Digital Infrastructure, Investment, and ICT Services Export: Evidence from the Organization of Turkic States

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Abstract

This research explores the factors behind ICT service exports in the Organization of Turkic States, comprising Azerbaijan, Türkiye, Uzbekistan, Kazakhstan, Kyrgyzstan, and Hungary, over the period 2000–2023. Using annual panel data published by the World Bank, we explore the effects of research and development (R&D), mobile cellular subscriptions, foreign direct investment (FDI), education, and individuals using the Internet on ICT service exports (as a percentage of total service exports). The paper employs panel-corrected standard errors (PCSE) estimations to account for heteroskedasticity and contemporaneous correlation across countries. The findings show that R&D spending, FDI, education spending, and Internet usage all have a statistically significant and positive association on ICT service exports while mobile cellular subscriptions had a small negative total effect. Further testing indicated the absence of evidence of omitted variable bias, with the findings considered robust. The contributions of this analysis point to the importance of continuous digital investment, and educational spending, as well as policies to stimulate targeted innovation, with a view to improve the digital trade scorecard of Turkic States. The policy recommendations stress the need for coordinated regional strategies to publicize digital infrastructure investments, elevate the innovation capacity within the region, and attract high-quality foreign direct investment, with a view to enhancing ICT service export growth.

Keywords: ICT services export; Digital infrastructure; R&D expenditure; Foreign direct investment; Turkic States; Panel data

1. Introduction

ICT services have propelled the growth of the global economy and further trade and commerce. Being ICT service exporters, emerging and developing countries have the opportunity to diversify and enter global value chains; these comprise telecommunications, computer services, and certain new components of digital trade. For the member states of the Organization of Turkic States - Azerbaijan, Türkiye, Uzbekistan, Kazakhstan, Kyrgyzstan, and Hungary - growing ICT service exports is of economic and strategic importance because this will promote cooperation and sustainable development in the region.

During the last ten years, these countries have implemented a variety of efforts aimed at better equipping their digital infrastructure, promoting innovation, and attracting foreign investment to the technology sectors. However, few things are known in this regional setting regarding the determinants of the performance of ICT services exports. Although some earlier studies have examined ICT trade in developed economies or broader regional groupings, there is no empirical study focused on the Turkic States, particularly using recent information and good econometric methods.

This study bridges this gap by empirically investigating the impact of spending on research and development (R&D), mobile cellular subscriptions, foreign direct investment (FDI), government expenditure on education, and Internet users on ICT services exports between 2000 and 2023. The World Bank's annual panel data are used and the data are estimated with panel-corrected standard errors (PCSE) to control for heteroskedasticity and cross-sectional dependence.

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The research outcomes contribute to the literature in two ways. Firstly, they provide a complete databased account of the most significant economic and technological drivers of Turkic States ICT services exports. Secondly, they provide practical policy suggestions for regional integration to support innovation, improve human capital, and improve digital trade competitiveness. The conclusions have important policy implications for policymakers who are interested in profiting from the digital economy as a source of sustainable development and global integration.

2. Literature Review

The relationship between digital infrastructure and economic performance has been a central concern in current economic research. Information and Communication Technology (ICT) service exports, as a part of the digital economy, have attracted attention because they can enhance international competitiveness, stimulate innovation, and diversify economies [1]. ICT-facilitated globalization has been discovered to facilitate the movement of knowledge, reduce the transaction cost, and enhance market access, particularly for the developing and transition economies [2].

Research and development (R&D) spending is ancillary to the above process. Increased R&D expenditure has been shown in numerous studies to enhance technological capabilities, foster innovation, and lead to the generation of competitive ICT services [3]. In developing economies, R&D investment has been linked with both ICT export expansion and productivity gain [4].

Extension of mobile cellular subscriptions and broader digital connectivity has also been underscored as another key driver of ICT services exports. Mobile penetration raises digital platform access, promotes adoption of e-commerce, and increases cross-border delivery of services [5]. This expansion in connectivity is particularly vital in landlocked and spatially dispersed economies, where physical infrastructure constraints can be bridged through digital intermediaries [6].

Foreign direct investment (FDI) has been found to directly and indirectly affect ICT service exports. FDI flows can potentially carry technology, managerial skills, and funds, which increase a country's capability to export as well as produce ICT services [7]. Empirical evidence is that countries having solid ICT infrastructure encourage higher efficiency-seeking FDI, hence opening an incentives loop between investment and service exports [8].

Government education expenditure is also a critical driver. Skilled labor is required to create, maintain, and export ICT services. Evidence exists that high-investing economies in education are more likely to have higher human capital, which strengthens knowledge-intensive industries such as ICT services [9]. Education spending not only enhances skilled labor supply but also enhances the nation's capacity to deal with rapidly changing technological environments [10].

Finally, the proportion of individuals with access to the internet is a yardstick of digital preparedness. Greater penetration of the internet expands local demand for digital services, stimulates private sector investment in ICT, and enables businesses to become connected to international service value chains [11]. In developing economies, internet uptake has been associated with structural transformation, whereby nations progress towards increased value-added services.

Despite this mounting body of work, empirical research on ICT service exports within the context of Turkic States has remained limited. As the dynamics of digital economies in some member states have been examined in previous research, few of those studies undertook a comparative panel data analysis involving ICT infrastructure, investment, and human capital variables. Plugging this gap, the present study analyzes ICT service export drivers of Azerbaijan, Türkiye, Uzbekistan, Kazakhstan, Kyrgyzstan, and Hungary during the period 2000-2023 based on R&D spending, mobile penetration, FDI inflows, public spending on education, and internet usage.

3. Methodology

This essay analyzes determinants of ICT services exports of Organization of Turkic States members – Azerbaijan, Türkiye, Uzbekistan, Kazakhstan, Kyrgyzstan, and Hungary – between 2000 and 2023. Six variables' data for one year were downloaded from the World Bank's World Development Indicators: ICT services exports (% of services exports, BoP) as the dependent variable and research and development expenditure (% of GDP), mobile cellular subscriptions (per 100 people), foreign direct investment net inflows (% of GDP), government expenditure on education (% of GDP), and individuals who use the Internet (% of population) as the independent variables.

Choices of the explanatory variables are based on theory and actual research evidence. Increased R&D spending needs to increase ICT innovation potential and hence the effect needs to come out positively on exports. Cell phone subscriptions need to have an effect on digital infrastructure, the sign of which would be based on whether they indicate consumption-led use (negative) or production potential (positive). FDI flows needs to have a positive effect through technology transfer facilitation and integration into global value chains. Government education expenditure needs to build human capital and hence have a positive effect on ICT exports. Internet use needs to have a positive effect through increased digital access and facilitation of ICT-based services. Panel regression specifications were

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estimated using pooled OLS, fixed effects, and panel-corrected standard errors (PCSE). Diagnostic tests were conducted to guide model selection: the Breusch–Pagan Lagrangian Multiplier (LM) test did not show any significant panel effects, for which pooled OLS was better than random effects; White's test showed heteroskedasticity; the Wooldridge test showed first-order autocorrelation; the Ramsey RESET test showed functional form adequacy; and the normality test showed non-normal residuals. In light of heteroskedasticity and autocorrelation, the PCSE estimator of Beck and Katz has been applied in the final model to produce robust standard errors and asymptotically unbiased coefficient estimates [12].

The econometric specification is as follows:

$$ICT_{it} = \beta_0 + \beta_1 RandD_{it} + \beta_2 MCS_{it} + \beta_3 FDI_{it} + \beta_4 GovExp_{it} + \beta_5 IUI_{it} + \epsilon_{it}$$

Where i indexes the country, t the year, ICT_{it} denotes ICT service exports (% of service exports, BoP), $RandD_{it}$ is research and development expenditure (% of GDP), MCS_{it} is Mobile cellular subscriptions (per 100 people), FDI_{it} is foreign direct investment, net inflows (% of GDP), $GovExp_{it}$ is government expenditure on education, total (% of GDP), and IUI_{it} represents individuals using the Internet (% of population)

All the estimations were conducted with Stata 18 and statistical significance assessed at 1%, 5%, and 10%. Tests of robustness were conducted by comparing results across estimation methods and correlation diagnostics to ensure there was no likelihood of multicollinearity.

4. Results

This section presents the empirical findings of the study, beginning with descriptive statistics and correlation analysis of the variables, followed by diagnostic tests to guide model selection. Subsequently, the results from the panel regression estimations, including pooled OLS and panel-corrected standard errors (PCSE), are reported. The discussion highlights the statistical significance, direction, and magnitude of the estimated coefficients, as well as the implications of the diagnostic tests for model validity.

Table 1: Descriptive Statistics of Variables for Turkic States (2000–2023)

Variable		Mean	Std. dev.	Min	Max	Observations
ICT	overall	4.123212	3.07177	0.1333986	15.42475	N = 144
	between		1.99353	2.041561	7.653718	n = 6
	within		2.469982	-0.9811543	15.42504	T = 24
RandD	overall	0.4693328	0.4459837	0.05876	1.64379	N = 144
	between		0.449465	-0.1466737	1.189876	n = 6
	within		0.1713919	0.0552411	0.9920111	T = 24
MCS	overall	81.01167	43.7762	0.1790999	174.709	N = 144
	between		16.30439	55.23929	99.08385	n = 6
	within		41.14947	-15.99437	157.4418	T = 24
FDI	overall	6.700319	15.14963	-40.10825	105.6358	N = 144
	between		5.148956	1.540051	13.33853	n = 6
	within		14.39665	-46.74646	98.99754	T = 24
GovExp	overall	4.402093	1.277884	2.06763	7.38422	N = 144
	between		1.212323	2.999824	5.882403	n = 6
	within		0.6321786	2.028081	5.903911	T = 24
IUI	overall	43.11587	31.59761	0.148	92.9	N = 144
	between		10.78701	31.24008	60.05	n = 6
	within		30.01274	-9.934132	100.8758	T = 24

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The descriptive statistics reveal significant variation in the six countries of the Turkic States organization during the 2000–2023 period. ICT service exports (% of service exports, BoP) have a mean of 4.12% with significant within-country variation, indicating varying phases of development of the digital service sector. Research and development expenditure has a mean of 0.47% of the GDP with modest investment in innovations. Mobile cellular subscriptions (MCS) have a high mean of 81.01 per 100 people with large within-country variation, indicating fast diffusion of mobile technologies. Foreign direct investment (FDI) inflows (% of GDP) have a large standard deviation of 15.15, indicating large volatility in external capital flows. Government expenditure on education has a mean of 4.40% of the GDP with relatively stable country trends. Lastly, individuals who use the internet (IUI) have a mean of 43.12% of the population with large growth opportunities in some of the member states. These statistics reveal substantial heterogeneity across the variables, rendering the use of panel data techniques necessary.

Table 2: Correlation Matrix of Key Variables for Turkic States (2000–2023)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) ICT	1.000					
(2) RandD	0.341	1.000				
(3) MCS	0.080	0.148	1.000			
(4) FDI	0.186	0.106	-0.057	1.000		
(5) GovExpenEdu	0.147	-0.069	0.046	-0.110	1.000	
(6) IUI	0.228	0.312	0.789	-0.073	-0.042	1.000

The correlation matrix exhibits mixed levels of association across the variables. ICT service exports are moderately positively correlated with expenditure on R&D (0.341) and internet use (0.228), such that greater innovation investment and increased internet penetration are each associated with improved ICT exports. MCS are highly positively correlated with internet use (0.789), indicating complementary growth in mobile access and online use. FDI inflows are weakly associated with most variables, such that there is little direct short-term coincidence with ICT sector performance. Government expenditure on education has weak correlations with most other indicators, such that there may be indirect or delayed effects on ICT-related outcomes. Generally, the correlations bear witness to some significant interconnections—most notably between digital infrastructure, use, and innovation investment—that justify further multivariate exploration.

Table 3: Variance inflation factor

	VIF	1/VIF
IUI	3.018	.331
MCS	2.769	.361
RandD	1.162	.86
FDI	1.038	.964
GovExpenEdu	1.033	.968
Mean VIF	1.804	.

The VIF measures show there are no serious multicollinearity issues with the independent variables since all are significantly below the standard cutoff point of 10. The VIF is highest for Individuals Using the Internet (IUI) with 3.018, and second-highest for Mobile Cellular Subscriptions (MCS) with 2.769, indicating moderate correlations with other estimators but not to a troublesome degree. The mean VIF of 1.804 also confirms the multicollinearity is not a problem, and the regression estimations are stable and reliable.

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Table 4: Pooled OLS Regression Results for ICT Service Exports

ICT	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
RandD	1.773	.559	3.17	.002	.668	2.878	***
MCS	-.017	.009	-1.96	.052	-.035	0	*
FDI	.039	.016	2.54	.012	.009	.07	**
GovExpenEdu	.513	.184	2.79	.006	.149	.876	***
IUI	.035	.013	2.79	.006	.01	.061	***
Constant	.636	.966	0.66	.512	-1.275	2.546	

Mean dependent var	4.123	SD dependent var	3.072
R-squared	0.219	Number of obs	144
F-test	7.738	Prob > F	0.000
Akaike crit. (AIC)	707.272	Bayesian crit. (BIC)	725.091

*** p<.01, ** p<.05, * p<.1

The combined OLS regression result reveals Research and Development expenditure (RandD), Foreign Direct Investment (FDI), Government expenditure on education (GovExpenEdu), and Individuals who use the Internet (IUI) have significant positive contributions to ICT service exports with p-values below 0.05. Mobile Cellular Subscriptions (MCS) has a marginally significant but negative contribution (p = 0.052). The model provides explanation for roughly 21.9% of the variation in ICT service exports, and the general F-test provides support for the collective significance of the predictors (p < 0.01).

Table 5: Random Effects Model Results for ICT Service Exports

ICT	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
RandD	1.773	.559	3.17	.002	.678	2.868	***
MCS	-.017	.009	-1.96	.05	-.034	0	*
FDI	.039	.016	2.54	.011	.009	.07	**
GovExpenEdu	.513	.184	2.79	.005	.152	.873	***
IUI	.035	.013	2.79	.005	.011	.06	***
Constant	.636	.966	0.66	.511	-1.258	2.529	

Mean dependent var	4.123	SD dependent var	3.072
Overall r-squared	0.219	Number of obs	144
Chi-square	38.689	Prob > chi2	0.000
R-squared within	0.055	R-squared between	0.620

‘ p<.01, ** p<.05, * p<.1

Random effects model reports that Research and Development expenditure (RandD), Foreign Direct Investment (FDI), Government expenditure on education (GovExpenEdu), and Individuals Using the Internet (IUI) have significant and positive impact on ICT service exports on the 1% level. Mobile Cellular Subscriptions (MCS) has a negative and borderline significant association (p = 0.05). The overall chi-square test proves the collective

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significance of the predictors ($p < 0.01$). The model accounts for 21.9% of the total variation of ICT service exports, with the inter-country variation (62%) being substantially larger compared to the intra-country variation (5.5%).

The Breusch and Pagan Lagrangian Multiplier (LM) test for random effects had a p-value of 1.0000, and thus indicated no significance of variance across panels and the inappropriateness of the Random Effects (RE) model. The RE model was therefore rejected in favour of one without the assumption of the existence of panel-specific effects. Diagnostic tests on the Pooled OLS specification were inconsistent. While the Breusch–Pagan/Cook–Weisberg test suggested homoskedasticity ($p = 0.9784$), White's test still suggested heteroskedasticity ($p = 0.0212$), suggesting possible misspecification of the variance structure in the model. The Wooldridge test for autocorrelation suggested significant first-order autocorrelation ($p = 0.0027$), and thus there exists serial correlation in the residual. The Ramsey RESET test suggested no significant evidence of omitted variable problems ($p = 0.0769$), and thus the functional form of the model remains satisfactory. However, the test for skewness and kurtosis of the residual indicated the non-normal distribution of the residuals ($p < 0.01$), and thus the validity of the inference under the OLS assumption may suffer. In light of the presence of heteroskedasticity and autocorrelation, the standard Pooled OLS estimates would lead to inefficient and biased standard errors. Accordingly, in order to address such concerns, the study employed the Panel-Corrected Standard Errors (PCSE) estimator, addressing the presence of heteroskedasticity and the presence of cross-sectional correlation, and thus providing inference that is more robust.

Table 6: Linear regression, correlated panels corrected standard errors (PCSEs)

Group variable:	Country_ID	Number of obs	=	144
Time variable:	Year	Number of groups	=	6
Panels:	correlated (balanced)	Obs per group:		
Autocorrelation:	no autocorrelation	min	=	24
		avg	=	24
		max	=	24
Estimated covariances	=21	R-squared	=	0.2190
Estimated autocorrelations	=0	Wald chi2(5)	=	75.21
Estimated coefficients	=6	Prob > chi2	=	0.0000

ICT	Coefficient	Panel-corrected std. err.	z	P>|z|	[95% Conf.	Interval]
RandD	1.773002	0.3899346	4.55	0.000	1.008744	2.53726
MCS	-0.0171925	0.0076107	-2.26	0.024	-0.0321091	-0.0022758
FDI	0.0394735	0.013349	2.96	0.003	0.01331	0.065637
GovExpenEdu	0.5125413	0.1945318	2.63	0.008	0.131266	0.8938165
IUI	0.0354283	0.0098656	3.59	0.000	0.0160921	0.0547645
_cons	0.6356142	0.8544314	0.74	0.457	-1.039041	2.310269

The PCSE estimation accounts for heteroskedasticity and contemporaneous correlation across countries, providing robust inference. The results indicate that research and development expenditure ($\beta = 1.773$, $p < 0.01$), foreign direct investment ($\beta = 0.039$, $p < 0.01$), government expenditure on education ($\beta = 0.513$, $p < 0.01$), and individuals using the Internet ($\beta = 0.035$, $p < 0.01$) all have a positive and statistically significant effect on ICT service exports. Mobile cellular subscriptions show a small but negative significant effect ($\beta = -0.017$, $p < 0.05$). The Wald chi-square statistic ($\chi^2 = 75.21$, $p < 0.01$) confirms the joint significance of the explanatory variables, and the R^2 value of 0.219 suggests that approximately 21.9% of the variation in ICT service exports is explained by the model.

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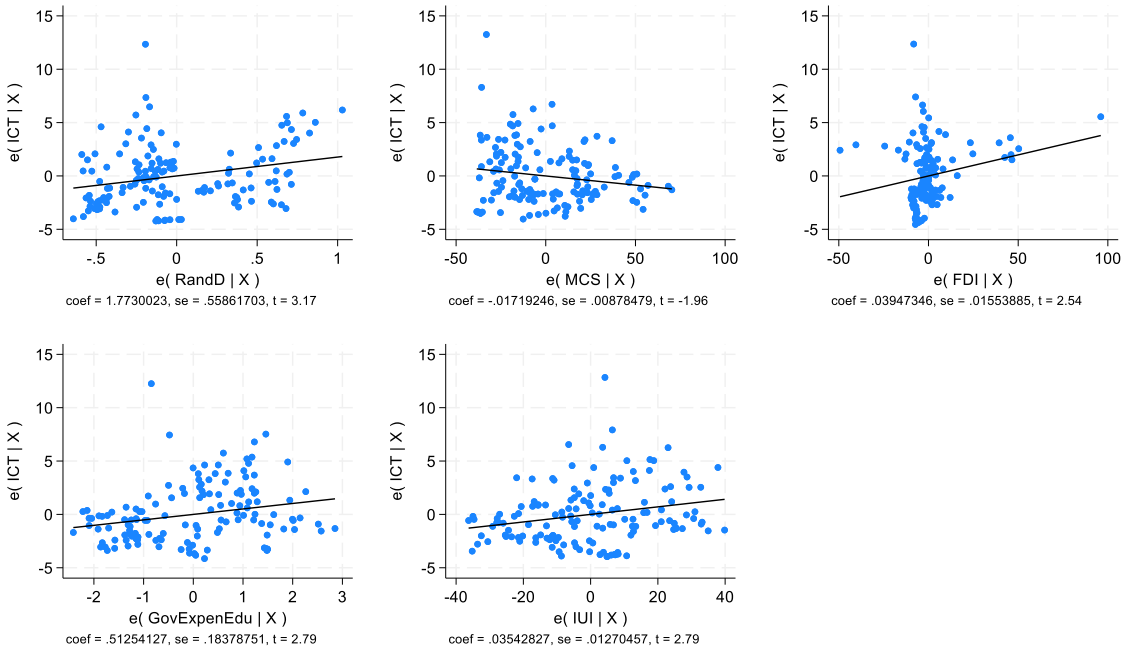

Figure 1. Partial Regression Plots from PCSE Estimation of ICT Service Exports

Figure 1 presents partial regression (added-variable) plots based on the Panel-Corrected Standard Errors (PCSE) estimation. These plots illustrate the isolated effect of each independent variable on ICT service exports, controlling for the influence of all other regressors in the model. The direction and strength of the linear trends visually confirm the statistical results reported earlier.

In particular, the charts reassert the positive and significant impact of expenditure on R&D, FDI inflows, public expenditure on education, and internet use on ICT service exports, in line with the PCSE results (all with $p < 0.01$). The tendencies confirm the thesis that innovation investment, access to the digital world, development of the human capital stock, and foreign capital inflows are the most important promoters of ICT export performance in the Organization of Turkic States.

On the contrary, mobile cellular subscriptions (MCS) show a weak and significantly negative correlation, as indicated above. The slight declining slope of the MCS graph is consistent with the thesis that mobile use can indicate consumer-focused adoption trends instead of inclusive digital productivity and perhaps account for the reversed impact on ICT export.

Collectively, these maps offer graphical support for the stability and accuracy of the regression coefficients and underpin the finding that investment in digital networks, skills, and innovation needs to be prioritized to increase ICT service export potential in the region.

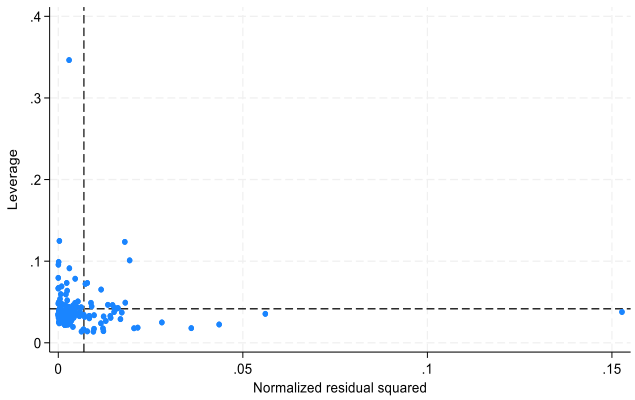

Figure 2. Leverage versus Normalized Residual Squared for PCSE Model

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The advantage plot demonstrates most of the observations remain well inside the safe advantage range and thus indicate no single observation exerts excessive influence on the regression findings. The few observations close to the vertical and horizontal reference lines indicate weak advantage or residual influence but none goes over critical limits. This lends support to the stability and the robustness of the model estimates.

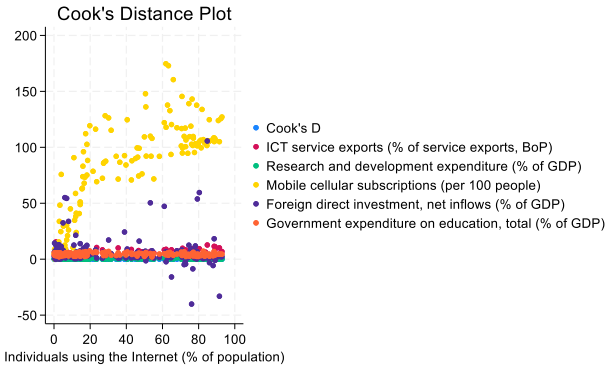

Figure 3. Cook's Distance Plot for Influential Observations in the PCSE Model

The Cook's Distance plot measures the effects of single points on the regression coefficients. Apart from ICT service exports, most of the variables such as R&D expenditure, FDI, and government expenditure on education have low values of Cook's D and hence indicate little effect of single observations. However, there are a few cases of mobile cellular subscriptions with yellow dots showing large values of Cook's D and so point to the possible presence of a few observations with a sizeable impact on the model. Though such points in no way discredit the findings, their occurrence requires cautious estimation of the coefficients for this variable.

5. Discussion

The results provide valuable evidence for the proposition that digitized infrastructure, innovation potential, and development of human capital are critical determinants of ICT service export in Turkic Republics. R&D spending had the strongest positive and statistically significant impact, showing directly the upgrading of the competitiveness of ICT services in the world market by innovation. The education expenditure by the government case also came up positively, signifying the imperative of the development of skills and learning for the sustenance of the ICT sector together with the rest of the economy [13,14].

Foreign direct investment also had a positive correlation with ICT service exports, meaning capital inflows can also accompany financial resources and technological spillovers enhancing the sector. Internet users had a significant positive impact, highlighting the significance of broad-based digital penetration in allowing ICT-based industries to flourish. Notably, mobile cellular subscriptions had a negative and marginally significant impact, perhaps a sign of substitution effects where mobile penetration without complementing infrastructures in the form of broadband or high speeds does not directly translate into export expansion.

These findings align with previous studies emphasizing the complementary role of infrastructure, innovation, and education in promoting ICT-based trade. However, they also reveal that simple quantitative expansion of connectivity (e.g., more mobile subscriptions) is not sufficient without quality improvements. From a policy perspective, the results suggest that targeted investments in R&D, education, and high-speed internet infrastructure, combined with attracting quality FDI, are essential for enhancing ICT service exports among Turkic States.

6. Conclusion and Policy Implications

In this paper, the factors of ICT service exports in the Turkic Republics of Azerbaijan, Turkey, Uzbekistan, Kazakhstan, Kyrgyzstan, and Hungary in the panel data of 2000–2023 were investigated. According to the results, R&D spending, government expenditure on education, foreign direct investment, and internet use are significant positive factors of ICT service exports. The results reflect the roles of innovation potential, the formation of human capital, and world investment flows in information and communication technology trade competitiveness.

Yet mobile cell subscriptions had a negative and slightly significant correlation with ICT service exports, indicating basic mobile access by itself is not adequate to facilitate export growth without complementary investments in broadband quality, high-speed connections, and next-generation ICT infrastructure.

The results of this research hold the following strategic implications for policymakers in the Turkic States:

- Invest more in research and development – Increase public and private expenditure on research and development, particularly in ICT-based sectors, to build more export-oriented competence.

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- Strengthen Education Systems – Align curricula with digital economy needs, improve ICT-related skills, and expand vocational training to build a competitive workforce.
- Attract and retain FDI – Create a favorable investment environment, ensure the safety of intellectual property rights, and provide selective investment incentives for foreign ICT investment.
- Upgrade Digital Infrastructure – Shift the policy emphasis from increasing mobile penetration levels to the acceleration of broadband speed, reliability, and coverage.

Encourage regional digital integration – Advocate for the inter-state collaboration in the Turkic States to coordinate ICT policies, standards, and trans border electronic trade regimes.

In this way, the Turkic States can capitalize on their combined strengths, accelerate the development of ICT service exports, and become more competitively positioned in the rapidly evolving global digital economy.

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