

WHEN DOES DIGITALISATION DELIVER PRODUCTIVITY GAINS? DIGITAL CONNECTIVITY, REGULATORY QUALITY AND LABOUR PRODUCTIVITY IN THE WESTERN BALKANS

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Abstract: Although digital connectivity has seen substantial progress during the past few years in the Western Balkans, its link with greater productivity is likely dependent on the institutional environment in which digital technologies are adopted and utilized. Our research examines the relationship between digital connectivity and labor productivity in five economies in the Western Balkan region during the 2007-2021 period — Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, and Serbia. Kosovo has been excluded from this study due to lack of sufficiently comparable data. Digitalisation is used in this analysis as a broad theoretical concept, whereas its observable aspect is operationalised through a Digital Connectivity Index (DCI) developed on the basis of internet use, mobile-cellular subscriptions and fixed broadband subscriptions. At the same time, the DCI represents a narrow approach, as all indicators measure accessibility rather than digitalisation process. As panel diagnostics did not yield results indicating long-term cointegration, the final specification is a short-term first-difference model with year fixed effects and Driscoll-Kraay standard errors. Lagged DCI doesn't show a significant unconditional relationship with productivity growth, thus H1 is not confirmed in the baseline scenario. However its interaction with lagged Regulatory Quality was found to be positive and significant ($\beta=0.0342$, $p=.004$), staying robust to equal weighted DCI, quadratic specification, and leave-one-country-out sensitivity tests. The interaction with Government Effectiveness and Rule of Law didn't yield similar results. The estimated relationship grows from 0.030 at low Regulatory Quality to 0.097 at high Regulatory Quality. These findings imply that productivity importance of DCI for Western Balkans economy depends solely on Regulatory Quality, although the small five-country sample implies the need for cautious interpretation.

Keywords: Digital connectivity, Digitalisation, Labour productivity, Regulatory quality, Institutional complementarity, Western Balkans, Panel data

1. INTRODUCTION

Digital transformation plays a crucial role in the process of economic development and European integration in the Western Balkans, but increased connectivity does not automatically result in the enhancement of productivity. The effectiveness of digital technologies depends on the presence of appropriate organisational, human and institutional conditions. The link between information-communication technologies (ICT) and productivity has always been subject to substantial diversity. Solow's productivity paradox illustrated the inconsistency related to rapid diffusion of computers from one side, and lack of evident proofs of aggregate productivity increase on the other side. Nevertheless, the understanding of the paradox has changed, it is viewed not as the confirmation that digital technology does not create any value, but rather as the proof that it is necessary to implement organisational changes and develop the relevant skills and capacities in order to get the positive effect from technological investments.

The Western Balkans is an appropriate region to consider this issue, as it represents a combination of relatively quick development of digital connectivity and enduring institutional evolution and European integration. Before a precise statement of the research question can be made, it is necessary to provide a clarification regarding the methodology. The three indicators that are available and have sufficient consistency in coverage across all five economies are individuals who use the internet, mobile-cellular subscriptions, and fixed broadband subscriptions. These indicators capture digital connectivity and access, but they do not capture the extent to which businesses or public institutions make productive use of digital technologies. Thus, it is necessary to distinguish the concept of digitalisation which refers to a holistic theory from digital connectivity which is an empirical construct calculated through the Digital Connectivity Index (DCI), which does not claim to fully represent the phenomenon of digitalisation.

This distinction should be taken into consideration while conducting a comparative study, for instance, the analysis of digitalisation and economic productivity in the Gulf Cooperation Council (GCC) countries which is set for completion in 2025. The present paper is related to that framework but differs in two respects: it examines transition economies undergoing simultaneous institutional and digital transformation rather than resource-rich rentier economies, and it explicitly distinguishes connectivity from digital adoption, narrowing the empirical claim to what the available indicators can actually support.

The study poses the following question: Under what institutional circumstances is increased productivity development in the Western Balkans linked to digital connectivity? A dynamic panel ARDL framework, which included Pooled Mean Group (PMG) estimation, was first taken into consideration in the study. However, the PMG estimates were numerically unstable and the empirical diagnostics did not support a long-run cointegrating specification. Thus, short-run first-difference models with year fixed effects and Driscoll-Kraay standard errors are used in the final empirical approach.

The primary empirical finding is that, when taken into account separately, delayed digital connection is not much correlated with productivity increase. Comparable interactions between Government Effectiveness and Rule of Law are not statistically supported, but its interaction with Regulatory Quality is positive and statistically supported, and it withstands a quadratic specification, an alternative DCI construction, and leave-one-country-out checks. Therefore, the paper's contribution is to show that the relationship between connectivity and productivity varies specifically with the regulatory environment in which digital technologies are absorbed and used, rather than to demonstrate a universal productivity effect of digital connectivity. The rest of the paper consists of the following sections: literature review (section 2), theory and hypotheses (section 3), data and methods (section 4), results (section 5) and discussion of findings (section 6).

2. LITERATURE REVIEW

The theoretical rationale for expecting digital technology to improve productivity is based on the concept of general-purpose technologies (Bresnahan & Trajtenberg, 1995), technologies that can be widely used, which undergo constant enhancement, and which can induce complementary innovations. Nevertheless, the literature on productivity shows that the diffusion of technology by itself does not translate into increases in productivity. The benefits of information technologies are contingent on complementary investments in organizational aspects (Brynjolfsson & Hitt, 2000); moreover, management practices also help explain the differences in the effects of ICT on productivity across countries and companies (Bloom, Sadun, & Van Reenen, 2012). More general studies support this idea as well; while there is indeed a degree to which ICT contributes to productivity overall, its contributions are very heterogeneous (Draca, Sadun, & Van Reenen, 2006). Moreover, the studies conducted in developing countries show that the relationship between ICT and productivity is positive, but only presuming certain complementary economic factors, including human capital and openness to trade (Yong, Law, Ibrahim, & Mohamad, 2024). The latest review of the literature states that studies must shift their focus from establishing a positive relationship between ICT and growth to determining the reasons for this, as well as when and under which conditions this occurs (Vu, Hanafizadeh, & Bohlin, 2020), which is exactly what this paper addresses. The Solow productivity paradox is the most prominent example of this misalignment. The phenomenon where rapid technological diffusion and low productivity growth coexist (Solow, 1987) has been dealt with by later studies not by refuting the existence of productivity but rather by identifying the conditions under which it manifests itself, such as learning-by-doing, complementary investment, and institutional capacity.

The cases of North Macedonia and Serbia provide supportive country-level evidence. Velichkovska (2025) discusses the development of productivity indicators juxtaposed to the expansion of digital infrastructure while noting that skill mismatches and uneven absorptive capacities of the respective economies continue to exist. Velichkovska, Mitić, and Kojić (2025) find that even with available digital tools, people encounter obstacles to adoption of these technologies in the form of costs, lack of skills, and insufficient awareness. Moreover, the benefits obtained differ from sector to sector.

Institutional complementarity takes this discussion far beyond economics, as technological and organizational systems can exert institutional complementary effects. In other words, the total productivity contribution of one element will depend on the presence of others (Milgrom & Roberts, 1990). Likewise, the wider discourse on ICT and development has acknowledged that the impact of technology on development cannot be separated from its institutional setting (Avgerou, 2010). For instance, some studies show that ICT governance is related to the socio-economic impact of ICT (Meso, Datta & Mbarika, 2006), while the quality of institutions plays an important role in conditioning the relationship between ICT and social services in developing nations (Evans, 2022). Besides, the institutional aspect of ICT's contribution to growth has been analyzed in the context of MENA economies (Abu Alfoul, Tajaddini, Gholipour, Bashar & Jamaani, 2024). The institutional variables utilized here - Regulatory Quality, Government Effectiveness, and Rule of Law - were adapted from the Worldwide Governance Indicators (Kaufmann, Kraay & Mastruzzi, 2010).

The conditional perspective in this case coincides with the previous findings regarding economic differences across the Western Balkans: Madzova and Velichkovska (2019) point to different relations of competitiveness to development across the economies of the Western Balkans, which implies that regional averages might mask significant structural distinctions. The argument in terms of institutional complementarity becomes particularly relevant for transition economies that undergo simultaneous technological and institutional transformations; the World Bank's World Development Report on digital dividends highlights the significance of "analogue complements" in the process of proving technological advancements leads to development benefits (World

Bank, 2016), while the OECD publication, "Western Balkans Competitiveness Outlook 2024," considers infrastructure, digital skills, business environment and digital transformation as interconnected issues, noting the persisting gap between digital application and capacity for institutional implementation (OECD, 2024). Evidence of digitalization in the Western Balkans from the comparative and firm levels confirms the notion that this region is characterized by significant variation in the process of digitalization, where not only lack of infrastructure is the difficulties for digitalization, but there are some barriers related to the skills of employees and the process of adopting digital technologies (Kelečević & Lesjak, 2025). Evidence from Enterprise Surveys demonstrates that these factors have significant influence on the effectiveness of SMEs at the level of the Western Balkans (Barbullushi, Kalaj, & Kastrati, 2023).

A 2025 GCC analysis (Al Shammre, 2025) that uses a composite digital index and Government Effectiveness as an institutional moderator is a helpful comparative, even if it wasn't determined here as the closest research by a systematic search. This topic is extended to the Western Balkans in the current study, but the institutional trajectory and economic structure are different (transition/EU-convergence instead of rentier), and the empirical assertion is limited to connection rather than enterprise-level adoption. As a result, the gap addressed is specific: does Regulatory Quality offer a stronger conditioning environment than other institutional dimensions, and does the connectivity-productivity connection vary consistently with institutional quality?

3. THEORETICAL FRAMEWORK AND HYPOTHESES

The framework integrates institutional complementarity and general-purpose technology theory into a four-stage process: (1) digital availability; (2) digital connectivity, which is measured by the DCI; (3) institutional and organizational absorption, where the main channel of complementarity is institutional quality; and (4) productivity transformation. The empirical model examines the relationship between Stages 2 and 4, interpreting institutional quality as a conditioning factor that operates in between: connectivity may have weaker measurable productivity implications where regulatory and administrative constraints limit absorption, but it may be more easily integrated into business processes and public services where regulatory institutions are more effective.

H1: Higher digital connectivity is positively associated with labour productivity growth in Western Balkan economies.

H2: Regulatory Quality positively moderates the relationship between digital connectivity and labour productivity growth, such that the association is more positive at higher levels of regulatory quality.

Since productivity, connectedness, and institutional quality may impact one another and the five-country panel does not permit causal identification, the hypotheses are framed in terms of association rather than causation. In the robustness analysis presented in Section 5.3, Government Effectiveness and Rule of Law are taken into consideration as alternative moderators, and a quadratic DCI term evaluates sensitivity to nonlinearity.

4. DATA AND METHODOLOGY

Five Western Balkan economies—Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, and Serbia—observed from 2007 to 2021 make up the sample (75 country-year observations; 70 after first-differencing and lagging). Every cell in the underlying dataset traces to a documented World Bank or Worldwide Governance Indicators source, and no interpolation was used. Kosovo was taken into consideration but excluded because comparable, sufficiently complete observations were not available across the necessary variables over a usable common period.

The dependent variable is log GDP per person employed, constant PPP dollars (World Bank/ILO-modeled): $LP_{it} = \ln(\text{GDP per person employed})_{it}$, where ΔLP_{it} can be roughly interpreted as productivity growth. The Digital Connectivity Index (DCI) uses principal component analysis to combine fixed broadband subscriptions, mobile-cellular subscriptions, and standardized internet use. The first component has an eigenvalue of 1.994, explains 66.47% of variance, and all three loadings are positive (0.662, 0.302, and 0.686, respectively). The PCA-based DCI and an equal-weighted alternative have a 0.978 correlation. The rule of law, government efficacy, and regulatory quality are all standardized. Global Governance Indicators: inflation, mean years of education, trade (as a percentage of GDP), and gross fixed capital creation are the controls. Table 1 provides complete definitions and sources for the variables.

Table 1. Variables used in the analysis

Variable	Definition	Source
Labour productivity	GDP per person employed, constant PPP \$	World Bank / ILO-modelled estimate
Digital Connectivity Index	PCA of internet use, mobile and fixed-broadband subscriptions	World Development Indicators
Regulatory Quality / Government Effectiveness / Rule of Law	WGI estimates	Worldwide Governance Indicators
Controls	Gross fixed capital formation, trade (% GDP), mean years of schooling, inflation	World Development Indicators; schooling source to be confirmed by author

Source: World Bank (2026), World Bank (2024) - Worldwide Governance Indicators; Global Data Lab (2024). Authors' compilation.

The original design for these strategies was a static ARDL dynamic panel model that could be estimated using PMG estimators (Pesaran et al., 1999), based on the potential linkages between the productivity, connection and the quality of institutions determined by the ARDL model in the past.

However, the diagnostic testing has proved otherwise. No support could be found using the unit-root tests of the panel, including the usual cross-section augmented version of Pesaran's tests (Pesaran, 2004, 2007), suggesting that the variables could be $I(0)/I(1)$, but there was no evidence of $I(2)$. Cointegration tests carried out by Pedroni (1999) and Westerlund (2007) are among those that rejected the assumption of cointegration (out of many residual-based cointegration tests, including those conducted by Kao, 1999) because of their adequate specifications for the panel with various regressors and cross-sectional dependencies. Residual tests in levels failed to identify stationary long-term equilibrium error. As a result, PMG estimates turned out to be unstable in terms of number (not reasonable coefficients, missing SE, unstable error correction terms), therefore, not used for analysis. PMG estimates are not employed for substantive inference since they were numerically unstable (implausible coefficients, missing standard errors, unstable error-correction terms). Table 2 provides an overview of the decision-making process.

Table 2. Econometric decision path: the final specification was determined by the diagnostic evidence rather than by retaining the initially proposed estimator after its assumptions were not supported.

Stage	Finding	Consequence
Panel integration tests	Mixed $I(0)/I(1)$; no $I(2)$ evidence	Dynamic modelling feasible in principle
Pedroni / Westerlund cointegration	No evidence of cointegration (Westerlund $p \approx .925-.999$)	Long-run equilibrium specification unsupported
Levels FE residual test	No stationary residual evidence	Supports avoiding a levels long-run model
PMG / MG estimation	PMG numerically unstable; MG interpretable but not cointegration-supported	Neither used for substantive inference
Final specification	First-difference model, year FE, lagged DCI/institutional variables, Driscoll-Kraay SEs	Main empirical framework

Source: Authors' calculations based on the panel dataset and econometric diagnostic tests.

As a result, the final specification is a short-run first-difference model with year fixed effects and Driscoll-Kraay standard errors robust to heteroskedasticity, serial correlation, and cross-sectional dependence; no separate country fixed effect is estimated because first differencing mechanically eliminates time-invariant country heterogeneity:

$$\Delta LP_{it} = \lambda_i + \beta_1 L.DCI_{it} + \beta_2 L.RQ_{it} + \beta_3 (L.DCI_{it} \times L.RQ_{it}) + \gamma'X_{it} + \varepsilon_{it}$$

The conditional connection of DCI is $\beta_1 + \beta_3 \cdot RQ$. The coefficient β_3 indicates whether the relationship between lagging DCI and productivity growth varies with lagged Regulatory Quality.

5. RESULTS

Table 3 gives the key estimates concerning the short-run outcome. The dependent variable here is the first difference of log labour productivity while the explanatory variables include a one-year lag; Driscoll-Kraay standard errors are given in parenthesis. The baseline coefficient for lagged DCI comes out positive (0.0664) but is not statistically significant ($p=.238$). The result remains unchanged after the inclusion of Regulatory Quality in column (2), thus the hypothesis is not validated in the primary outcome irrespective of the institutional component being included. As DCI measures connectivity instead of providing a direct measure of actual usage

of digital technologies, this no result does not mean that digital technologies do not matter as far as productivity is concerned. It means that productivity implications of connectivity depend on certain complimentary institutional conditions.

Table 3. First-difference models with year fixed effects; Driscoll-Kraay standard errors in parentheses. *
*p<0.10, ** p<0.05, *** p<0.01.*

	(1) DCI only	(2) DCI + RQ	(3) DCI × RQ
Lagged DCI	0.0664 (0.0537)	0.0598 (0.0491)	0.0622 (0.0463)
Lagged Regulatory Quality	—	-0.0118 (0.00894)	-0.0321*** (0.00923)
Lagged DCI × Lagged Regulatory Quality	—	—	0.0342*** (0.00993)
Change in Gross Fixed Capital Formation	-0.000783 (0.00201)	-0.000607 (0.00226)	-0.000627 (0.00208)
Change in Trade	0.00163 (0.00122)	0.00166 (0.00127)	0.00202* (0.00111)
Mean Years of Schooling	0.00813 (0.0116)	0.00683 (0.00984)	0.0283** (0.0119)
Inflation	-0.000452 (0.00385)	0.000147 (0.00349)	0.00258 (0.00305)
Observations	70	70	70
Within R-squared	0.461	0.480	0.549

Source: Authors' calculations based on data from the World Bank, Worldwide Governance Indicators, and Global Data Lab.

The DCI × Regulatory Quality interaction is presented in Column (3) as 0.0342 (SE=0.00993, p=.004), significant at 1% (F(1,13)=11.85, p=.0044). This is H2, the main supported hypothesis of the paper, although support varies between its two components: the conditional DCI slope (Table 4) only reaches marginal significance (10%) at +1 SD Regulatory Quality and is indistinguishable from zero at the median or below, while the interaction itself is significant at 1%.

Table 4. Conditional association = β DCI + β (DCI×RQ)·RQ.

Regulatory Quality	Conditional DCI association	SE	p-value
-1 SD	0.0301	0.0477	.539
Median	0.0701	0.0463	.154
+1 SD	0.0969	0.0470	.060

Source: Authors' calculations based on the regression estimates reported in Table 3.

Only the highest level is slightly significant (10%, not 5%), with the estimated relationship increasing from 0.030 at poor regulatory quality to 0.097 at high regulatory quality. Therefore, at every level of Regulatory Quality, the greatest evidence relates to the interaction term itself rather than a substantial conditional DCI coefficient. These are two different hypotheses that should not be confused.

Four robustness checks against the primary DCI × Regulatory Quality result are summarized in Table 5. The lack of statistical support for interactions between lagged DCI and the alternative institutional mediators Government Effectiveness and Rule of Law suggests that the research is focused on regulatory quality rather than institutional quality in general. The interaction remains large and fundamentally unaltered when an equal-weighted index is used in place of the PCA-based DCI. The finding is not an artifact of an omitted nonlinearity because a quadratic lagged-DCI effect is negligible in and of itself and leaves the primary interaction virtually unaltered. As in Table 3, all four tests employ the identical first-difference specification with Driscoll-Kraay standard errors and account for inflation, trade, gross fixed capital creation, and education.

Table 5. Robustness check

Robustness check	Interaction coefficient	SE	p-value
DCI × Government Effectiveness	0.0031	0.0115	.795
DCI × Rule of Law	0.0009	0.00337	.787
Equal-weighted DCI × Regulatory Quality	0.0320	0.0113	.014
Quadratic specification: DCI × Regulatory Quality	0.0338	0.00982	.004

Note: Each row is a separate model with the same controls and specification as Table 3, column (3); only the interaction term of interest is shown. The quadratic specification additionally includes an insignificant lagged-DCI-squared term ($\beta=-0.00187$, p=.669).

Source: Authors' calculations based on data from the World Bank, Worldwide Governance Indicators, and Global Data Lab.

A last, informal check is provided by leave-one-country-out estimates (Table 6). Since each exclusion leaves just four nations, this is sensitivity evidence rather than an independent robustness test. In each of the five exclusions, the interaction is still substantial and beneficial.

Table 6. Leave-one-country-out sensitivity

Country excluded	DCI × Regulatory Quality coefficient	p-value
Albania	0.0248	.031
Bosnia and Herzegovina	0.0385	.023
Montenegro	0.0333	.031
North Macedonia	0.0419	.004
Serbia	0.0284	.002
Full sample (reference)	0.0342	.004

Note: DCI × Regulatory Quality coefficient from Table 3, column (3).

Source: Authors' calculations based on data from the World Bank, Worldwide Governance Indicators, and Global Data Lab.

6. DISCUSSION, POLICY IMPLICATIONS AND LIMITATIONS

The results provide qualified support for the institutional-complementarity perspective in Section 3. The absence of a significant unconditional DCI-productivity association is consistent with the broader productivity literature's emphasis that digital technologies require complementary organisational and institutional investment before their effects become observable. The central, robust finding is that this association strengthens with Regulatory Quality: connectivity creates the technological possibility for digital transformation, while regulatory institutions may affect the extent to which firms and public organisations convert that connectivity into productive activity, by reducing administrative friction and increasing predictability. The evidence should not be read as causal — productivity may itself encourage institutional reform or digital investment, and common developments may affect both connectivity and regulatory quality. The absence of comparable interactions for Government Effectiveness and Rule of Law suggests this is not a generic governance effect; one tentative interpretation is that regulatory predictability specifically affects firms' ability to reorganise and invest in response to technological opportunity, though this should be read cautiously given correlated governance indicators and the five-country sample. This also qualifies the comparison with the GCC literature motivating this paper: that evidence points to Government Effectiveness in a resource-rentier setting, whereas the present analysis finds evidence tied to Regulatory Quality in a transition, EU-convergence context — an illustration that the institutional conditions surrounding digital technologies can differ across regional contexts, which a transition-economy extension of that framework was designed to surface.

Two policy implications follow. First, digital-infrastructure investment and regulatory reform should be treated as complementary rather than separate policy tracks, consistent with the OECD's regional framing; infrastructure spending may generate disproportionately smaller productivity returns where regulatory quality is weaker unless paired with regulatory reform. Second, the connectivity/adoption distinction is itself a policy-relevant finding: this analysis cannot determine whether firms actually use available digital infrastructure productively, and better comparable enterprise-level indicators — cloud computing, e-commerce, digital payments — would substantially improve future empirical work in the region.

The analysis has several limitations. Five countries and fifteen years yield only 13 denominator degrees of freedom in the Driscoll-Kraay inference, a fragility that should be read as a standing caveat on every result, not only the marginal ones. The DCI measures connectivity rather than actual digital adoption; the governance indicators are broad composite measures; the design does not provide causal identification; and the absence of cointegration evidence means the results concern short-run productivity growth rather than a long-run equilibrium relationship.

7. CONCLUSION

This study explores the question of whether the relationship between digital connectivity and labour productivity in the Western Balkans depends on institutional quality. It uses a balanced panel for five economies, covering the period from 2007 to 2021, using a first differencing approach. The analysis shows that there is no significant unconditional relationship between lagged digital connectivity and productivity growth. But there is a positive, significant, and robust interaction effect between lagged digital connectivity and Regulatory Quality according to the equal-weighted index, quadratic model, and leave-one-country-out checks. However, no similar interaction affects between lagged digital connectivity and Government Effectiveness and that in the case of Rule of Law has found no evidence. This gives a conclusion that digital connectivity is important for productivity in this sample due to positive interaction with Regulatory Quality, but not in terms of unconditional return to digitalisation. Thus, the implication of this research shows that digitalisation should be

evaluated in conjunction with institutional conditions instead of being viewed exclusively as a source of productivity increase.

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