# THE BILATERAL LINKAGES BETWEEN INNOVATIONS AND DIGITALIZATION. EVIDENCE FROM CIS COUNTRIES

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***Abstract.*** *In the framework of the advancement of the knowledge economy, innovation and digital technology play crucial roles. Simultaneously, there is an ongoing question on the relative importance of each of these elements. To examine this matter, the article examines the statistics on 9 Commonwealth of Independent States (CIS) republics. The modelling findings indicate that the components exhibit comparable significance, implying a reciprocal association between innovation and the degree of digitalization. Hence, a 10% enhancement in the innovation ecosystem may lead to a maximum 3% increase in the degree of digitalization. Simultaneously, an inverse relationship exists: a 10% rise in the adoption of digitalization leads to a 2% boost in innovation.*

***Keywords:*** *innovations, digitalization, economic growth, CIS.*

**Introduction.** Innovation is a source of progress and growth. They drive technological progress, improve the quality of life and create new opportunities for businesses and individuals alike. Therefore, innovation with its broader positive impact on all of humanity's achievements will drive demand for new developments in ICT, including tools and systems.

On the other hand, with the development of ICTs, in particular the Internet, there has been an easier access to information and co-operation, which has also had an impact on innovation.

It is worth noting that the impact of ICT development on innovation occurs through three channels (Arvin et al., 2021):

ICT development increases the cost-effectiveness of ideas used in the innovation process;

Enables more effective innovation co-operation with peripheral partners;

Directly influences the innovation process in various forms

Also, the positive indirect effects of ICT on society include increased competition in the ICT industry and increased profitability of IT companies, which has implications for increased R&D investment in ICT development (Pradhan et al., 2018).

**Literature review.** Numerous studies have emphasized the key role of ICT as a catalyst for innovation in various sectors of the economy. The widespread adoption of digital technologies such as cloud computing, big data analytics and the Internet of Things (IoT) has greatly enhanced research and development (R&D) capabilities (Usai, A. et al., 2021). ICT tools and platforms have streamlined collaboration, data sharing and communication among researchers, leading to accelerated innovation cycles and disruptive technologies.

ICT has also enabled organizations to use data to make informed decisions, develop products and optimize processes. The integration of artificial intelligence (AI) and machine learning algorithms has enabled companies to automate routine tasks, unlock new business opportunities and provide personalized solutions to meet changing consumer demands (Abrokwah-Larbi, K. et.al., 2023). As a result, ICT has not only facilitated incremental innovation but also paved the way for transformational breakthroughs in various industries.

At the same time, the drive for innovation has played an important role in shaping the direction of ICT development. Research and development aimed at improving the performance, reliability and security of digital infrastructure has fueled the development of ICT hardware, software and networking technologies. The search for more efficient and sustainable solutions has led to energy-efficient computing systems, high-speed broadband networks and robust cybersecurity measures (Fernández-Portillo, A., 2022).

Moreover, innovative business models and entrepreneurial endeavors have changed the landscape of ICT services and products. Both start-ups and established companies have introduced new applications, platforms and services that have revolutionized the way people deal with technology. The emergence of social media, mobile applications and e-commerce ecosystems are examples of how innovative concepts have changed consumer behavior and expectations in the digital sphere.

**Data and descriptive statistics.** In order to understand the relationship between the innovation environment and ICT, this study uses econometric models to analyze panel data. Based on the aim and objectives of the study, data was collected for 9 CIS countries (Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Uzbekistan) from 2010 to 2020 (11 years) on a number of key indicators of innovation environment and ICT. As a result, 99 observations were collected.

Data on indicators such as the number of people with access to the internet (internet, in %), fixed broadband connection (fixed broad band, in %), mobile connection (mobile, in %), trademarks of residents (trademarkres, pcs.) and non-residents (trademarknonres, pcs.), number of patents obtained in the country (patent, pcs.), exports of high-tech products (high-tech, in USD) were obtained from the World Bank World Development Indicators database. Data on the Global Innovation Index (GII, index) were collected from the Global Innovation Index database[1].

Taking into account that the generalized ICT Development Index, which is calculated by the International Telecommunication Union at the UN, has a large number of missing data, the generalized ICT development index (ICT, index) was calculated using formula (1):

$$ICT = \ln(fixedbroadband) + \ln(mobile) + \ln(internet) \quad (1)$$

Table 1 demonstrates the descriptive statistics of the indicators used.

***Table 1.***

***Descriptive statistics***

| Indicator | Observations | Mean | Min | Max |
|---|---|---|---|---|
| ICT | 99 | 4,48 | 1,74 | 5,54 |
| GII | 99 | 31,30 | 22,20 | 40,9 |
| GDP (PPP) | 99 | 13203,95 | 2382,25 | 27254,57 |
| internet | 99 | 51,93 | 11,55 | 85,94 |
| fixedbroadband | 99 | 12,15 | 0,06 | 33,79 |
| mobile | 99 | 117,15 | 68,72 | 176.79 |
| trademarkres | 99 | 25839,77 | 160 | 341414 |

[1] https://www.globalinnovationindex.org/analysis-indicator

| | | | | |
|---|---|---|---|---|
| trademarknonres | 99 | 15105,69 | 4102 | 67367 |
| Hightech | 99 | 1.368e+09 | 0,115e+09 | 1.145e+10 |
| patent | 99 | 4906,76 | 2 | 45517 |

*Source: authors' calculations*

GDP PPP per capita (GDP (PPP), in constant 2017 prices), reflecting the purchasing power of the population, is considered as a control variable. Purchasing power is a determinant of ICT demand and innovation development.

**Missed values.** Missing values were found in all variables except GDP PPP per capita. In this study, it was decided not to replace missing values with data from the national statistics of countries in order to maintain the common denominator (international standard) of the methodology for calculating the variables.

MCAR (missing completely at random) tests were conducted to see if the missing values were of random nature. The test results (Prob > chi-square = 0.0006) showed that the missing values are not random. Consequently, continuing the simulation without filling in the missing values leads to biased estimates.

***For reference:*** *The null hypothesis in the missing completely at random test considers the random nature of missing values. The refutation of the hypothesis signals that the missing values are not random and they may have an impact on the final result of the simulation (Cheng Li & Evanston I., 2013).*

In order to preserve the completeness of the observations, it was decided to fill in the missing values in 3 ways depending on their position in time:

If the missing value was at the beginning of the study period (there were no observed values before it), the value was filled in with the growth rate in subsequent years.

$$x_t = x_{t+1} - (x_{t+2} - x_{t+1}) \qquad (2)$$

If the missing value fell between the observed values, then linear growth over the unobserved period is implied.

If the missing value is at the end of the period, the growth rate for previous periods is assumed

$$x_t = x_{t-1} + (x_{t-1} - x_{t-2}) \qquad (3)$$

While this methodology does not eliminate estimation bias due to steady growth over the periods shown, it provides more accurate estimates than other common methodologies such as filling in the previous value (used for non-calculated SDG indices), the average, and other methods.

Most factors are physically observable and computable values (except for the GII and ICT indices), so gradual improvement in such variables is the most likely option.

**Methodology.** In contrast to Pradhan R. (2022), our study decided to use panel data analysis methods: fixed effects model, random effects model, panel-corrected standard errors model and Driscroll-Cray standard errors model. The choice between models and the necessary tests for cross-sectional dependence and autocorrelation were performed according to the Princeton University methodology (*Granger causality test*).

$$ICT = f(GDPPP,\ GII,\ trademarkres,\ trademarknonres,\ patent, hightech) \qquad (4)$$

$$GII = f(GDPPP,\ ICT, fixedbroadband,\ mobile,\ internet) \qquad (5)$$

In contrast to Pradhan R. (2022), our study decided to use panel data analysis methods: fixed effects model, random effects model, panel-corrected standard errors model and Driscroll-Cray standard errors model. The choice between models and the necessary tests for cross-sectional dependence and autocorrelation were performed according to the Princeton University methodology[2] (*Panel 101, Princeton University*).

The econometric model from equation (4) is as follows:

$$ICT = \beta_0 + \beta_1 * \ln(GDPPPP) + \beta_2 * GII + \beta_3 * \ln(trademarkres) + b_4 * (trademarknonres) + b_5 * \ln(patent) + b_6 * \ln(hightech) \quad (6)$$

The use of logarithmic variables is explained by the fact that these independent variables are estimated in absolute values. A linear model in logarithms with constant elasticity allows estimating the percentage change in the dependent variable for the percentage change in the independent variable.

The econometric model from equation (5) is as follows:

$$GII = \alpha_0 + \alpha_1 * \ln(GDPPP) + \alpha_2 * fixedbroadband + \alpha_3 * mobile + \alpha_4 * internet) \quad (7)$$

Equation (7) does not use logarithms in the ICT development indicators because they are estimated as percentages in the database.

**Impact of innovation factors on ICT.** The results of the regression analysis are presented in Table 2. The choice between models was based on the Hausman test (choosing between Fixed effects and Random effects), as well as diagnostics of the presence of cross-dependence and autocorrelation. According to the results of the Hausman test (*Prob> chi2 = 0.0000*), the Fixed effects model is more favorable than the Random effects model.

Pesaran's test of cross-sectional independence according to Princeton University guidelines was used to test for the presence of cross-sectional dependence[3]. The null hypothesis of the test assumes that there is no cross dependence between the objects. According to the results of the Pesaran test, the null hypothesis is rejected (*Pr = 0.0000*), hence there is cross-sectional dependence between countries.

The presence of autocorrelation was examined using the Wooldridge test for autocorrelation in panel data. According to the null hypothesis, previous values have no significant effect on subsequent values. The results of the Wooldridge test show that the null hypothesis is rejected (*Prob > F = 0.0009*), hence there is a time dependence (autocorrelation).

***Table 2.***

***Impact of innovation factors on ICTs***

| Dependent variable: lnICT | Fixed effects (*Stata: xtreg, fe*) | Random effects (*Stata: xtreg, re*) | PCSE (*Stata: xtpcse*) | DKSE (*Stata: xtscc*) |
|---|---|---|---|---|
| lnGDPPPP | 0,778*** (0,102) | 0,555*** (0,707) | 0,468*** (0,153) | 0,273*** (0,027) |
| lnGII | -0,047 (0,111) | -0.018 (0,114) | 0,221** (0,009) | 0,331*** (0,064) |
| lnHightech | 0,008 (0,005) | 0,014*** (0,005) | 0,007 (0,018) | 0,037** (0,013) |

[2] https://www.princeton.edu/~otorres/Panel101.pdf
[3] https://www.princeton.edu/~otorres/Panel101.pdf

| | | | | |
|---|---|---|---|---|
| lnTrademarknonres | -0,020<br>(0,208) | -0,273<br>(0,173) | -0,716***<br>(0,527) | -0,891***<br>(0,062) |
| lnTrademarkres | 0,015<br>(0,066) | 0,067<br>(0,064) | 0,221***<br>(0,241) | 0,048<br>(0,080) |
| lnPatent | -0,042*<br>(0,025) | -0,051**<br>(0,020) | -0,011<br>(0,067) | 0,075**<br>(0,033) |
| const | -5,534***<br>(1,219) | -2,573***<br>(0,702) | -1,546***<br>(1.805) | 0,555<br>(0,463) |
| R2 | 0,70 | 0,70 | 0,97 | 0,84 |

**** - 1%, ** - 5%, * - 10% level of significance*
*Source: authors' calculations*

Based on the tests performed, it can be concluded that the most efficient estimates, with consideration of cross-sectional and temporal dependencies, can be obtained using the PCSE and DKSE models. A 10% increase in the purchasing power of the population improves ICT from 2.7% (estimated by the DKSE model) to 4.7% (estimated by the PCSE model). It is noteworthy that this indicator is significant at 1% significance level in both models.

The innovation development index has a positive impact on ICT: a 10% increase in the index can improve ICT by 2.2-3.3%. The estimate is significant at the 5% significance level in the PCSE model and at the 1% level in the DKSE model. In the DKSE model, there are also positive significant effects on ICT from high-tech exports (a 1% increase in exports can improve ICT by 0.37%) and patents (a 1% increase in patents can improve ICT by 0.75%). Both factors are significant at 5% level.

It is worth noting that the factor of the number of trade marks by non-residents is negatively related to ICT growth.

**Impact of ICT factors on the innovation development index.** Table 3 presents the results of the regression analysis. The choice between models followed a similar pattern, using the Hausman test (choosing between Fixed effects and Random effects), and tests for cross-sectional dependence and autocorrelation. According to the results of the Hausman test (*Prob> chi2 = 0.9136*), the random effects model is more favorable than the fixed effects model.

Tests for cross sectional independence (*Pesaran's test of cross-sectional independence*) and autocorrelation (*Wooldridge test for autocorrelation in panel data*), determined the presence of cross-sectional dependence (*Pr = 0.0000*) and autocorrelation (*Prob > F = 0.0039*).

***Table 3.***

***The influence of ICT development factors on the innovation environment***

| Dependent variable: lnGII | Fixed effects (*Stata: xtreg, fe*) | Random effects (*Stata: xtreg, re*) | PCSE (*Stata: xtpcse*) | DKSE (*Stata: xtscc*) |
|---|---|---|---|---|
| lnGDPPPP | 0,098<br>(0,126) | 0,120*<br>(0,070) | 0,072**<br>(0,029) | 0,072<br>(0,043) |
| lnICT | 0,077<br>(0,139) | 0,075<br>(0,121) | 0,212***<br>(0,070) | 0,212***<br>(0,051) |
| fixedbroadband | 0,003<br>(0,003) | 0,003<br>(0,003) | 0,006***<br>(0,001) | 0,006***<br>(0,001) |

| | | | | |
|---|---|---|---|---|
| mobile | -0,0002 (0,0007) | -0,00002 (0,0007) | 0,002*** (0,0004) | 0,002*** (0,0004) |
| internet | -0,002* (0,001) | -0,002** (0,001) | -0,005*** (0,0009) | -0,004*** (0,001) |
| const | 2,493** (1,058) | 2,278*** (0,563) | 2,374** (0,184) | 2,374 (0,339) |
| R2 | 0,44 | 0,45 | 0,54 | 0,54 |

**** - 1%, ** - 5%, * - 10% level of significance*
*Source: authors' calculations*

Based on the conducted diagnostics, it can be concluded that the PCSE and DKSE models are the most preferred. Every aspect of information and communication technologies has a strong impact on innovation. The innovation index improved by 2.1% as a result of a 10% increase in the generalized information and communication technology index. There is a significant relationship between high-speed Internet access and innovation: a 1 p.p. increase in the number of users leads to a 0.6% improvement in innovation. Similarly, a 1 p.p. increase in the number of mobile phone users leads to a 0.2 % increase in innovation.

It is noteworthy that in all 4 models, the internet has a significant negative impact on innovation. This may be due to the fact that the internet can also lead to a high flow of non-essential information and distraction, which may hinder creativity and innovation. In addition, the ease of access to existing solutions on the Internet may reduce the desire to think differently and come up with innovative solutions.

The model quality indicator $R2 = 0.54$ symbolises that the model is only able to explain half of the variation in the innovation index. Although this value is not low, it indicates that part of the variation in the innovation index is not accounted for by the model. This could be due to unmeasured variables, random variability or non-linear relationships that the model cannot capture. Therefore, while the model may provide some insight into the factors affecting the innovation index, it is important to consider other information and factors outside the scope of the model when making decisions related to innovation strategies.

**Conclusion.** In modern digital world ICT contributes to faster development of scientific thought and innovation in general, but cannot replace all the factors that influence it. Under the influence of ICT factors, the exchange of ideas, their testing and implementation are accelerated. However, financial factors, competition factors (export and import of technologies, etc.), intellectual property protection, etc. remain an important component of innovation development.

Innovation, in turn, has a much stronger impact on digitalization and ICT development. This is due to the fact that positive dynamics in this area depends primarily on new technologies, the emergence of which is due to the development of innovation activities.

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