 for 56 countries in the Silk Road region. In the current analysis, the estimation has been extended to include 86 countries. Notable variations in TFP can be observed across different income groups and within each income group. Specifically, the comparison between the formulas A_1 and A_2 reveals that $A_1 < A_2$ only for the UMICs. This indicates that including natural resource rent (N) as an additional input in the TFP formula (A_2) leads to higher productivity compared to excluding it (A_1). This finding highlights the significant role of natural resources in enhancing overall productivity, alongside capital (K) and labor (L) inputs.

The positive impact of natural resources on TFP is clear within income groups. For instance, China and Russia have A_1 values of 13.53 and 16.94, respectively, indicating that China is more productive. However, their A_2 values are similar, at 31.72 for China and 32.54 for Russia, suggesting that Russia has utilized its natural resources more efficiently and narrowed the productivity gap with China.

In another comparison, Italy and Lithuania show nearly identical A_1 values (8.19 and 8.34, respectively), yet their A_2 values differ significantly (4.51 for Italy and 5.23 for Lithuania), demonstrating the positive effect of natural resources on Lithuania's productivity.

When comparing Uzbekistan and Pakistan, both countries have nearly equal TFP values for capital and labor (30.08 and 30.21, respectively), but their TFP values that include natural resources differ substantially (19.78 and 20.84, respectively).

Turkey is 14% more productive than China when considering labor and capital, and 46% more productive when including labor, capital, and natural resources. Additionally, Germany is 5.5% more productive than the UK when all three inputs are taken into account, and demonstrates higher productivity when comparing labor and capital alone. Further analysis could provide deeper insights into the productivity of these and other nations.

5. Conclusion

To estimate TFP levels and growth rates, the study used the GA method. The econometric model applied was the Cobb-Douglas production function, which includes three inputs: capital, labor, and natural resources. The analysis utilized panel data from 1991 to 2019, covering 86 nations in the historical Silk Road region. The GOLS model was identified as the most suitable for both the overall sample of 86 nations and for individual income groups (HIC, UMIC, LMIC, and LIC). The calculated TFP indices provide insights into the comparative achievements of the participating nations. Consequently, the analysis focused on the following key issues:

Regional Comparisons: TFP values are compared across countries within the Silk Road region to identify variations and trends. This analysis helps to identify countries that are relatively more productive or have experienced significant improvements in productivity.

Resource Allocation: TFP provides insight into the effective distribution and utilization of resources among Silk Road member nations, including labor, capital, and natural resources. This research can pinpoint places where productivity could be enhanced through better resource allocation.

Technological Advancements: TFP analysis can help identify countries that have successfully integrated new technologies into their production processes. By comparing TFP figures, we can assess how technological advancements have driven productivity growth in the Silk Road region.

Policy Implications: Analyzing TFP values offers insights into the impact of economic policies, regulations and governance on productivity performance. This information can guide decision-makers in identifying opportunities for enhancing productivity and supporting sustainable economic development through policy initiatives.

International Comparisons: Comparing TFP values of Silk Road countries with those from other regions or global benchmarks helps determine their relative productivity levels. This analysis provides a clearer picture of the Silk Road region's economic standing and competitiveness compared to other areas.

By examining the TFP values of countries in the Silk Road region, policymakers, researchers, and businesses can gain valuable insights into productivity dynamics, identify areas for improvement, and develop strategies to enhance productivity and foster economic growth.

List of used literature

1. Nedopil, Ch. (2024), China Belt and Road Initiative (BRI) Investment Report 2023, Griffith Asia Institute, Griffith University (Brisbane) and Green Finance & Development Center, FISF Fudan University (Shanghai), https://doi.org/10.25904/1912/5140

2. World Bank. (2023), World Development Indicators, available at: https://databank.worldbank.org/source/world-development-indicators#. (accessed 14 Feb 2024)

3. World Bank. (2023), available at: https://databankfiles.worldbank.org/public/ddpext_download/site-content/OGHIST.xls (accessed 25 Feb 2024)

4. Adika, G. (2022), Regional economic integration, natural resources and foreign direct investment in SADC, *Journal of Economics and Development*, 24(1), 33-46, https://doi.org/10.1108/JED-02-2021-0021

5. Ataev, F.R. (2022), Estimating the total factor productivity: evidence from the Great Silk Road Region, *Iqtisodiyot va innovatsion texnologiyalar (Economics and Innovative technologies)*. https://doi.org/10.55439/EIT/vol10_iss6/a18

6. Qiu, W., Zhang, J., Wu, H., Irfan, M. and Ahmad, M. (2022), The role of innovation investment and institutional quality on green total factor productivity: evidence from 46 countries along the "Belt and Road", *Environmental Science and Pollution Research*, 29, 16597-16611, https://doi.org/10.1007/s11356-021-16891-y

7. UNWTO. (2022), available at: https://www.unwto.org/silk-road (accessed 3 March 2024)

8. Zhang, X., Huang, Zh. and Jiang, S. (2022), The impact of two-way FDI on total factor productivity in China and countries of the belt and road initiative, *Economic Research-Ekonomska Istraživanja*, 35:1, 2868-2888, https://doi.org/10.1080/1331677X.2021.1984268

9. Crafts, N. and Woltjer, P. (2021), Growth accounting in economic history: findings, lessons and new directions, *Journal of Economic Surveys*. 35(3). https://doi.org/10.1111/joes.12348

10. Hughes, A.C., Lechner, A.M., Chitov, A., Horstmann, A., Hinsley, A., Tritto, A., Chariton, A., Li, B.V., Ganapin, D., Simonov, E., Morton, K., Toktomushev, K., Foggin, M., Tan-Mullins, M., Orr, M.C., Griffiths, R., Nash, R., Perkin, S., Glemet, R., Kim, M. and Yu, D.W. (2020) Horizon scan of the Belt and Road Initiative, *Trends in Ecology and Evolution*, 35(7), 583-593, https://doi.org/10.1016/j.tree.2020.02.005

11. Malik M.A. and Masood T. (2020), Economic growth, productivity, and convergence of Middle East and North Africa countries, *Journal of Economic Cooperation and Development*, 41(4), https://jecd.sesric.org/pdf.php?file=ART19040201-2.pdf

12. Louwerse, J. (2018), The problems with growth accounting: unrealistic assumptions and biased results, *Business Economics*, available at: http://hdl.handle.net/2105/41623 (accessed 22 Dec 2023)

13. Nordin, N.N. and Nordin, N.H. (2018), The role of economic freedom in research and development productivity growth nexus: study based on different income level on developing countries, *Journal of Economic Cooperation and Development*. 38(1), https://jecd.sesric.org/pdf.php?file=ART15031001-2.pdf

14. Hu, X. and Liu, Ch. (2017), Total factor productivity measurement with carbon reduction, *Engineering, Construction and Architectural Management*, 24(4), 575-592, https://doi.org/10.1108/ECAM-06-2015-0097

15. Feenstra Robert C., Robert Inklaar and Marcel P. Timmer. (2015), The next generation of the Penn World Table, *American Economic Review*, 105(10), 3150-3182, https://doi.org/www.ggdc.net/pwt

16. See, K.F. and Coelli, T. (2014), Total factor productivity analysis of a single vertically integrated electricity utility in Malaysia using a Törnqvist index method, *Utilities Policy*, Vol.28, 62-72, https://doi.org/10.1016/j.jup.2013.11.001

17. Kiani, A.K., Iqbal, M. and Javed, T. (2008), Total factor productivity and agricultural research relationship: evidence from crops sub-sector of Pakistan’s Punjab, *European Journal of Scientific Research*. ISSN 1450-216X Vol.23 No.1, pp.87-97, http://www.eurojournals.com/ejsr.htm

18. Bosworth, B. and Collins, S.M. (2003), The empirics of growth: an update, *Brookings Papers on Economic Activity*, 2, 113–206. https://doi.org/10.1353/eca.2004.0002

19. Mahadevan, R. (2003), To measure or not to measure total factor productivity growth? *Oxford Development Studies*, 31:3, 365-378, https://doi.org/10.1080/1360081032000111742

20. Senhadji, A. (2000), Sources of economic growth: an extensive growth accounting exercise, *IMF Staff Papers*, Vol.47, No.1, 129-157, https://www.jstor.org/stable/3867628

21. Hall, R.E. and Jones, C.I. (1999), Why do some countries produce so much more output per worker than others? *The Quarterly Journal of Economics*, 114(1), 83-116, https://doi.org/10.1162/003355399555954

22. Griliches, Z. (1995), The discovery of the residual: an historical note, *NBER Working paper*, 5348, https://ssrn.com/abstract=225411

23. Auty, R. (1993), Sustaining Development in Mineral Economies, The Resource Curse Thesis, Routledge, London. ISBN 9780415094825.

24. Solow, R. M. (1957), Technical change and the aggregate production function, *Review of Economics and Statistics*, 39(3), 312-320, http://www.jstor.org/stable/1926047?origin=JSTOR-pdf

25. Solow, R.M. (1956), A contribution to the theory of economic growth, The Quarterly Journal of Economics, 70(1), 65-94, https://doi.org/10.2307/1884513

26. Swan, T. (1956), Economic growth and capital accumulation, Economic record, 32(2), 334-361, https://doi.org/10.1111/j.1475-4932.1956.tb00434.x

27. Copeland, M.A. (1937), Concepts of national income. Studies in income and wealth, V1, New York: NBER, 3-63, http://www.nber.org/chapters/c8136

28. Taylor, F.W. (1911), The principles of scientific management. Harper and Brothers.

29. Ricardo, D. (1817), On the Principles of Political Economy and Taxation, London: John Murray, 1-ed. ISBN 9783487409290.

30. Malthus, Th. (1798), An essay on the principle of population. Scholarly Publishing Project.

31. Smith, A. (1776), An inquiry into the nature and causes of the wealth of nations. History of Economic Thought Books, McMaster University Archive for the History of Economic Thought.