# Infrastructure and Economic Growth: Evidence from Central Asia

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**Abstract**

This study surveys the role of infrastructure development in Central Asia's economic growth using a theoretical formulation based on an exogenous growth model that includes infrastructure. With a panel dataset of six Central Asian countries, the empirical work compares the long-run relationships estimated using the "first-generation" methods with the cross-sectional independence assumption and the "second generation" methods allowing for cross-sectional dependency. When the cross-sectional dependency is not considered, the results show a significant impact of infrastructure on economic growth, although the magnitude varies across countries and sectors. However, an overall non-significant effect is observed once cross-sectional dependency is taken into account, possibly due to an international externality and spillover effects. The panel causality test between infrastructure development and economic growth shows that while the causality is country- and sector-specific with no clear consensus on the direction, stronger economies tend to be associated with more sectoral causal relationships. This result confirms the critical role of infrastructure regarding economic performance.

*Keywords*: Belt and Road Initiative (BRI); Central Asia; China; Economic growth; Infrastructure; Panel data model.

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# I. INTRODUCTION

A vast body of theoretical and empirical evidence underpins infrastructure services' role in productivity and growth, largely due to the reduction in production and transport costs and the facilities provided for new agents to enter the market. For instance, where the telecommunications infrastructure is weak, firms' transaction costs when gathering information and finding services tend to be high, whereas improving the quality of communication networks reduces the cost of doing business and increases firm profits. The impact of expanding the infrastructure goes beyond the effect of additional capital stock for three main reasons: economies of scale, network externalities, and enhanced competition owing to improved market access as a result of the infrastructure development (Égert *et al*., 2009). On the other hand, longitudinal data have become the primary data structure used to determine the effect of infrastructure investment on growth. Such data make it possible to implement estimation methods that: (i) allow the capture of specific effects for countries that are invariant over time, and (ii) allow for the estimation or simulation of the average country's behavior.

Much of the existing literature focuses on assessing the impact of a specific type of infrastructure on growth because the high correlation that usually exists between the variables that measure different types of infrastructure negatively impacts the estimation methods used. On the other hand, cross-sectional independence is also widely assumed among existing studies because of the limitation of the "first-generation" methods. However, this has changed due to the development of econometric methodologies that have revolutionized empirical economic analyses. Regarding geographic region, Central Asia has been the economic and cultural corridor between the East and West on the Eurasian continent since ancient times. Currently, studies on the infrastructure of Central Asia are far from adequate and require in-depth quantitative analyses of the infrastructure network. This is especially true given China's recent Belt and Road Initiative (BRI), which seeks to revitalize the ancient Silk Road by establishing an infrastructure and trade network in this region connecting East Asia with Europe and Africa.

This study aims to quantify the long-run impact of infrastructure stock on economic growth in six Central Asian countries (Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan).[1] We use a set of infrastructure indicators from sectors including electricity, telecommunications, internet, and sanitation, covering the period from 1995 to 2016. The remainder of the paper is organized as follows. After a brief literature review in Part II, Part III introduces the economic model, and Parts IV, V, and VI

[1] Azerbaijan may or may not fall into the category of Central Asian countries, depending on the definition. In this study, we refer to it as a Central Asian country for simplicity.
The causality between infrastructure development and economic growth is also investigated.

discuss the econometric methodologies, data, and empirical results, respectively.[2] In Part VII, we employ a set of "second-generation" methods to investigate the effect of the infrastructure on economic growth, given the existence of cross-sectional dependency. After confirming the cross-sectional dependency in Section 7.1, Sections 7.2 and 7.3 verify the existence of stable long-run relationships by testing for unit root and cointegration. Section 7.4 presents the estimation of the long-run relationship using the common correlated effects mean group estimator (CCEMG). Finally, in Section 7.5, we investigate the direction of the causality between infrastructure development and economic growth. Part VIII concludes the paper.

## II. LITERATURE REVIEW

The role of infrastructure on economic growth has captured considerable attention in both the quantitative and qualitative literature. There are two main quantitative approaches used to model infrastructure. The first approach studies infrastructure through the lens of revised cost functions, under the neoclassical assumption that firms maximize their profits. Demetriades and Mamuneas (2000) find positive long-run effects of public capital on both the output supply and the input demand using an intertemporal optimization framework with a data sample of 12 OECD countries. Moreno *et al*. (2003) show that the regional and sectoral variability of the cost elasticity of infrastructure is far from negligible, based on a sample of Spanish regional economies from 1980 to 1991. Satya *et al*. (2004) find strong evidence of the critical role of public infrastructure in the productivity of Canadian manufacturing industries by estimating a flexible cost function that incorporates the public capital infrastructure. The second approach examines production functions that include infrastructure.

One of the earliest experiments to use this approach is that of Aschauer (1989), who incorporates infrastructure into the production function as an input factor in addition to capital and labor, and finds the nonmilitary public capital stock is more important in determining productivity than is either the flow of nonmilitary or military spending Ford and Poret (1991) find mixed results when studying public capital's influence on total factor productivity for 11 OECD economies. Calderón and Servén (2002) provide evidence of a strong empirical association between output and infrastructure using a panel data set with annual data covering the period 1960 to 1997 from 101 industrial and developing countries, although the results do not necessarily reflect the direction of causality. By developing and estimating a structural model of infrastructure and output growth for 75 countries, Esfahani and Ramirez (2003) find that the contribution

[2] Cross-sectional dependence is not considered in Parts IV to VI. There are two reasons for assuming cross-sectional independence at the beginning. First, the relationship between infrastructure and growth in the six Central Asian countries has not been extensively studied, even using the traditional "first-generation" methods. Second, a comparative analysis can potentially provide us with more information and economic insight, as we see later in this paper.

of infrastructure services to GDP is substantial and, in general, exceeds the cost of providing these services.[3] Using a data sample of 24 OECD countries for the period 1960 to 2005, Égert *et al*. (2009) find a positive impact of infrastructure investment on growth, although this effect varies across countries and sectors and over time.

Several studies use the vector auto-regression (VAR) or vector error correction model (VECM) approach. Flores de Frutos *et al*. (1998) suggest there are long-term public investment effects on private sector variables in Spain. Wesselhöft (2013) estimates the dynamic effect of public capital on real GDP for 22 OECD countries using a vector auto-regression approach, and finds a positive effect of public capital on output in the short-medium and long run in most countries, although a negative effect is also found in some countries.[4]

Finally, comparative methodological studies have been conducted to assess the performance of different approaches. For instance, Torrisi (2010) performs a comparative analysis of the relationship between infrastructure and economic performance using four different approaches,[5] finding a general robust economic enhancing effect of infrastructure even with different methodologies.

## III. THE MODEL

This study's theoretical formulation is based on the exogenous growth model proposed by Mankiw, Romer, and Weil (1992).[6] The MRW model is derived from a human capital augmented Cobb–Douglas production function, in which a human capital variable is added in addition to the production, capital, labor, and technology variables. The production function is expressed as $Y_t = {K_t}^{\alpha} {H_t}^{\beta} (A_t L_t)^{1-\alpha-\beta}$, where $Y_t$, $K_t$, $H_t$, $A_t$, and $L_t$ represent GDP, total capital, human capital, the technology level, and the labor force, respectively. Furthermore, diminishing marginal returns (i.e., $\alpha + \beta < 1$) are assumed. The capital accumulation functions and the econometric specification are derived as follows:

$$\dot{k_t} = (s^K) y_t - (n + g + \delta) k_t$$

$$\dot{h_t} = (s^H) y_t - (n + g + \delta) h_t$$

[3] The author also shows that institutional improvements are required to achieve better infrastructure outcomes on economic growth.
[4] The author also analyzes the following possible explanations for the negative effect: different productivities of investments, crowding out, and high growth rates of government debt.
[5] The four approaches studied are the production function approach, the cost function approach, growth models, and vector auto-regression models.
[6] The abbreviation "MRW" is used.

$$\ln\left(\frac{Y_t}{L_t}\right) = \ln(a_0) + gt + \frac{\alpha}{1-\alpha}\ln(k_t) + \frac{\beta}{1-\alpha}\ln(h_t) - \frac{\alpha}{1-\alpha}\ln(n_t + g + \delta), \quad [1]$$

where, $k_t = (K_t / A_t L_t)$, $h_t = (H_t / A_t L_t)$, $n_t$ is the growth rate of the labor force, $g$ is the growth rate of the technological level, and $\delta$ is the rate of depreciation.

One way to model infrastructure is to create a production function that includes an infrastructure variable. Under the assumption that the effect of infrastructure stock may differ from the average effect of total capital due to the characteristics of a natural monopoly or a public good,[7] infrastructure can be singled out as an additional factor in the Cobb–Douglas production function and interpreted as the additional effect of infrastructure, which differs from the effects of other types of capital on GDP (Égert *et al.*, 2009). Let $F_t$ be the stock of infrastructure at time $t$, and $f_t = (F_t / A_t L_t)$ be the infrastructure stock per effective unit of labor. A simple infrastructure augmented Cobb–Douglas production function can then be expressed as $Y_t = {K_t}^{\alpha} {F_t}^{\beta} (A_t L_t)^{1-\alpha-\beta}$, with the following specification:

$$\ln\left(\frac{Y_t}{L_t}\right) = \ln(a_0) + gt + \frac{\alpha}{1-\alpha}\ln(k_t) + \frac{\beta}{1-\alpha}\ln(f_t) - \frac{\alpha}{1-\alpha}\ln(n_t + g + \delta). \quad [2]$$

Consider an infrastructure and human capital augmented Cobb–Douglas production function, $Y_t = K_t^{\alpha} H_t^{\beta} F_t^{\gamma} (A_t L_t)^{1-\alpha-\beta-\gamma}$, with the intensive form $y_t = k_t^{\alpha} h_t^{\beta} f_t^{\gamma}$. The diminishing marginal returns assumption is now defined as $\alpha + \beta + \gamma < 1$. Thus, the capital accumulation functions become:

$$\dot{k_t} = s_k y_t - (n + g + \delta) k_t = s_k k_t^{\alpha} h_t^{\beta} f_t^{\gamma} - (n + g + \delta) k_t$$

$$\dot{h_t} = s_h y_t - (n + g + \delta) h_t = s_h k_t^{\alpha} h_t^{\beta} f_t^{\gamma} - (n + g + \delta) h_t$$

$$\dot{f_t} = s_f y_t - (n + g + \delta) f_t = s_f k_t^{\alpha} h_t^{\beta} f_t^{\gamma} - (n + g + \delta) f_t.$$

Let $\dot{k_t} = 0$, $\dot{h_t} = 0$, and $\dot{f_t} = 0$, the economy then converges to the following steady state:

$$k^* = \left(\frac{{s_f}^{\gamma} \cdot {s_k}^{1-\beta-\gamma} \cdot {s_h}^{\frac{2\beta(\alpha-\gamma)}{\alpha}}}{n + g + \delta}\right)^{\frac{1}{1-\alpha-\beta-\gamma}}$$

$$h^* = \left(\frac{{s_k}^{\alpha} \cdot {s_f}^{\gamma} \cdot {s_h}^{1-\alpha+\gamma}}{n + g + \delta}\right)^{\frac{1}{1-\alpha-\beta-\gamma}}$$

$$f^* = \left(\frac{{s_h}^{\beta} \cdot {s_k}^{\alpha} {s_f}^{1-\alpha-\beta}}{n + g + \delta}\right)^{\frac{1}{1-\alpha-\beta-\gamma}}.$$

[7] Examples include economies of scale, externalities, spillover effects, improved market access, and enhanced competition.

Using the $k^*$, $h^*$, and $f^*$, rewrite the production function as follows:

$$\frac{Y_t}{L_t} = A_t \left( \frac{s_f{}^{\gamma} \cdot s_k{}^{1-\beta-\gamma} \cdot s_h{}^{\frac{2\beta(\alpha-\gamma)}{\alpha}}}{n+g+\delta} \right)^{\frac{\alpha}{1-\alpha-\beta-\gamma}} \left( \frac{s_k{}^{\alpha} \cdot s_f{}^{\gamma} \cdot s_h{}^{1-\alpha+\gamma}}{n+g+\delta} \right)^{\frac{\beta}{1-\alpha-\beta-\gamma}} \left( \frac{s_h{}^{\beta} \cdot s_k{}^{\alpha} s_f{}^{1-\alpha-\beta}}{n+g+\delta} \right)^{\frac{\gamma}{1-\alpha-\beta-\gamma}}.$$

From the above equation, we obtain the following econometric specification by taking the natural logarithm of both sides:

$$\ln\left(\frac{Y_t}{L_t}\right) = b_0 + b_1 t + b_2 \ln(k_t) + b_3 \ln(h_t) + b_4 \ln(f_t) + b_5 \ln(n_t + g + \delta), \qquad [3]$$

where $b_2 = \frac{\alpha}{1-\alpha-\beta-\gamma}$, $b_3 = \frac{\beta(\alpha+1)}{1-\alpha-\beta-\gamma}$, $b_4 = \frac{\gamma}{1-\alpha-\beta-\gamma}$, and $b_5 = \frac{\alpha+\beta+\gamma}{\alpha+\beta+\gamma-1}$.

In this paper, we estimate both equation [2] and [3] for comparison.

## IV. ECONOMETRIC METHODOLOGY [8]

To determine the stationarity or the order of integration of the variables, we apply the unit root test in the heterogeneous panels of Im, Pesaran, and Shin (2003). Let $N$ denote the number of cross-sections and $T$ denote the number of periods, and suppose $y_{it}$ is generated by the ($p_i + 1$)-order autoregressive process. Then, $y_{it} = u_i \phi_i(1) + \sum_{j=1}^{p_i+1} \phi_{ij} y_{it-j} + \varepsilon_{it}, i = 1, \ldots, N, \mathrm{t} = 1, \ldots, T$, or, equivalently,

$$\Delta y_{it} = \alpha_i + \beta_i y_{it-1} + \sum_{j=1}^{p_i} \rho_{ij} \Delta y_{it-j} + \varepsilon_{it}, i = 1 \ldots N, \mathrm{t} = 1 \ldots T,$$

where $\phi_i(1) = 1 - \sum_{j=1}^{p_i+1} \phi_{ij}$, $\alpha_i = u_i \phi_i(1)$, $\beta_i = -\phi_i(1)$, and $\rho_{ij} = -\sum_{h=j+1}^{p_i+1} \phi_{ih}$. The null and alternative hypotheses when testing for a unit root are $H_0\colon \beta_i = 0,$ for all $i$, and $H_1\colon \beta_i < 0$, where $i = 1, 2, \ldots, N_1$, $\beta_i = 0$, and $i = N_1 + 1, N_1 + 2, \ldots, N$. Under this formulation, the alternative hypothesis allows $\beta_i$ to vary in the cross-sections, which is less restrictive than the alternative hypothesis of homogeneity ($\beta_i = \beta < 0$, for all $i$) of the unit root tests such as in Levin, Lin, and Chu (2002). Furthermore, the formulation is applicable to unbalanced panels, making it appropriate for this part of the study.

Pedroni (1999) introduces a set of statistics to test the null hypothesis of no cointegration in heterogeneous panels with multiple regressors, analogous to the Engle–Granger test based on residuals, which verifies cointegration in the case of time series.[9] These statistical tests are constructed from the residuals of the hypothetical cointegration regression in the following equation:

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[8] Cross-sectional dependency is not considered in this section.
[9] For the statistical formulae, see Table 1 of Pedroni (1999).

$$y_{it} = \alpha_i + \beta_{1i}x_{1it} + \beta_{2i}x_{2it} + \cdots + \beta_{Mi}x_{Mit} + e_{it}, \quad [4]$$

where $N$ and $T$ denote the number of cross-sections and periods, respectively. The slope coefficients $\beta_1, \beta_2, \ldots, \beta_M$ can vary across the cross-sections, and $\alpha_i$ is the fixed-effects parameter.

Pedroni (2004) derives the asymptotic distribution and evaluates the performance of seven statistics in small samples. Of the seven statistics, four are grouped according to the within-dimension (constructed by adding the numerator and denominator terms separately along the $N$-dimension), and the remaining three are grouped according to the between-dimension (constructed by dividing the numerator and denominator terms and then adding over the $N$-dimension). With the estimated residuals $\hat{e}_{it}$ from equation [4], the auxiliary regression $\hat{e}_{it} = \hat{\gamma}_i\hat{e}_{it-1} + \sum_{k=1}^{K_i}\hat{\gamma}_{ik}\Delta\,\hat{e}_{it-k} + \hat{u}_{it}^{*}$ is considered. For the within-dimension statistics, the null hypothesis of no cointegration and the alternative hypothesis are written as $H_0\colon \gamma_i = 1, \text{for all } i$, and $H_1\colon \gamma_i = \gamma < 1, \text{for all } i$, respectively. For the between-dimension statistics, the null hypothesis of no cointegration and the alternative hypothesis are $H_0\colon \gamma_i = 1, \text{for all } i$, and $H_1\colon \gamma_i < 1, \text{for all } i$, respectively. The alternative hypothesis in the between-dimension case is less restrictive because it allows for heterogeneity between the panels. We refer to the within-dimension statistics as panel cointegration statistics and the between-dimension statistics as group-mean panel cointegration statistics.

After testing for unit roots and cointegration, we estimate the long-run equilibrium relationships using the ordinary least squares method in a dynamic panel (group-mean PDOLS estimator) developed by Pedroni (2001), which is an extension of the individual time-series dynamic ordinary least squares (DOLS) method. Finally, to determine whether long-run relationships revert to the equilibrium in the presence of short-run disequilibria, the following error correction model is estimated:[10]

$$\Delta\ln(y_{it}) = \beta_{0i} + \sum_j \beta_{1it-j}\Delta\ln(s_{it-j}) + \sum_j \beta_{2it-j}\Delta\ln(h_{it-j}) + \sum_j \beta_{3it-j}\Delta\mathrm{n}_{it-j} + \lambda_i ECM_{it-1}.$$

## V. THE DATA

The data used in this study are panel data covering six countries for the 22 years from 1995 to 2016. The data are incomplete for some countries. Hence, these are unbalanced panels. The six countries considered in this study are Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. The infrastructure variables are taken from the following four categories:[11]

i. Electricity

[10] The error correction model without the human capital variable is also considered.
[11] In this paper, Infrastructure variables are estimated one-by-one to avoid error increases from multicollinearity.

ii. Telecommunications
iii. Internet
iv. Sanitation

Transportation and water infrastructure are excluded from this study because of a lack of sufficient data for quantitative analysis. Furthermore, given the limited educational data available for these countries, we can only use the rate of secondary education completion as a rough, inefficient measurement of human capital.[12] Table 1 shows the definitions and sources of the variables and indicators.

**Table 1**
**Economic Variables and Infrastructure Indicators**

| ID | Variables Definition | Source |
|---|---|---|
| gdp | GDP, PPP (constant 2011 international $) | The World Bank |
| s | Gross fixed capital formation (proportion of GDP) | The World Bank |
| l | Labor Force total (Population ages 15-64) | The World Bank |
| n | Labor force growth rate | The World Bank |
| h | Lower secondary completion rate (% of relevant age group) | The World Bank |
| | Infrastructure Indicators (f) | |
| ey | Electricity - Gross Production (Million Kilowatt-hours) | United Nations Statistics Division |
| ecap | Installed capacity for electricity generation (Million Kw) | U.S. Energy Information Administration |
| tele | Fixed telephone subscriptions | The World Bank |
| it | Individuals using the Internet (% of population) | The World Bank |
| san | Improved sanitation facilities (% of population with access) | The World Bank |

## VI. EMPIRICAL RESULTS

Table 2 shows the results from the Im–Pesaran–Shin (IPS) test introduced in Part IV.[13] The GDP per capita ($gdp_t/l_t$), gross fixed capital formation ($s_t$), labor force growth rate ($n_t$), gross electricity production ($ey_t$), installed capacity of electricity generation ($ecap_t$), and improvements in sanitary services ($san_t$) are all I(1) variables, which are stationary in their first differences at the 1% significance level. Human capital ($h_t$) and the percentage of the population using the internet ($it_t$) are stationary at the 5% significance level, but the null hypothesis of at least one unit root cannot be rejected at the 1% significance level. On the other hand, the variable that measures fixed telephone subscriptions ($tele_t$) is shown to have two unit roots. Therefore, the first difference is used to verify the long-run equilibrium relationships.

[12] Better measurements would be the average years of education or the rate of college completion. However, these data are not available for the six countries studied here.
[13] The variables are measured in natural logarithm form, except for the labor force's growth rate ($n_t$).

**Table 2**
**Unit Roots Test in Heterogeneous Panels**

| | Null Hypothesis | | | | | |
|---|---|---|---|---|---|---|
| | I (1) | | I (2) | | I (3) | |
| Variables | Test Stat. | Prob. | Test Stat. | Prob. | Test Stat. | Prob. |
| $gdp_t/l_t$ | 4.315 | 1.000 | -8.180 *** | 0.000 | | |
| $s_t$ | -0.873 | 0.191 | -7.193 *** | 0.000 | | |
| $n_t$ | 0.083 | 0.533 | -2.714 *** | 0.003 | | |
| $h_t$ | -2.175 ** | 0.015 | -5.028 *** | 0.000 | | |
| $ey_t$ | 2.520 | 0.994 | -7.668 *** | 0.000 | | |
| $ecap_t$ | 0.881 | 0.811 | -7.881 *** | 0.000 | | |
| $tele_t$ | 4.768 | 1.000 | -0.268 | 0.395 | -13.262 *** | 0.000 |
| $it_t$ | -2.147 ** | 0.016 | -3.696 *** | 0.000 | | |
| $san_t$ | 0.301 | 0.618 | -7.858 *** | 0.000 | | |

Note: The result is from Im-Pesaran-Shin (IPS) unit root test. (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis of unit root can be rejected.

**Table 3**
**Pedroni Cointegration Statistics**

| Cointegration Regression $gdp_t/l_t$, $s_t$, $n_t$, $(h_t)$, $\boldsymbol{f_t}$ | Panel Statistics | | | | Group Statistics | | |
|---|---|---|---|---|---|---|---|
| | | | t-statistic | | | t-statistic | |
| | ν-statistic | ρ-statistic | Non-parametric | Parametric | ρ-statistic | Non-parametric | Parametric |
| $\boldsymbol{f_t}$ | *(Without Human Capital)* | | | | | | |
| $ey_t$ | -1.126 | 1.174 | -0.243 | 1.275 | 1.967 ** | -0.021 | 2.655 *** |
| $ecap_t$ | -0.691 | 0.868 | -0.171 | 4.143 *** | 1.921 ** | 0.389 | 5.798 *** |
| $\Delta tele_t$ | -1.423 * | 1.809 ** | 1.345 * | 4.255 *** | 2.536 *** | 2.063 ** | 6.595 *** |
| $it_t$ | -0.289 | 0.228 | -0.974 | -0.834 | 1.355 * | -0.545 | 0.858 |
| $san_t$ | 0.771 | 0.035 | -1.447 * | 0.951 | 1.006 | -1.358 * | 2.032 ** |
| | *(With Human Capital)* | | | | | | |
| $ey_t$ | -1.639 * | 1.742 ** | -0.059 | 1.318 * | 2.404 *** | -0.055 | 1.265 |
| $ecap_t$ | -1.311 * | 1.543 * | 0.227 | 2.567 *** | 2.391 *** | 0.556 | 3.328 *** |
| $\Delta tele_t$ | -1.854 ** | 2.257 ** | 1.412 * | 5.775 *** | 3.090 *** | 2.201 ** | 6.280 *** |
| $it_t$ | -0.807 | 0.865 | -0.761 | 0.274 | 1.831 ** | -0.421 | 2.928 *** |
| $san_t$ | 0.451 | 0.277 | -2.169 ** | 4.182 *** | 1.163 | -2.154 ** | 5.121 *** |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis of no cointegration can be rejected.

**Table 4**
**Ordinary Least Squares in Dynamic Panel**

| | Electricity | | | | Telecommunication | | Internet | | Sanitation | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $ey_t$ | | $ecap_t$ | | $\Delta tele_t$ | | $it_t$ | | $san_t$ | |
| | | | | | *Long Run (Mean Group)* | | | | | |
| Investment | 0.087 ** | 0.660 ** | 0.373 | 1.894 ** | 0.206 ** | 0.310 ** | 0.262 ** | 0.169 ** | 0.139 ** | 0.226 ** |
| Population Growth | 16.890 ** | 5.010 ** | -0.023 ** | 67.850 ** | 14.970 ** | 5.940 ** | -3.832 ** | -0.614 ** | 11.600 ** | 1.202 ** |
| Human Capital | --- | 1.107 ** | --- | 5.876 ** | --- | 0.954 ** | --- | 0.275 ** | --- | 0.048 ** |
| Infrastructure | 2.310 ** | -2.254 ** | 2.313 ** | -9.370 ** | 1.714 | 7.014 ** | 0.131 ** | 0.044 ** | 0.375 ** | 22.770 ** |
| | | | | | *Country Specific Coefficients for Infrastructure* | | | | | |
| Azerbaijan | 3.776 ** | -12.120 ** | 3.779 ** | 2.740 ** | 6.948 ** | 12.300 ** | 0.246 ** | 0.030 ** | 2.738 ** | 3.608 ** |
| Kazakhstan | 1.161 ** | 0.674 ** | 4.677 ** | 3.756 | -1.965 ** | -3.433 ** | 0.146 ** | 0.010 * | -3.648 ** | --- |
| Kyrgyzstan | -0.063 | -0.311 ** | 2.238 ** | -56.470 ** | 3.915 ** | 25.330 ** | 0.032 ** | 0.272 ** | 6.762 ** | -11.780 |
| Tajikistan | 4.047 * | 0.943 ** | 3.167 ** | 3.466 ** | -0.973 ** | -0.870 ** | 0.082 ** | -0.107 ** | 5.564 ** | 12.530 ** |
| Turkmenistan | 1.109 ** | --- | -8.512 ** | --- | 0.780 | --- | 0.191 ** | --- | -6.339 ** | --- |
| Uzbekistan | 3.831 ** | -0.458 ** | 8.530 ** | -0.342 ** | 1.579 * | 1.742 ** | 0.087 ** | 0.013 | -2.827 ** | 4.213 ** |
| | | | | | *Short Run (Mean Group)* | | | | | |
| Error Correction Term (-1) | -0.026 * | -0.028 * | -0.031 * | -0.006 | -0.028 * | -0.029 * | -0.029 * | -0.026 * | -0.028 * | -0.026 * |
| Adjusted $R^2$ Short Run | 0.363 | 0.470 | 0.374 | 0.443 | 0.369 | 0.465 | 0.368 | 0.464 | 0.366 | 0.465 |
| F-test | 7.990 | 7.800 | 8.360 | 6.990 | 8.180 | 7.640 | 8.160 | 7.590 | 8.070 | 7.640 |
| Observations | 111 | 93 | 111 | 93 | 111 | 93 | 111 | 93 | 111 | 93 |

Note: (*) and (**) denote the 10% and 1% significance level. Some coefficients marked with (*) are also significant at 5% level. These include electricity production in Tajikistan ($ey_t$=4.047) and internet in Kazakhstan ($it_t$=0.010). For the error correction terms, all the coefficients marked with (*) are significant at 5% level except for internet with human capital (-0.026). The coefficient of the infrastructure stock should be interpreted as the effect in addition to the effect of pure productive capital stock increase. Thus, a positive (negative) coefficient implies that the total impact on output would be higher (lower).

Table 3 presents the results of the Pedroni cointegration tests (1999, 2004). The specification of the cointegration regression is given by equation [2] and [3]. Because the variable ($n_t + g + \delta$) is fundamentally determined by the labor force growth rate ($n_t$), and the sum of technology growth rate and the depreciation rate ($g + \delta$) is usually very small in samples from countries with similar or convergent economic conditions, we assume that the term ($n_t + g + \delta$) is approximately equal to ($n_t$).[14]

Table 3 shows a greater frequency of rejection of the null hypothesis of no cointegration by the group-mean panel cointegration statistics (between-dimension), implying the acceptance of an alternative hypothesis that favors the existence of long-run equilibrium relationships that differ across countries. On the other hand, the null hypothesis of no cointegration for the variable that measures the percentage of the population using the internet ($it_t$) can only be rejected at the 10% significance level by the ρ-statistic in the model without human capital. However, stronger rejections are shown when including human capital in the regression of cointegration.

In general, the evidence provided by Table 3 suggests the existence of a stable long-run equilibrium relationship in all cointegration regressions. Next, we estimate the equilibrium relationships using the group-mean PDOLS estimator. The results are presented in Table 4.

At a global level, the estimation using the dynamic OLS of the investment coefficient is positively significant, as suggested by economic theory. Additionally, the estimated coefficients are in the interval (0.087, 1.894). The coefficient of investment is not statistically significant only in the long-run relationship that includes electricity generation capacity ($ecap_t$) and excludes human capital ($h_t$). However, when human capital is included in this same long-run relationship, the response of productivity to a 1% increase in total capital is more than proportional (1.89%). On the other hand, the lower response in the economy's productivity (0.087%) to a 1% increase in gross capital formation is associated with the long-run equilibrium relationship that includes gross electricity production ($ey_t$). The growth rate of the labor force is significant in all specifications. However, the negative sign suggested by Mankiw, Romer, and Weil (1992) is sustained only in long-run equilibrium relationships that include electricity capacity ($ecap_t$) and internet ($it_t$). This could reflect an insufficient labor force or a shrinking of the population in this region.[15]

The country-specific coefficients of the infrastructure variables are mostly significant, providing evidence in favor of rejecting the hypothesis of a common effect of infrastructure on production. The following sectoral observations are made from the estimation results.

[14] $(n_t + g + \delta) \cong n_t$.

[15] This result is aligned with recent economic and demographic reports of this region. See Cadavid *et al*. (2017).

### 6.1 Electricity

An increase in electricity production is associated with an increase in GDP for Azerbaijan, Kazakhstan, Tajikistan, Turkmenistan, and Uzbekistan, but the association is negative for Kyrgyzstan. On the other hand, in the case of electricity generating capacity, the effects are positive and significant for Azerbaijan, Kazakhstan, and Tajikistan, but negative for Kyrgyzstan, Turkmenistan, and Uzbekistan. The negative effects may reflect an overinvestment in electricity generating capacity or a high cost of increasing the electricity generating capacity.

### 6.2 Telecommunication and the Internet

Internet subscriptions have a positive and significant effect on per capita output in all countries except Tajikistan, but the effect is relatively inelastic. Based on recent data, the population's access to the internet in countries such as Kyrgyzstan, Tajikistan, and Turkmenistan is 34.5% (2016), 20.5% (2016), and 12.2% (2014), respectively. Hence, the low impact could reflect a high cost of increasing installed capacity. On the other hand, fixed telephone subscribers have a positive and significant impact for Azerbaijan, Kyrgyzstan, and Uzbekistan, but a negative impact for Kazakhstan and Tajikistan.

### 6.3 Sanitation

The expansion of sanitary services has a conclusive positive impact on growth in Azerbaijan and Tajikistan. In the other countries, the effect is ambiguous, taking a positive or negative sign depending on whether the long-run relationship includes human capital.

The estimated coefficient of the error-correction mechanism $ECM_{it-1}$ has a negative sign in all cases, ensuring the reversion to the equilibrium of the long run relationships. The magnitudes of the coefficients are small, indicating that in the presence of a long-run disequilibrium, the reversion to the equilibrium of the long-run relationship is slow.

## VII. CROSS-SECTIONAL DEPENDENCE

Thus far, we have not explicitly investigated the issue of cross-sectional dependency, which is highly possible given the geographical, cultural, and economic connections between these countries. Ignoring cross-sectional dependency can cause substantial size distortions in conventional unit root tests (O'Connell, 1998) and lead to misleading inferences (Phillips and Sul, 2003, 2007). Therefore, our empirical analysis in this part begins with a set of cross-sectional dependency (CD) tests to investigate the contemporaneous correlation across countries in the panel.[16]

### 7.1 Cross-sectional Dependence

Intuitively, cross-sectional dependency occurs when a shock to one economy effects the other economies. Because testing for cross-sectional dependency is essentially equivalent to testing the contemporaneous correlations in the errors, we can use the Lagrange multiplier (LM) statistic developed by Breush and Pagan (1980) for this purpose. The test is based on the following test statistic: $CDLM_1 = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2$, where $\hat{\rho}_{ij}$ is the estimated correlation coefficient of the residuals obtained from individual OLS estimations. With $N$ fixed and $T \to \infty$, the $CDLM_1$ is asymptotically distributed as chi-squared with $N(N - 1)/2$ degrees of freedom, under the null hypothesis of no cross-sectional dependency.

Pesaran (2004) proposes two alternative test statistics to overcome the drawbacks of not allowing a large $N$ and the potential size distortion in the $CDLM_1$ test. The two proposed test statistics are formulated as follows:

$$CDLM_2 = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{\rho}_{ij}^2 - 1), \qquad CD = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}.$$

By allowing $T \to \infty$ and then $N \to \infty$, the $CDLM_2$ is asymptotically distributed as standard normal under the null hypothesis of no cross-sectional dependency. The CD test, being a solution to the possible size distortions in the $CDLM_1$ when $N > T$, is also asymptotically distributed as standard normal under the null hypothesis of no cross-sectional dependency when $T \to \infty$ and $N \to \infty$, in any order.

Finally, the bias-adjusted LM test of Pesaran *et al.* (2008) is also employed to test for cross-sectional dependency. Using the following formulation of the test statistic, the bias-adjusted LM test has the advantage of being consistent, even when the CD test is inconsistent, because the finite sample behavior of the test successfully controls for the size (Pesaran *et al.*, 2008).

$$LM_{adj} = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{(T-k)\hat{\rho}_{ij}^2 - \mu_{Tij}}{v_{Tij}}.$$

[16] To obtain a balanced panel, our empirical work in this part uses data covering 21 years (1995–2015) instead of 22 years, with the year 2016 excluded.

**Table 5**
**Cross-sectional Dependence Tests**

| Variables | | | CDLM-1 | CDLM-2 | CD | $LM_{adj}$ |
|---|---|---|---|---|---|---|
| $gdp_t/l_t$ | Intercept | Test Stat. | 29.802 ** | 2.703 *** | -1.799 ** | 2.891 *** |
| | | Prob. | 0.013 | 0.003 | 0.036 | 0.002 |
| | Intercept and | Test Stat. | 25.736 ** | 1.960 ** | -1.950 ** | 3.210 *** |
| | Trend | Prob. | 0.041 | 0.025 | 0.026 | 0.001 |
| $s_t$ | Intercept | Test Stat. | 19.374 | 0.799 | -1.246 | 5.222 *** |
| | | Prob. | 0.197 | 0.212 | 0.106 | 0.000 |
| | Intercept and | Test Stat. | 21.200 | 1.132 | -0.946 | 4.722 *** |
| | Trend | Prob. | 0.131 | 0.129 | 0.172 | 0.000 |
| $n_t$ | Intercept | Test Stat. | 20.058 | 0.923 | -2.031 ** | 11.885 *** |
| | | Prob. | 0.170 | 0.178 | 0.021 | 0.000 |
| | Intercept and | Test Stat. | 46.089 *** | 5.676 *** | -2.115 ** | 10.951 *** |
| | Trend | Prob. | 0.000 | 0.000 | 0.017 | 0.000 |
| $h_t$ | Intercept | Test Stat. | 31.975 *** | 3.099 *** | -1.589 * | 1.645 * |
| | | Prob. | 0.006 | 0.001 | 0.056 | 0.050 |
| | Intercept and | Test Stat. | 41.573 *** | 4.852 *** | -1.586 * | 2.108 ** |
| | Trend | Prob. | 0.000 | 0.000 | 0.056 | 0.018 |
| $ey_t$ | Intercept | Test Stat. | 37.145 *** | 4.043 *** | -2.286 ** | 7.147 *** |
| | | Prob. | 0.001 | 0.000 | 0.011 | 0.000 |
| | Intercept and | Test Stat. | 21.514 | 1.189 | -2.562 *** | 6.604 *** |
| | Trend | Prob. | 0.121 | 0.117 | 0.005 | 0.000 |
| $ecap_t$ | Intercept | Test Stat. | 28.673 ** | 2.496 *** | -2.498 *** | 6.466 *** |
| | | Prob. | 0.018 | 0.006 | 0.006 | 0.000 |
| | Intercept and | Test Stat. | 24.902 * | 1.808 ** | -2.832 *** | 6.638 *** |
| | Trend | Prob. | 0.051 | 0.035 | 0.002 | 0.000 |
| $tele_t$ | Intercept | Test Stat. | 38.145 *** | 4.226 *** | -0.485 | -0.077 |
| | | Prob. | 0.001 | 0.000 | 0.314 | 0.531 |
| | Intercept and | Test Stat. | 34.871 *** | 3.628 *** | -0.099 | 1.092 |
| | Trend | Prob. | 0.003 | 0.000 | 0.461 | 0.138 |
| $it_t$ | Intercept | Test Stat. | 23.272 * | 1.510 * | -0.937 | 7.315 *** |
| | | Prob. | 0.079 | 0.065 | 0.174 | 0.000 |
| | Intercept and | Test Stat. | 9.087 | -1.080 | 0.021 | 1.608 * |
| | Trend | Prob. | 0.873 | 0.140 | 0.492 | 0.054 |
| $san_t$ | Intercept | Test Stat. | 37.676 *** | 4.140 *** | -2.627 *** | 5.990 *** |
| | | Prob. | 0.001 | 0.000 | 0.004 | 0.000 |
| | Intercept and | Test Stat. | 41.415 *** | 4.823 *** | -2.323 ** | 4.820 *** |
| | Trend | Prob. | 0.000 | 0.000 | 0.010 | 0.000 |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis of no cross-sectional dependence can be rejected.

As shown in Table 5, the bias-adjusted LM test rejects the null hypothesis of no cross-sectional dependency for all variables except for telephone subscriptions (*$tele_t$*) which shows strong cross-sectional dependence at the 99% confidence level in both the $CDLM_1$ and $CDLM_2$ tests.[17] Given the existence of cross-sectional dependency, the "first-generation" techniques used previously become inefficient. In the following sections, we use a set of "second-generation" tests and estimation methods to further investigate the effects of the infrastructure in the presence of cross-sectional dependence.

### 7.2 Integration

To determine the stationarity of the series in the presence of cross-sectional dependency, we employ the cross-sectionally augmented ADF (CADF) test of Pesaran (2007). The test is applicable for both $N > T$ and $N < T$, and its critical values are obtained from Monte Carlo simulations. Based on the formation of the following regression:

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta \bar{y}_t + e_{it},$$

the CADF test has a null hypothesis of existing unit root in the panel data with cross-sectional dependence in the form of common factor dependence. The cross-sectionally augmented IPS (CIPS) test statistic is then calculated as the simple average of the individual CADF statistics.

**Table 6**
**CIPS Unit Roots Test**

| | Null Hypothesis | |
|---|---|---|
| | I (1) | I (2) |
| Variables | Test Stat. | Test Stat. |
| $gdp_t/l_t$ | -1.647 | -2.306 * |
| $s_t$ | -1.848 | -3.329 *** |
| $n_t$ | -1.882 | -2.402 ** |
| $h_t$ | -2.347 ** | -4.773 *** |
| $ey_t$ | -1.152 | -3.329 *** |
| $ecap_t$ | -2.172 | -3.480 *** |
| $tele_t$ | -0.241 | -0.497 |
| $it_t$ | -2.088 | -3.094 *** |
| $san_t$ | -1.624 | -3.096 *** |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels. The null hypothesis of the test is unit root in panel data with cross-sectional dependence in the form of a common factor dependence. The tests are performed with intercept corresponding to the Case II of Pesaran (2007).

Table 6 shows the unit root test results with the CIPS statistics.[18] The tests are performed with an intercept, corresponding to Case II of Pesaran (2007). In general, the variables maintain similar patterns of

[17] This is true in both the model with the intercept only and in the model with the intercept and the trend.
[18] Individual CADF test statistics are available from the author upon request.

stationarity to those in the "first-generation" IPS test. Gross fixed capital formation ($s_t$), human capital ($h_t$), electricity production ($ey_t$), installed capacity for electricity generation ($ecap_t$), individuals using the internet ($it_t$), and improved sanitation facilities ($san_t$) are all stationary in their first differences at the 1% significance level.[19] The labor force growth rate ($n_t$) is stationary in the first difference only at the 5% significance level. The first difference of the variable GDP per capita ($gdp_t/l_t$) is stationary at the 10% significance level in the model with the intercept, but stationary at the 5% significance level when both the intercept and the trend are included.[20] The fixed telephone subscription ($tele_t$) is still shown to be of I(2). Hence, its first difference is used in later tests and estimations.

### 7.3 Cointegration

Because the variables are I(1),[21] we now investigate the cointegration relationships between GDP per capita ($gdp_t/l_t$) and its potential determinants. The LM bootstrap panel cointegration test proposed by Westerlund and Edgerton (2007) is carried out for this purpose. In the scalar variate $y_{it} = \alpha_i + x_{it}'\beta_i + z_{it}$, where $t = 1, \dots, T$, $i = 1, \dots, N$, the disturbance $z_{it}$ is assumed to be $z_{it} = u_{it} + v_{it}$, with $v_{it} = \sum_{j=1}^{t} \eta_{ij}$. The independent and identically distributed (i.i.d) process $\eta_{ij}$ has a zero mean and variance $\sigma_i^2$. Under this formulation, the LM bootstrap cointegration test has the null hypothesis $H_0: \sigma_i^2 = 0$, for all *i*, and the alternative hypothesis $H_1: \sigma_i^2 > 0$, for some *i*. Here, we test the null hypothesis of cointegration between GDP per capita ($gdp_t/l_t$) and its potential determinant series against the alternative of no cointegration relationships.

Table 7 provides strong evidence of cointegration relationships. The table reports both bootstrap $p$-values and asymptotic $p$-values for the purpose of comparison, although the latter are not of interest because they are computed under the assumption of cross-sectional independence. According to the bootstrap test results, the null hypothesis of cointegraion is accepted in all cointegration regressions in the model with the intercept and the trend. When fixed telephone subscriptions ($\Delta tele_t$) is entered as the infrastructure variable ($f_t$), the null hypothesis is rejected at the 5% level of significance for the model with the intercept only, with a bootstrap $p$-value of 0.024. However, the null hypothesis is accepted at all levels of significance with a bootstrap $p$-value of 0.872 once the trend is allowed in the model. In all other cointegration regressions, the null hypothesis is accepted at all levels of significance in both models.

[19] Human capital ($h_t$) is non-stationary only at the 1% significance level, whereas the other variables are non-stationary at all significance levels. When further testing in the model with both the intercept and the trend, human capital ($h_t$) is non-stationary at all significance level with a CIPS test statistic of -2.613.

[20] The model with both the intercept and the trend corresponds to Case III of Pesaran (2007). In this case, when testing the stationarity of GDP per capita ($gdp_t/l_t$) at the first difference, the test statistic is -3.099, which is rejected at the 5% significance level.

[21] With the fixed telephone subscription ($tele_t$) in its first difference ($\Delta tele_t$).

**Table 7**
**LM Bootstrap Panel Cointegration Test**

| | Without Human Capital | | | | | | With Human Capital | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Intercept | | | Intercept & Trend | | | Intercept | | | Intercept & Trend | | |
| $f_t$ | Stat. | Boot-p | Asy-p | Stat. | Boot-p | Asy-p | Stat. | Boot-p | Asy-p | Stat. | Boot-p | Asy-p |
| $ey_t$ | 2.362 | 0.917 | 0.009 | 5.058 | 0.905 | 0.000 | 5.513 | 0.885 | 0.000 | 11.698 | 0.492 | 0.000 |
| $ecap_t$ | 2.527 | 0.921 | 0.006 | 4.206 | 0.993 | 0.000 | 4.665 | 0.965 | 0.000 | 11.963 | 0.504 | 0.000 |
| $\Delta tele_t$ | 5.737 ** | 0.024 | 0.000 | 5.122 | 0.872 | 0.000 | 7.197 | 0.128 | 0.000 | 10.890 | 0.593 | 0.000 |
| $it_t$ | 2.535 | 0.928 | 0.006 | 4.430 | 0.996 | 0.000 | 4.794 | 0.958 | 0.000 | 11.000 | 0.620 | 0.000 |
| $san_t$ | 2.077 | 0.874 | 0.019 | 4.892 | 0.836 | 0.000 | 4.370 | 0.956 | 0.000 | 9.984 | 0.791 | 0.000 |

Note: The test is developed by Westerlund and Edgerton (2007). (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis of cointegration can be rejected. The cointegration regression is formulated as follows: $gdp_t/l_t$, $s_t$, $n_t$, $(h_t)$, $f_t$.

### 7.4 The Estimation of Long-Run Relationships

Given the existence of panel cointegration, the long-run relationships of the model can be further estimated using estimation procedures that take into account cross-sectional dependence. The common correlated effects mean group (CCEMG) estimator of Pesaran (2006) provides a simple, but powerful solution for this type of estimation. By including the cross-sectional averages of both the dependent and the independent variables, the CCEMG estimator has the advantage of being computable by least squares applied to auxiliary regressions, and able to yield consistent estimates in situations such as serial correlation in errors, unit roots in the factors, and possible contemporaneous dependence of the observed regressors with unobserved factors (Pesaran, 2006; Pesaran and Tosetti, 2011; Coakley *et al*., 2006; Kapetanios and Pesaran, 2006; Kapetanios *et al*., 2011). Under the CCEMG formulation, the specification of our infrastructure-augmented growth model becomes

$$\ln(y_{it}) = a_i + b_i X_{it} + \mu_1 \overline{\ln(y_{it})} + \mu_2 \overline{X_t} + \varepsilon_{it},$$

where $i = 1, \ldots, N$ and $t = 1, \ldots, T$. The coefficient $\mu_1$ represents the estimated elasticity of the dependent variable $\ln(y_{it})$ with respect to its cross-sectional average. The variable $X$ contains all the independent variables. Therefore, the coefficient $\mu_2$ is the elasticity of $\ln(y_{it})$ with respect to the cross-sectional averages of the independent variables or the observed regressors. In this procedure, The CCEMG estimator is calculated as the simple average of the individual common correlated effects (CCE) estimators, expressed as follows:

$$\hat{b}_{CCEMG} = \sum_{I=1}^{N} \frac{CCE_i}{N}, \qquad SE(\hat{b}_{CCEMG}) = \frac{\sum_{i=1}^{N} \sigma(\hat{b}_{CCE_i})}{\sqrt{N}}.$$

**Table 8A**

**Common Correlated Effects Mean Group (CCEMG) Estimation**

| | Electricity | | | | Telecommunication | | Internet | | Sanitation | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $ey_t$ | | $ecap_t$ | | $\Delta tele_t$ | | $it_t$ | | $san_t$ | |
| Investment | 0.010 | -0.004 | 0.054 | 0.053 | 0.052 | 0.015 | 0.016 | 0.014 | 0.059 | 0.020 |
| | (0.053) | (0.048) | (0.057) | (0.075) | (0.074) | (0.094) | (0.044) | (0.051) | (0.050) | (0.051) |
| Population Growth | 0.027 | 1.119 | -1.482 | -1.124 | 0.996 | -1.208 | 1.236 | 3.206 | -0.518 | -1.290 |
| | (2.415) | (2.775) | (2.135) | (3.296) | (1.955) | (2.530) | (3.234) | (4.732) | (3.190) | (3.540) |
| Human Capital | --- | 0.040 | --- | -0.275 ** | --- | -0.167 *** | --- | 0.091 | --- | -0.075 |
| | --- | (0.130) | --- | (0.133) | --- | (0.058) | --- | (0.233) | --- | (0.052) |
| Infrastructure | 0.044 | 0.027 | 0.098 | -0.293 | -0.002 | -0.136 | -0.001 | -0.005 | 10.959 | 13.223 |
| | (0.112) | (0.025) | (0.290) | (0.534) | (0.095) | (0.177) | (0.015) | (0.004) | (8.738) | (16.758) |
| Wald-test | 0.870 | 2.460 | 7.240 | 15.210 | 2.030 | 2662.430 | 0.290 | 6.160 | 8.070 | 331.360 |
| Observations | 126 | 105 | 126 | 105 | 120 | 100 | 126 | 105 | 126 | 105 |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels.

**Table 8B**

**Fixed-effects Model Estimation**

| | Electricity | | | | Telecommunication | | Internet | | Sanitation | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $ey_t$ | | $ecap_t$ | | $\Delta tele_t$ | | $it_t$ | | $san_t$ | |
| Investment | -0.028 | -0.077 | 0.248 *** | 0.164 ** | 0.098 | -0.037 | -0.012 | -0.118 * | 0.309 *** | 0.214 *** |
| | (0.083) | (0.098) | (0.085) | (0.066) | (0.116) | (0.129) | (0.059) | (0.067) | (0.069) | (0.068) |
| Population Growth | 4.690 | 4.726 | 13.335 *** | 20.063 *** | 6.082 | 10.404 ** | -0.649 | 2.570 | 6.920 ** | 11.508 *** |
| | (3.520) | (3.982) | (3.674) | (2.565) | (5.230) | (5.088) | (2.582) | (2.683) | (2.961) | (2.584) |
| Human Capital | --- | 0.810 *** | --- | 0.212 | --- | 1.283 *** | --- | 0.203 | --- | 0.250 |
| | --- | (0.267) | --- | (0.186) | --- | (0.328) | --- | (0.190) | --- | (0.189) |
| Infrastructure | 1.432 *** | 1.423 *** | 2.834 *** | 3.551 *** | 0.287 ** | 0.391 | 0.113 *** | 0.103 *** | 4.937 *** | 4.605 *** |
| | (0.133) | (0.197) | (0.286) | (0.230) | (0.139) | (0.748) | (0.006) | (0.007) | (0.342) | (0.307) |
| F-test | 41.620 | 22.300 | 35.580 | 80.280 | 2.030 | 4.970 | 115.270 | 75.950 | 73.920 | 76.130 |
| Observations | 126 | 105 | 126 | 105 | 120 | 100 | 126 | 105 | 126 | 105 |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels.

In Table 8A, we see that the CCEMG estimator provides seemingly different results from those of the "first-generation" methods. Almost all estimates become non-significant when the cross-sectional dependency is considered.[22] For comparison purposes, a traditional "first-generation" fixed-effects model is also estimated and reported in Table 8B, where the infrastructure variables are mostly positive and significant at the 99% level of confidence. This dramatic change in the significance of the estimates could potentially be associated with the existence of international externality and spillover effects of the infrastructure and other variables between the six countries. This is because the CCE procedure eliminates the effects of all forms of spatial and temporal correlations, irrespective of whether these are due to spatial or unobserved common factors (Pesaran and Tosetti, 2011). Furthermore, eliminating the cross-sectional correlations can be especially effective for infrastructure variables when the coefficient of infrastructure ($b_4$) in equation [3] primarily measures externalities and other indirect effects of infrastructure development.[23] In the next section, we examine the causality between infrastructure and growth in order to gain insight from a different perspective.

### 7.5 Causality between Infrastructure and Economic Growth

Granger causality occurs when the forecasts of one variable (Y) are improved by the knowledge of past values of another variable (X). To test the direction of causality, a traditional approach is to estimate a panel vector error correction model (VECM) using the generalized method of moments (GMM) estimator. However, this approach considers neither heterogeneity nor cross-sectional dependency. Therefore, it may produce inconsistent and potentially highly misleading estimates unless the slope coefficients are in fact identical or homogeneous (Pesaran et al., 1999). Given the existence of cross-sectional dependency across individuals in the panel, estimating sets of equations using seemingly unrelated regressions (SUR) becomes more efficient than using an equation-by-equation estimation with least-squares (Zellner, 1962). In light of this, Kónya (2006) proposes an SUR-based method that considers both the heterogeneity and the cross-sectional dependency across the individuals of a panel. The equation system in this approach contains two sets of equations:

$$y_{1,t} = \alpha_{1,1} + \sum_{i=1}^{ly_1} \beta_{1,1,i}\, y_{1,t-i} + \sum_{i=1}^{lx_1} \delta_{1,1,i}\, x_{k,1,t-i} + \varepsilon_{1,1,t}$$

[22] Although the coefficients of human capital are shown to be negative and significant at the 95% and 99% confidence levels in the models of electricity capacity and telecommunication, they do not provide meaningful economic insight because the definition of $h_t$ (lower secondary completion rate) is an inefficient measurement of human capital.
[23] The effect of a pure stock increase of infrastructure is included in the coefficient of the gross fixed capital formation ($b_2$).

$$y_{2,t} = \alpha_{1,2} + \sum_{i=1}^{ly_1} \beta_{1,2,i}\, y_{2,t-i} + \sum_{i=1}^{lx_1} \delta_{1,2,i}\, x_{k,2,t-i} + \varepsilon_{1,2,t}$$

$$\vdots$$

$$y_{N,t} = \alpha_{1,N} + \sum_{i=1}^{ly_1} \beta_{1,N,i}\, y_{N,t-i} + \sum_{i=1}^{lx_1} \delta_{1,N,i}\, x_{k,N,t-i} + \varepsilon_{1,N,t}$$

and

$$x_{k,1,t} = \alpha_{2,1} + \sum_{i=1}^{ly_2} \beta_{2,1,i}\, y_{1,t-i} + \sum_{i=1}^{lx_2} \delta_{2,1,i}\, x_{k,1,t-i} + \varepsilon_{2,1,t}$$

$$x_{k,2,t} = \alpha_{2,2} + \sum_{i=1}^{ly_2} \beta_{2,2,i}\, y_{2,t-i} + \sum_{i=1}^{lx_2} \delta_{2,1,i}\, x_{k,2,t-i} + \varepsilon_{2,2,t}$$

$$\vdots$$

$$x_{k,N,t} = \alpha_{2,N} + \sum_{i=1}^{ly_2} \beta_{2,N,i}\, y_{N,t-i} + \sum_{i=1}^{lx_2} \delta_{2,N,i}\, x_{k,N,t-i} + \varepsilon_{2,N,t},$$

where $i = 1, .., N$ and $t = 1, ..., T$ denote the number of countries and periods, respectively, $y$ denotes the GDP per capita, and $x_k$ represents the infrastructure indicator. Under this formulation, for any country $j$, there is no Granger causality between infrastructure (X) and GDP per capita (Y) if all $\delta_{1,j,i}$ and $\beta_{2,j,i}$ are zero. There is two-way Granger causality between X and Y if neither $\delta_{1,j,i}$ nor $\beta_{2,j,i}$ are zero. There is one-way Granger causality from X to Y if not all $\delta_{1,j,i}$ are zero, but all $\beta_{2,j,i}$ are zero. Lastly, there is one-way Granger causality from Y to X if all $\delta_{1,j,i}$ are zero, but not all $\beta_{2,j,i}$ are zero.

Table 9 provides a summary of the directions of causality.[24] The notation "→" indicates causality from infrastructure development to economic growth (Panel A) and "←" represents causality from economic growth to infrastructure development (Panel B). The table shows that economic growth is sensitive to at least one infrastructure sector in all countries except Kyrgyzstan, as shown in Panel A. For Azerbaijan, economic growth is sensitive to electricity infrastructure ($ey_t$, $ecap_t$) development only. Economic growth shows the most sensitivity to infrastructure development in the case of Kazakhstan, with four causalities found under three sectors ($ey_t$, $ecap_t$, $tele_t$, $it_t$). For Tajikistan, the evidence indicates that

[24] See Appendix A for the detailed results of the panel Granger causality tests. The maximum number of lags in these tests is allowed to be three, using the Schwarz Bayesian Criterion.

only an improvement in sanitation facilities (*$san_t$*) induces economic growth. In Turkmenistan, both electricity generation capacity (*$ecap_t$*) and sanitation facilities (*$san_t$*) improvements cause economic growth. In Uzbekistan, economic growth is associated with the development of electricity gross production (*$ey_t$*), internet use (*$it_t$*), and improvements in sanitation facilities (*$san_t$*). The reverse causality shown in Panel B indicates that infrastructure development is most sensitive to economic growth in Kazakhstan, with causalities found under three infrastructure indicators (*$ey_t$*, *$ecap_t$*, *$tele_t$*). Economic growth can also lead to the development of the fixed telephone infrastructure (*$tele_t$*) in Kyrgyzstan and an improvement in sanitation facilities (*$san_t$*) in Uzbekistan.

**Table 9**
**Summary of the Direction of Causality**

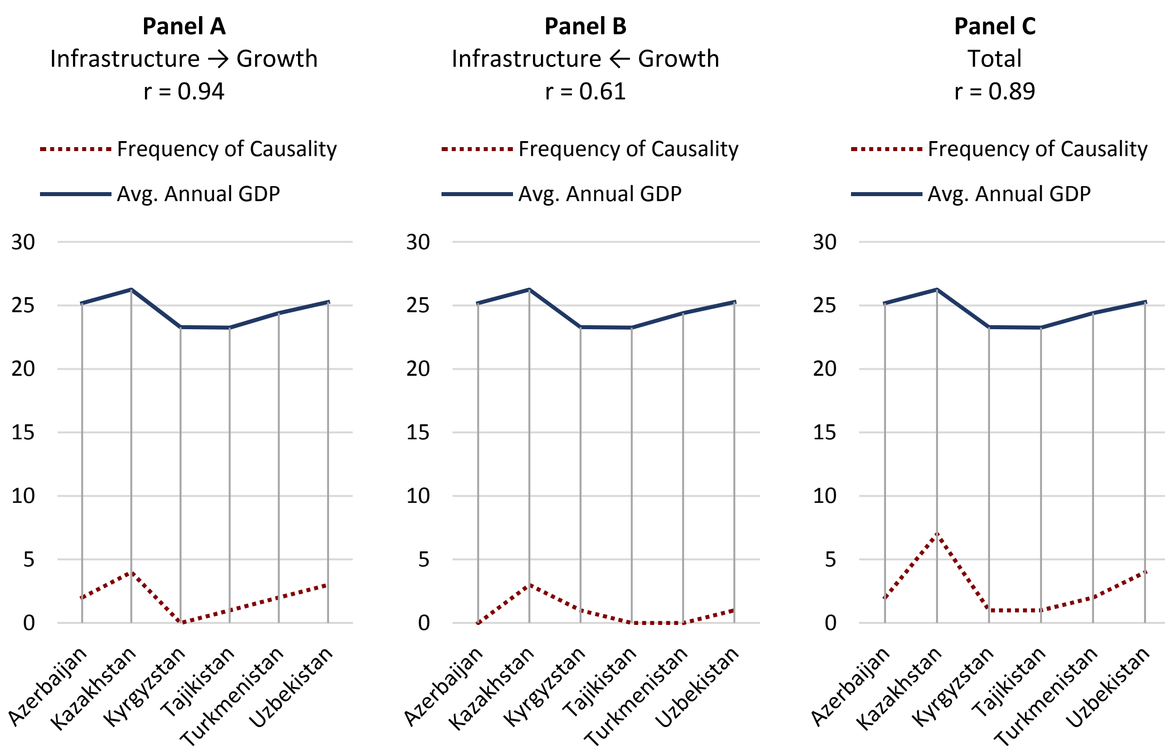
| $f_t$ / *Country* | Electricity Production $ey_t$ | Electricity Capacity $ecap_t$ | Fixed Telephone $tele_t$ | Internet $it_t$ | Sanitation $san_t$ |
|---|---|---|---|---|---|
| *Panel A:* | *Infrastructure Development → Economic Growth* | | | | |
| Azerbaijan | → | → | | | |
| Kazakhstan | → | → | → | → | |
| Kyrgyzstan | | | | | |
| Tajikistan | | | | | → |
| Turkmenistan | | → | | | → |
| Uzbekistan | → | | | → | → |
| Panel | → | → | | → | → |
| *Panel B:* | *Infrastructure Development ← Economic Growth* | | | | |
| Azerbaijan | | | | | |
| Kazakhstan | ← | ← | ← | | |
| Kyrgyzstan | | | ← | | |
| Tajikistan | | | | | |
| Turkmenistan | | | | | |
| Uzbekistan | | | | | ← |
| Panel | | ← | ← | | |

Given the non-uniform distribution of the frequency of causality across countries and sectors in Table 9,[25] we further investigate the relationship between the frequency of causality and each country's overall economic performance. In order to provide a brief overview, each country's frequency of causality is counted and plotted, along with the average annual GDP over the period of 21 years.[26] The results are shown in Figure 1, where Panels A and B correspond to Panels A and B in Table 9, respectively, and Panel

[25] For instance, Kazakhstan has the highest frequency of causality in both Panel A (frequency = 4) and Panel B (frequency = 3), whereas countries such as Kyrgyzstan and Tajikistan show much lower frequencies of causality.
[26] The average annual GDPs are measured in natural logarithms.

C counts the total frequency of causality from both Panel A and Panel B. Panel A indicates a strong correlation between the frequency of causality and the average GDP, with a coefficient of correlation $r = 0.94$. In other words, in stronger economies, we tend to see more causal relationships from infrastructure to growth. A relatively weaker correlation is found in Panel B, with a coefficient of correlation $r = 0.61$, when the direction of causality considered in Panel A is reversed. This still implies that stronger economies show more causal relationships from economic growth to infrastructure development. When the total frequency of causalities from both Panels A and B are counted, the correlation relationship remains strong ($r = 0.89$), as shown in Panel C. This provides evidence supporting the hypothesis that when growth is sensitive to infrastructure development, the overall economic performance tends to be better. The results in Panel C further confirm that a well-established causal interactive relationship between infrastructure development and economic growth is pivotal to overall economic performance.

**Figure 1 - Number of Causality and Average GDP**




The above results reveal a potential institutional aspect of infrastructure development: an institution that helps establish a causal relationship between infrastructure and growth leads to a better-performing economy in general. Two steps can be employed to establish the causality. First, under the assumption of economies of scale, it is critical to increase the infrastructure stock level to the point where economies of scale can take effect. Second, once the infrastructure stock accumulates to a certain level, ensuring that the infrastructure's externality and network effect efficiently prevail would further enhance the effectiveness and eventually lead to a well-established causal relationship and a faster-growing economy.[27]

## VIII. CONCLUSION

This study examined the relationship between infrastructure development and economic growth in six Central Asian countries (Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) using the infrastructure-augmented production function approach. The empirical evidence from the "first-generation" econometric methods showed the significant role infrastructure plays in economic growth in the long run, although the magnitude varies across countries and sectors. However, the long-run relationships became non-significant once cross-sectional dependency was taken account using a set of "second-generation" estimation methods. This revealed the potential existence of international externality and spillover effects of the base model variables, although it requires further evaluation. The direction of causality between infrastructure development and economic growth was verified across countries and sectors, taking into account cross-sectional dependency. In more robust economies, we found that more sectoral causal relationships tend to occur between infrastructure development and economic growth in both directions. We briefly discussed the policy implications from an institutional perspective and proposed two steps to increase the effect of infrastructure and establish a causal relationship between infrastructure and growth.

[27] Institutional factors such as government credibility and the level of corruption can potentially impact the effect of infrastructure on growth. Esfahani and Ramírez (2003) provide a relevant study on this topic.

## Appendix A. Results From Bootstrap Panel Causality Test

**Table A1 - Panel Causality Test for Electricity Gross Production**

| $f_t = ey_t$ | $H_0$: $f_t$ does not cause $gdp_t/l_t$ | | | | | $H_0$: $gdp_t/l_t$ does not cause $f_t$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bootstrap Critical Values | | | | | Bootstrap Critical Values | | |
| Country | Wald Stat. | Boot-p | 1% | 5% | 10% | Wald Stat. | Boot-p | 1% | 5% | 10% |
| Azerbaijan | 12.777 ** | 0.020 | 15.560 | 9.976 | 7.731 | 0.670 | 0.904 | 12.914 | 8.611 | 6.564 |
| Kazakhstan | 12.444 *** | 0.001 | 5.828 | 3.301 | 2.520 | 54.090 *** | 0.000 | 28.124 | 20.496 | 17.139 |
| Kyrgyzstan | 0.268 | 0.523 | 6.686 | 3.420 | 2.193 | 3.482 | 0.112 | 11.104 | 5.248 | 3.778 |
| Tajikistan | 0.060 | 0.823 | 6.903 | 4.216 | 2.916 | 8.705 | 0.342 | 27.277 | 16.666 | 14.202 |
| Turkmenistan | 1.844 | 0.957 | 30.359 | 20.830 | 15.376 | 1.016 | 0.991 | 28.178 | 19.748 | 16.616 |
| Uzbekistan | 3.840 * | 0.050 | 7.842 | 3.813 | 2.647 | 9.262 | 0.771 | 39.667 | 29.368 | 23.918 |
| Panel Fisher | 29.405 *** | 0.003 | | | | 7.264 | 0.840 | | | |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis can be rejected.

**Table A2 - Panel Causality Test for Electricity Capacity**

| $f_t = ecap_t$ | $H_0$: $f_t$ does not cause $gdp_t/l_t$ | | | | | $H_0$: $gdp_t/l_t$ does not cause $f_t$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bootstrap Critical Values | | | | | Bootstrap Critical Values | | |
| Country | Wald Stat. | Boot-p | 1% | 5% | 10% | Wald Stat. | Boot-p | 1% | 5% | 10% |
| Azerbaijan | 3.547 ** | 0.043 | 5.881 | 3.283 | 2.386 | 9.154 | 0.575 | 26.279 | 20.208 | 17.072 |
| Kazakhstan | 3.349 ** | 0.019 | 4.851 | 2.617 | 1.697 | 11.013 *** | 0.005 | 8.135 | 5.361 | 4.225 |
| Kyrgyzstan | 1.405 | 0.233 | 6.293 | 3.486 | 2.410 | 5.490 | 0.149 | 12.397 | 8.249 | 6.546 |
| Tajikistan | 2.087 | 0.445 | 18.424 | 11.873 | 8.243 | 4.152 | 0.428 | 12.419 | 8.344 | 7.082 |
| Turkmenistan | 28.372 *** | 0.000 | 3.699 | 2.008 | 1.429 | 0.568 | 0.301 | 4.777 | 2.580 | 1.783 |
| Uzbekistan | 0.844 | 0.468 | 14.406 | 6.391 | 4.392 | 8.310 | 0.291 | 23.299 | 15.984 | 12.704 |
| Panel Fisher | 20.271 * | 0.062 | | | | 22.078 ** | 0.037 | | | |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis can be rejected.

**Table A3 - Panel Causality Test for Telecommunication**

| $f_t = \Delta tele_t$ | $H_0$: $f_t$ does not cause $gdp_t/l_t$ | | | | | $H_0$: $gdp_t/l_t$ does not cause $f_t$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bootstrap Critical Values | | | | | Bootstrap Critical Values | | |
| Country | Wald Stat. | Boot-p | 1% | 5% | 10% | Wald Stat. | Boot-p | 1% | 5% | 10% |
| Azerbaijan | 0.389 | 0.497 | 6.791 | 3.576 | 2.346 | 1.868 | 0.152 | 7.441 | 3.949 | 2.511 |
| Kazakhstan | 5.156 ** | 0.025 | 6.630 | 3.578 | 2.603 | 19.962 *** | 0.003 | 15.119 | 8.961 | 5.888 |
| Kyrgyzstan | 2.226 | 0.183 | 7.790 | 4.824 | 3.319 | 14.431 *** | 0.001 | 12.165 | 6.871 | 5.356 |
| Tajikistan | 3.123 | 0.709 | 39.585 | 22.129 | 16.139 | 0.310 | 0.643 | 10.595 | 5.172 | 3.913 |
| Turkmenistan | 0.792 | 0.307 | 10.705 | 5.345 | 3.039 | 4.620 | 0.140 | 14.124 | 6.670 | 5.275 |
| Uzbekistan | 1.346 | 0.501 | 19.727 | 10.173 | 7.384 | 2.027 | 0.248 | 12.089 | 5.539 | 3.893 |
| Panel Fisher | 16.605 | 0.165 | | | | 36.806 *** | 0.000 | | | |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis can be rejected.

**Table A4 - Panel Causality Test for Internet**

| $f_t = it_t$ | $H_0$: $f_t$ does not cause $gdp_t/l_t$ | | | | | $H_0$: $gdp_t/l_t$ does not cause $f_t$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bootstrap Critical Values | | | | | Bootstrap Critical Values | | |
| Country | Wald Stat. | Boot-p | 1% | 5% | 10% | Wald Stat. | Boot-p | 1% | 5% | 10% |
| Azerbaijan | 7.541 | 0.291 | 20.547 | 14.317 | 11.641 | 0.000 | 0.992 | 9.355 | 5.041 | 3.403 |
| Kazakhstan | 12.676 ** | 0.021 | 14.845 | 10.240 | 7.927 | 0.318 | 0.836 | 6.235 | 4.643 | 3.720 |
| Kyrgyzstan | 0.698 | 0.948 | 18.718 | 12.517 | 10.585 | 0.701 | 0.941 | 23.744 | 16.177 | 13.094 |
| Tajikistan | 2.067 | 0.997 | 36.416 | 24.912 | 20.757 | 0.305 | 0.998 | 27.692 | 20.748 | 17.015 |
| Turkmenistan | 3.845 | 0.567 | 16.963 | 11.387 | 9.498 | 0.405 | 0.986 | 31.067 | 20.124 | 16.555 |
| Uzbekistan | 10.578 *** | 0.006 | 9.935 | 6.559 | 5.687 | 3.233 | 0.387 | 8.284 | 6.272 | 5.239 |
| Panel Fisher | 21.675 ** | 0.041 | | | | 2.427 | 0.998 | | | |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis can be rejected.

**Table A5 - Panel Causality Test for Sanitation**

| ***$f_t$ = $san_t$*** | $H_0$: $f_t$ does not cause $gdp_t/l_t$ | | | | | | $H_0$: $gdp_t/l_t$ does not cause $f_t$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Bootstrap Critical Values | | | | | | Bootstrap Critical Values | | |
| Country | Wald Stat. | | Boot-p | 1% | 5% | 10% | Wald Stat. | | Boot-p | 1% | 5% | 10% |
| Azerbaijan | 0.379 | | 0.895 | 14.623 | 9.562 | 7.072 | 0.822 | | 0.574 | 6.464 | 4.217 | 3.328 |
| Kazakhstan | 5.846 | | 0.624 | 27.630 | 19.036 | 15.314 | 10.041 | | 0.666 | 45.102 | 31.799 | 25.712 |
| Kyrgyzstan | 29.113 | | 0.242 | 63.782 | 47.589 | 39.126 | 0.445 | | 0.590 | 11.217 | 6.116 | 4.526 |
| Tajikistan | 91.160 | *** | 0.004 | 78.192 | 45.759 | 38.791 | 1.138 | | 0.815 | 22.329 | 12.528 | 9.673 |
| Turkmenistan | 11.408 | * | 0.098 | 19.992 | 13.743 | 11.310 | 0.078 | | 0.954 | 10.240 | 6.670 | 5.285 |
| Uzbekistan | 22.041 | *** | 0.000 | 13.970 | 10.578 | 8.425 | 28.471 | *** | 0.000 | 11.866 | 8.244 | 6.202 |
| Panel Fisher | 19.691 | * | 0.073 | | | | 3.482 | | 0.991 | | | |

Note: (*), (**), and (***) denote the 10%, 5%, and 1% significance levels at which the null hypothesis can be rejected.

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