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GOVTECH AS A "TECHNOLOGICAL - INSTITUTIONAL – HUMAN" SYSTEM: NON-LINEAR EFFECTS ON SOCIAL PROGRESS AND HUMAN WELL-BEING

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Abstract: *GovTech has become a key driver of societal transformation, yet its impact on human well-being and social progress remains complex and potentially non-linear. This study aims to examine how GovTech development, as a "Technological – Institutional – Human" system, shapes social progress by identifying its mechanisms, non-linear dynamics, and structural conditions. The analysis is based on a panel dataset of 1,964 observations for 2003–2024, employing two-way fixed-effects models with Driscoll–Kraay standard errors and non-linear specifications. The results show that the aggregate EGDI has a positive and significant effect on social progress, even after controlling for time effects (β = 3.37, p = 0.036). A non-linear relationship is identified, with a turning point at approximately 0.61, indicating diminishing returns at higher levels of digital development. Component-level analysis reveals that telecommunications infrastructure has the strongest impact (β = 14.09, p < 0.001), followed by online services (β = 4.16, p = 0.002), while human capital exhibits a threshold effect (turning point ≈ 0.26). Additionally, social progress increased steadily until 2020 (β ≈ 6.10) but declined in 2022 (β = 3.04), reflecting global shocks.*

Keywords: *digital government, GovTech, social progress, human well-being, e-government development, non-linear effects, "Technological – Institutional – Human" system, panel data analysis.*

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INTRODUCTION

The rapid expansion of GovTech has become a central pillar of contemporary socio-economic transformation, reshaping how public services are designed, delivered, and experienced by citizens. International organisations increasingly emphasise that digitalisation in the public sector is not merely a technical upgrade but a broader socio-technical shift affecting governance quality, inclusiveness, and human well-being. The OECD (2020) highlights that GovTech strategies enhance public value by improving service accessibility, responsiveness, and citizen engagement, thereby contributing to better life outcomes. At the same time, the World Bank (2021) stresses that digital transformation strengthens state capacity, supports resilience during crises, and facilitates inclusive growth, particularly in developing economies where access to services remains uneven. These developments underscore the growing relevance of examining GovTech through a human-centred lens, focusing not only on efficiency gains but also on broader societal impacts.

At the European level, GovTech has been positioned as a key instrument for achieving sustainable and inclusive development. The European Commission, through its Digital Decade policy framework, emphasises that digital public services are essential for enhancing citizens' quality of life, strengthening democratic participation, and reducing inequalities in access to public goods. However, recent policy debates also point to emerging challenges associated with digitalisation, including disparities in digital skills, unequal access to infrastructure, and risks related to algorithmic governance. Evidence from OECD and European Commission reports indicates that the benefits of GovTech are not uniformly distributed and depend heavily on institutional capacity, human capital, and complementary socio-economic conditions (OECD, 2020; European Commission, 2025). This suggests that the relationship between digitalisation and well-being is likely to be complex and non-linear, rather than uniformly positive.

Furthermore, the increasing integration of digital technologies into governance systems raises important questions about how digital transformation translates into tangible improvements in social progress. The World Bank (2021) emphasises that while digital tools can significantly enhance service delivery, their effectiveness depends on the broader ecosystem, including governance frameworks, infrastructure, and citizen capabilities. Similarly, the OECD (2020) notes that GovTech maturity does not automatically guarantee better societal outcomes, as the impact depends on how technologies are embedded within institutional and social contexts. These insights highlight the need for empirical research that moves beyond linear assumptions and investigates the mechanisms and thresholds through which GovTech influences human well-being. In this context, analysing GovTech as a "Technological – Institutional – Human" system with potentially non-linear effects becomes essential for understanding its true contribution to social progress.

LITERATURE REVIEW

GovTech has increasingly been conceptualised as a "Technological – Institutional – Human" system that integrates technological infrastructures, institutional arrangements, and human capabilities to generate public value and improve societal outcomes. The contemporary research landscape shows that digital transformation in the public sector is closely linked to

broader economic and innovation dynamics, in which technological advancement supports competitiveness, resilience, and sustainable development. Digitalisation contributes to national competitiveness, innovation performance, and economic transformation, particularly in advanced economies, while also revealing structural disparities across countries and regions (Alouani et al., 2025; Jarzębowski et al., 2024; Kiseľáková et al., 2024; Valaskova et al., 2025a; Yarovenko et al., 2025; (Lukács & Völgyi, 2021). At the same time, digital transformation processes remain uneven, reflecting differences in policy frameworks, governance capacity, and institutional quality, which shape the effectiveness of digital public administration systems (Valaskova et al., 2025b; Samarkhanov et al., 2025; Paraschiv et al., 2024; Pakhnenko et al., 2025). These patterns are further reinforced by the role of digital convergence, intelligent automation, and systemic transformation processes that link technological progress with governance and economic outcomes (Kuzior & Sira, 2025; Kuzior et al., 2022; Kuanaliyev et al., 2024; Razavi & Sierpinski, 2024; Zámek & Zakharkina, 2024), highlighting the need to analyse GovTech within a broader socio-technical and strategic framework.

A growing body of literature emphasises the role of governance, institutional quality, and public management in determining the outcomes of digital transformation. The evolution of public administration towards digital governance requires new competencies, innovative management models, and adaptive institutional frameworks that integrate technology with human-centred service delivery (Androniceanu & Streimikiene, 2025; Stănescu, 2024; Ntuli et al., 2025). Digital governance has been shown to enhance organisational resilience and antifragility in the public sector, while also supporting transparency, accountability, and trust in government (Bartuseviciene & Butkus, 2024; Vasylieva et al., 2023; Guemmou, 2024; Palffy & Ablonczy-Mihalyka, 2024). At the same time, governance failures, eroding accountability, and rent-seeking behaviour may undermine the benefits of digitalisation, suggesting that technological advancement alone does not guarantee positive societal outcomes (Ugulava, 2026; Crowley & Mujtaba, 2026). Moreover, digital transformation within public administration systems is increasingly associated with broader reforms in governance models and public value creation, including personalised services and deinstitutionalisation processes (Sułkowski et al., 2025; Mardosaite et al., 2024; Filipova et al., 2025; Makarenko et al., 2025), reinforcing the importance of institutional design in shaping digital outcomes.

The literature also highlights the increasing importance of behavioural, social, and human-centred dimensions of digital transformation. The adoption and effectiveness of digital services depend on trust, user behaviour, social influence, and digital literacy, which shape how individuals interact with digital systems and derive benefits from them (Budiyanto et al., 2025; Kowalska & Nguyen, 2025; Soussou & Hamrouni, 2025; Crăciun et al., 2025; Pálffy, 2025). Behavioural economics approaches, including nudging and incentives, have been identified as important tools for enhancing GovTech adoption and improving public outcomes (Burrell et al., 2025). Furthermore, digitalisation influences various aspects of individual well-being, including financial behaviour, mental health, and social inclusion, while also generating new risks related to stress, inequality, and digital exclusion (Chen et al., 2024; Gupta et al., 2025; Iordache et al., 2025; Mujtaba, 2025; Hong et al., 2024). The role of ethics, security, and subjective well-being has also been emphasised in the context of national strategies and socio-economic resilience (Hakobyan et al., 2025; Oe & Yamaoka, 2025; Prati, 2024; Zahorodnia et al., 2026), indicating that digital transformation must be aligned with broader societal values and well-being objectives. The persistence of the digital divide and unequal access to digital resources

further complicates the relationship between digitalisation and well-being, highlighting the need for inclusive digital policies (Kovac et al., 2024; Ruthvika & Hedau, 2025).

Another important strand of research focuses on the link between digital transformation and broader societal and sustainability outcomes. Digitalisation has been shown to contribute to achieving Sustainable Development Goals, improve supply chain sustainability, and support sectoral development, such as tourism and healthcare, thereby enhancing social and economic well-being (Gariba et al., 2024; Khatami et al., 2024; Szcześniak & Gorzelańczyk, 2024; Tossekbayev et al., 2025; Pálffy, 2024) . At the same time, digital public services and financial technologies play a crucial role in improving access to services, especially during crises, as demonstrated by the use of digital solutions for emergency cash transfers (Una et al., 2020). The expansion of digital financial systems and reporting practices also reflects broader transformations in economic governance and transparency, shaping how information is produced and used in decision-making processes (Darmawati et al., 2025; Guemmou, 2024; Huseynov et al., 2025; Mtengwane, 2024). However, the benefits of digitalisation are not uniformly distributed and depend on the interaction between technological, economic, and institutional factors, as well as sector-specific policies and governance quality (Makarenko et al., 2025; Filipova et al., 2025; Huseynov et al., 2025). These findings underline the importance of examining GovTech within a broader socio-economic ecosystem.

Recent studies also highlight emerging risks and challenges associated with digital transformation, particularly in the context of artificial intelligence and data-driven governance. Issues such as data bias, algorithmic decision-making, and ethical concerns may affect fairness, trust, and social outcomes, raising questions about the long-term implications of digital governance systems (Wojciechowski & Korjonen-Kuusipuro, 2025; Yarovenko et al., 2024; Pisică & Zaharia, 2025). At the same time, digital transformation can create new forms of inequality and vulnerability, particularly in informal sectors or regions with limited technological capacity (Mtengwane, 2024; Batizani, 2024). These challenges emphasise the need for responsible and human-centred digital governance frameworks that balance efficiency with ethical and social considerations.

Despite the growing body of research, several gaps remain. First, much of the existing literature assumes linear relationships between digitalisation and societal outcomes, overlooking potential threshold effects and diminishing returns. Second, limited attention has been given to the disaggregated analysis of GovTech components, which may operate through different mechanisms. Third, the interaction between digital infrastructure, human capital, and service delivery has not been sufficiently explored within a unified empirical framework. Finally, while the importance of institutional and behavioural factors is widely acknowledged, their integration into quantitative cross-country analyses remains limited. The existing scientific landscape demonstrates that GovTech plays a critical role in shaping social progress and human well-being. However, its effects are complex, context-dependent, and mediated by multiple factors. This underscores the need for empirical research that adopts a socio-technical perspective, incorporates non-linear modelling approaches, and disentangles the mechanisms through which different dimensions of digitalisation influence societal outcomes.

This study aims to examine how GovTech development shapes human-centred societal outcomes, as measured by social progress, by identifying the underlying mechanisms, non-linear dynamics, and structural conditions through which digital systems influence well-being across countries.

METHODS

This study employs a quantitative panel data approach to examine the relationship between GovTech development and social progress across countries over time. The empirical analysis is based on a balanced panel dataset comprising 1,964 observations covering the period 2003–2024, with data collected at irregular but consistent intervals across countries. The dependent variable is the Social Progress Index (SPI), which captures multidimensional aspects of societal well-being beyond purely economic indicators. The SPI data were obtained from Social Progress Imperative. (n.d.). The key explanatory variable is the E-Government Development Index (EGDI), alongside its three subcomponents: the Human Capital Index (HCI), the Online Service Index (OSI), and the Telecommunications Infrastructure Index (TTI), sourced from the World Bank (n.d.-a). Control variables include unemployment (percentage of the total labour force), GDP per capita in purchasing power parity terms, and the share of the urban population, all retrieved from the World Bank (n.d.-b). These variables capture labour market conditions, economic development, and structural demographic characteristics.

Prior to estimation, descriptive statistics were conducted to assess the distributional properties of all variables. The results indicated that EGDI and its subcomponents, as well as SPI and urbanisation, exhibit approximately symmetric distributions. In contrast, GDP per capita and unemployment exhibit strong positive skewness and excess kurtosis. To address these issues and ensure compliance with standard econometric assumptions, GDP per capita was transformed using the natural logarithm, and unemployment was transformed using the logarithmic specification $\ln(x + 1)$. These transformations substantially improved normality and reduced the influence of extreme observations, while the remaining variables were retained in their original scales.

The empirical strategy is based on panel regression models, allowing for the control of unobserved heterogeneity across countries. Both fixed-effects (FE) and random-effects (RE) models were initially estimated. The FE model captures within-country variation over time while controlling for time-invariant characteristics, such as institutional structures and cultural factors. In contrast, the RE model exploits both within- and between-country variation. Model selection was guided by the Hausman test, which consistently rejected the null hypothesis of the RE estimator's consistency, indicating that the FE specification is more appropriate for inference.

To ensure robustness of inference in the presence of potential heteroskedasticity, serial correlation, and cross-sectional dependence, all models were estimated using Driscoll–Kraay standard errors. These standard errors are particularly suitable for macro-panel datasets with a relatively large time dimension and possible cross-country interdependencies. The baseline specification estimates the relationship between SPI and the aggregate EGDI. In contrast, an alternative specification replaces the aggregate index with its components (HCI, OSI, and TTI) to identify the underlying mechanisms of GovTech effects.

To further improve model specification and account for global shocks and common temporal trends, two-way fixed-effects models were employed, incorporating both country-specific and time-specific effects. In addition, an alternative specification using period-specific dummy variables was estimated to capture non-linear and irregular time dynamics explicitly. This approach is particularly appropriate given the non-uniform time spacing of observations.

To explore potential non-linearities in the relationship between GovTech and social progress, quadratic terms were introduced for both the aggregate EGDI and its components. This allows

testing for diminishing returns or threshold effects. The turning points of these relationships were calculated analytically using the standard formula $-\beta_1/(2\beta_2)$, enabling the identification of levels of digital development at which marginal effects begin to decline or increase.

Finally, country-specific fixed effects were extracted from the two-way FE model to capture time-invariant structural differences across countries. These effects reflect persistent institutional, socio-economic, and governance-related characteristics that the model does not directly capture and provide additional insights into cross-country heterogeneity in social progress outcomes.

All data processing, transformations, and econometric estimations were performed using the R statistical software environment, ensuring reproducibility and transparency of the analytical procedure.

The methodological framework combines robust panel econometric techniques with non-linear modelling and structural decomposition, enabling a comprehensive analysis of both the magnitude and nature of the relationship between GovTech development and social progress.

RESULTS

The descriptive statistics (Table 1) show that the dataset is well-balanced, comprising 1,964 observations for 2003–2024. The mean EGDI is 0.50, indicating a moderate level of GovTech development, with low dispersion (SD = 0.23) and an approximately symmetric distribution (skewness = 0.05). Among its components, HCI has the highest average (0.71), while TTI remains the weakest (mean = 0.36), pointing to structural imbalances. The negative skewness of HCI (−0.87) suggests that many countries have already reached relatively high levels of human capital, whereas infrastructure remains more unevenly distributed.

The SPI averages 65.56 with moderate variability (SD = 16.74) and near symmetry (skewness = −0.12), indicating relatively balanced cross-country differences. In contrast, macroeconomic variables show substantial heterogeneity. GDP per capita exhibits high dispersion (SD = 23,858.34) and strong right skewness (1.84), reflecting large income disparities. Unemployment is also highly right-skewed (1.60) and leptokurtic (kurtosis = 3.04), indicating extreme labour market conditions in some countries.

Urbanisation is relatively high (mean = 57.77%) with moderate dispersion (SD = 22.11) and slight negative skewness (−0.13), suggesting a dominance of highly urbanised countries. Overall, digital and institutional indicators are relatively stable and symmetric, whereas economic variables—especially GDP per capita and unemployment—display significant inequality and non-normality. This supports the use of variable transformations and robust estimation techniques in subsequent analysis.

EGDI and its components (HCI, OSI, TTI) do not exhibit problematic skewness and are bounded between 0 and 1; therefore, they are retained in their original form. The SPI and urban population are also approximately symmetric, so no transformation is required. In contrast, GDP per capita shows strong positive skewness and high kurtosis and is therefore transformed using the natural logarithm. Unemployment is similarly right-skewed and is transformed using $\log(x + 1)$. All other variables are kept at levels.

These transformations substantially improve distributional properties. The logarithmic transformation of GDP per capita reduces skewness and excess kurtosis, producing an

approximately symmetric distribution. For unemployment, both logarithmic and inverse hyperbolic sine transformations reduce skewness; however, log(x + 1) provides the closest approximation to normality and is therefore used in the main analysis.

Table 1. Descriptive statistics of variables. [Source: Created by the authors.]

Variable	Mean	SD	Median	Min	Max	Skewness	Kurtosis
EGDI	0.50	0.23	0.49	0.00	0.98	0.05	–0.88
EGDI_HCI	0.71	0.21	0.76	0.00	1.00	–0.87	0.17
EGDI_OSI	0.45	0.28	0.44	0.00	1.00	0.17	–1.05
EGDI_TTI	0.36	0.29	0.30	0.00	1.00	0.49	–1.06
Social Progress Index	65.56	16.74	66.53	22.13	95.56	–0.12	–0.98
Unemployment (%)	7.67	5.87	5.84	0.11	37.32	1.60	3.04
GDP per capita (PPP)	22,177.31	23,858.34	13,380.98	777.88	143,830.55	1.84	4.10
Urban population (%)	57.77	22.11	59.29	8.68	100.00	–0.13	–0.90

The estimation results based on Driscoll–Kraay standard errors provide consistent evidence on the determinants of social progress and reveal important differences between the aggregate and disaggregated specifications of e-government development.

In Model 1 (Table 2), which incorporates the aggregate EGDI, the fixed-effects results indicate that EGDI does not exert a statistically significant impact on the SPI ($\beta = 4.50$, $p = 0.346$). This suggests that, after controlling for unobserved country-specific heterogeneity, improvements in overall e-government development are not directly associated with measurable changes in social progress within countries over time. In contrast, all control variables are positive and highly significant. Unemployment shows a positive, statistically significant relationship with social progress ($\beta = 2.11$, $p < 0.001$), which may reflect countercyclical policy responses or social protection mechanisms rather than a direct causal effect. GDP per capita (log-transformed) shows a strong, robust positive association ($\beta = 6.45$, $p < 0.001$), confirming that economic development remains a key driver of social outcomes. Urbanisation also shows a highly significant positive effect ($\beta = 0.30$, $p < 0.001$), indicating that more urbanised societies tend to achieve higher levels of social progress.

The random-effects estimates for Model 1 yield patterns of sign and significance similar to those for the control variables. However, the coefficient magnitudes are slightly larger, particularly for GDP per capita ($\beta = 7.22$, $p < 0.001$). The EGDI coefficient remains statistically insignificant ($\beta = 7.09$, $p = 0.215$), reinforcing the conclusion that the aggregate index fails to capture the mechanisms linking GovTech to social outcomes. However, the Hausman test strongly rejects the null hypothesis ($\chi^2 = 97.19$, $p < 0.001$), indicating that the random-effects estimator is inconsistent. Therefore, the fixed-effects specification should be preferred for inference, implying that within-country dynamics are more reliable than cross-sectional variation in explaining social progress.

Table 2. Panel Regression Results (SPI = EGDI + Controls). [Source: Created by the authors.]

Variable	FE (DK SE)	RE (DK SE)
EGDI	4.502 (4.780)	7.092 (5.712)
UNEMP	2.109*** (0.595)	2.172*** (0.438)
GDPPC (ln)	6.448*** (1.358)	7.219*** (0.972)
URBAN	0.304*** (0.035)	0.202*** (0.040)
Constant	–	–21.868** (6.818)
Observations	1964	1964
Hausman test	$\chi^2 = 97.19$, p-value <0.0001***	

Note. Driscoll–Kraay standard errors in parentheses. Significance codes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The Driscoll–Kraay estimation results provide consistent evidence on the determinants of social progress and highlight differences between aggregate and disaggregated specifications.

In Model 1 (Table 2), using aggregate EGDI, fixed-effects estimates show no statistically significant impact on SPI ($\beta = 4.50$, $p = 0.346$). This indicates that, after controlling for country-specific heterogeneity, overall e-government development is not directly associated with within-country changes in social progress. In contrast, all control variables are positive and highly significant. Unemployment is positively associated with social progress ($\beta = 2.11$, $p < 0.001$), likely reflecting policy or institutional effects. GDP per capita remains the strongest predictor ($\beta = 6.45$, $p < 0.001$), while urbanisation also shows a significant positive effect ($\beta = 0.30$, $p < 0.001$).

Random-effects estimates show similar signs and significance patterns, though with slightly larger coefficients, especially for GDP per capita ($\beta = 7.22$, $p < 0.001$). The EGDI remains insignificant ($\beta = 7.09$, $p = 0.215$), confirming that the aggregate index does not capture the underlying mechanisms. However, the Hausman test strongly rejects the random-effects model ($\chi^2 = 97.19$, $p < 0.001$), indicating inconsistency. Therefore, the fixed-effects specification is preferred, suggesting that within-country dynamics are more informative than cross-sectional variation.

Table 3. Panel Regression Results (SPI = EGDI Components + Controls). [Source: Created by the authors.]

Variable	FE (DK SE)	RE (DK SE)
EGDI_HCI	–4.466 (3.711)	0.211 (3.486)
EGDI_OSI	4.411* (2.216)	5.308* (2.346)
EGDI_TTI	–0.992 (3.302)	–0.146 (3.869)
UNEMP	1.987*** (0.587)	2.157*** (0.439)
GDPPC (ln)	6.142*** (1.050)	7.487*** (1.047)
URBAN	0.287*** (0.020)	0.199*** (0.038)
Constant	–	–23.111*** (6.806)
Observations	1964	1964
Hausman test	$\chi^2 = 166.85$, p-value <0.0001***	

Note. Driscoll–Kraay standard errors in parentheses. Significance codes: *** p < 0.01, ** p < 0.05, * p < 0.1.

The two-way fixed-effects estimates (Table 4), which control simultaneously for unobserved country-specific heterogeneity and common time effects, provide more robust and substantively meaningful evidence on the relationship between GovTech and social progress.

Table 4. Two-Way Fixed Effects Results (SPI and E-Government Development). [Source: Created by the authors.]

Variable	Model 1: EGDI	Model 2: Components
EGDI	3.372* (1.605)	–
EGDI_HCI	–	2.565* (1.286)
EGDI_OSI	–	0.855 (0.658)
EGDI_TTI	–	1.847*** (0.345)
UNEMP	1.399*** (0.353)	1.433*** (0.369)
GDPPC (ln)	3.233*** (0.225)	3.141*** (0.222)
URBAN	0.154*** (0.030)	0.156*** (0.030)
Country FE	Yes	Yes
Time FE	Yes	Yes
Observations	1964	1964

Note. Driscoll–Kraay standard errors in parentheses. Significance codes: *** p < 0.01, ** p < 0.05, * p < 0.1.

In Model 1, the inclusion of time effects fundamentally changes the role of the aggregate EGDI. Unlike the one-way fixed-effects model, EGDI becomes positive and statistically significant ($\beta = 3.37$, $p = 0.036$). This indicates that, once global shocks and common trends are controlled for, improvements in e-government development are associated with higher SPI scores. The earlier insignificance, therefore, reflects omitted time effects rather than the absence of a true relationship. The coefficient suggests a moderate but meaningful contribution of GovTech to social progress.

Control variables remain stable and highly significant. GDP per capita has the strongest effect ($\beta = 3.23$, $p < 0.001$), confirming the central role of economic development. Urbanisation is also positive and significant ($\beta = 0.15$, $p < 0.001$), while unemployment retains a positive coefficient ($\beta = 1.40$, $p < 0.001$), likely reflecting policy or institutional mechanisms.

Model 2, which decomposes EGDI, provides further insight. Both HCI and TTI become statistically significant. HCI shows a positive effect ($\beta = 2.57$, $p = 0.046$), indicating the importance of digital skills and education. TTI has a strong, highly significant impact ($\beta = 1.85$, $p < 0.001$), highlighting infrastructure as a key enabling factor. In contrast, OSI becomes insignificant ($\beta = 0.86$, $p = 0.194$), suggesting that its earlier importance was driven by global trends rather than within-country variation.

Across both models, control variables remain consistent and significant. Overall, the results indicate that GovTech's impact on social progress is primarily driven by human capital and infrastructure, while the role of service delivery is more sensitive to global dynamics.

The non-linear specification (Table 5) provides strong evidence that the relationship between e-government development and social progress is not linear but follows a concave (inverted U-shaped) pattern. Both the linear and squared terms of EGDI are statistically significant at the 1% level, with opposite signs: the coefficient on EGDI is positive ($\beta = 15.20$, $p < 0.001$), while the squared term is negative ($\beta = -12.53$, $p < 0.001$). This confirms the presence of diminishing returns to GovTech development.

Table 5. Two-Way Fixed Effects with Non-Linear Specification (SPI and EGDI). [Source: Created by the authors.]

Variable	Coefficient (DK SE)
EGDI	15.196*** (3.859)
EGDI²	-12.530*** (2.965)
UNEMP	1.110*** (0.278)
GDPPC (ln)	3.198*** (0.246)
URBAN	0.117*** (0.024)
Country FE	Yes
Time FE	Yes
Observations	1964

Note. Driscoll–Kraay standard errors in parentheses. Significance codes: *** p < 0.01, ** p < 0.05, * p < 0.1.

Substantively, this implies that at lower and moderate levels of e-government development, improvements in EGDI are associated with substantial gains in the SPI. However, as countries reach higher levels of digital maturity, the marginal benefits of further digitalisation decline and may eventually stabilise. This pattern is consistent with the idea that early stages of digital transformation generate significant efficiency gains and improvements in service accessibility. In contrast, advanced stages face saturation effects, institutional constraints, or increasing implementation costs.

The estimated turning point of the relationship can be approximated as $-\beta_1/(2\beta_2)$, which, in this case, corresponds to approximately 0.61 on the EGDI scale. This suggests that the positive impact of GovTech on social progress is strongest at moderate-to-high levels of development, after which additional improvements yield smaller marginal effects. Given that the sample mean of EGDI is approximately 0.50, most countries are still located on the upward-sloping segment of the curve, indicating that further digitalisation is likely to continue producing positive social returns for the majority of cases.

The control variables remain stable and highly significant, confirming the model's robustness. GDP per capita continues to exert a strong positive influence ($\beta = 3.20$, $p < 0.001$), reinforcing the central role of economic development. Urbanisation also remains positively associated with social progress ($\beta = 0.12$, $p < 0.001$). At the same time, unemployment retains a positive and statistically significant coefficient ($\beta = 1.11$, $p < 0.001$), again suggesting the presence of policy or institutional mediation mechanisms.

The non-linear specification refines the earlier findings by demonstrating that the impact of e-government is conditional on its level of development. Rather than a uniformly increasing effect, GovTech exhibits diminishing marginal returns, highlighting the importance of focusing not only on expansion but also on the quality, efficiency, and integration of digital systems at more advanced stages.

The non-linear component-level specification (Table 6) provides strong evidence that the relationship between e-government dimensions and social progress is heterogeneous and strongly non-linear, with distinct patterns across subindices.

Table 6. Two-Way Fixed Effects with Non-Linear EGDI Components (SPI as Dependent Variable). [Source: Created by the authors.]

Variable	Coefficient (DK SE)
EGDI_HCI	–4.544 (3.003)
EGDI_HCI²	8.632** (2.666)
EGDI_OSI	4.162** (1.340)
EGDI_OSI²	–3.580*** (1.045)
EGDI_TTI	14.093*** (1.149)
EGDI_TTI²	–11.831*** (1.689)
UNEMP	0.907*** (0.252)
GDPPC (ln)	2.182*** (0.306)
URBAN	0.058** (0.022)
Country FE	Yes
Time FE	Yes
Observations	1964

Note. Driscoll–Kraay standard errors in parentheses. Significance codes: *** p < 0.01, ** p < 0.05, * p < 0.1.

The HCI exhibits a U-shaped relationship with social progress. The linear term is negative and insignificant ($\beta = -4.54$, $p = 0.130$), while the squared term is positive and significant ($\beta = 8.63$, $p = 0.001$), indicating a threshold effect. At low levels, increases in human capital do not immediately improve social progress, likely because complementary conditions are insufficient. Beyond a critical level, however, further improvements generate accelerating positive effects, suggesting that investments in digital skills become effective only after reaching a minimum threshold.

In contrast, OSI and TTI display inverted U-shaped relationships, indicating diminishing returns. For OSI, the linear term is positive ($\beta = 4.16$, $p = 0.002$) and the squared term negative ($\beta = -3.58$, $p < 0.001$), implying that gains from digital services decline at advanced stages.

Similarly, TTI shows a strong positive effect ($\beta = 14.09$, $p < 0.001$) alongside a large negative quadratic term ($\beta = -11.83$, $p < 0.001$), indicating that infrastructure is highly impactful at early stages but eventually saturates.

The magnitude of coefficients suggests that infrastructure is the most influential component, followed by online services, while human capital plays a conditional, threshold-dependent role. This indicates that the overall nonlinearity of EGDI is mainly driven by infrastructure and service delivery, whereas human capital follows a distinct non-monotonic pattern.

Control variables remain robust and significant. GDP per capita exerts a strong positive effect ($\beta = 2.18$, $p < 0.001$), confirming its central role. Unemployment remains positive ($\beta = 0.91$, $p < 0.001$), likely reflecting institutional mechanisms, while urbanisation also contributes positively ($\beta = 0.06$, $p = 0.007$), though with a smaller magnitude.

The results confirm that GovTech effects are highly non-linear and component-specific. Infrastructure and services generate strong but diminishing returns, whereas human capital requires a threshold before becoming effective. This highlights the need for balanced and sequenced digital development strategies.

Turning-point estimates reinforce these findings. The aggregate EGDI peaks at approximately 0.61, while OSI and TTI reach turning points at around 0.58 and 0.60, respectively, indicating diminishing returns at higher levels. In contrast, HCI shows a lower threshold of about 0.26, consistent with its U-shaped pattern. These results suggest that most countries remain below or near optimal levels, but the effectiveness of individual components varies, underscoring the importance of stage-sensitive digitalisation policies.

The specification, including period-specific effects (Table 7), provides additional insight into the temporal dynamics underlying the relationship between GovTech and social progress. The coefficient on EGDI remains positive and statistically significant ($\beta = 3.37$, $p = 0.036$), confirming that improvements in e-government development are associated with increases in the Social Progress Index even after explicitly controlling for time-specific shocks. This reinforces the robustness of the baseline findings and indicates that the effect of digitalisation is not solely driven by global trends, but reflects meaningful within-country improvements. The control variables remain stable and highly significant: GDP per capita continues to exert the strongest influence ($\beta = 3.23$, $p < 0.001$), followed by urbanisation ($\beta = 0.15$, $p < 0.001$) and unemployment ($\beta = 1.40$, $p < 0.001$), confirming the structural importance of economic development and demographic factors.

Table 7. Two-Way Fixed Effects with Period Dummies (SPI as Dependent Variable). [Source: Created by the authors.]

Variable	Coefficient (DK SE)
EGDI	3.372* (1.610)
UNEMP	1.399*** (0.354)
GDPPC (ln)	3.233*** (0.226)
URBAN	0.154*** (0.030)
Period 2004	0.220*** (0.043)
Period 2005	0.764*** (0.069)
Period 2008	2.261*** (0.126)
Period 2010	3.513*** (0.138)
Period 2012	4.256*** (0.227)
Period 2014	4.883*** (0.225)
Period 2016	5.547*** (0.275)
Period 2018	5.934*** (0.363)
Period 2020	6.099*** (0.483)
Period 2022	3.039*** (0.486)
Period 2024	0.865 (0.548)
Country FE	Yes
Period Effects	Yes
Observations	1964

Note. Driscoll–Kraay standard errors in parentheses. Significance codes: *** p < 0.01, ** p < 0.05, * p < 0.1.

The inclusion of period dummies reveals a clear and economically meaningful time pattern. All coefficients from 2004 to 2020 are positive and highly significant, with steadily increasing magnitudes, indicating a strong upward trend in social progress relative to 2003. The effect peaks in 2018–2020 ($\beta \approx 5.93$–6.10), reflecting a period of substantial global improvement, likely driven by cumulative technological and institutional progress. However, this trend weakens afterwards: the coefficient declines in 2022 ($\beta = 3.04$, $p < 0.001$) and becomes insignificant in 2024. This likely reflects the impact of recent global shocks, including the aftermath of COVID-19, geopolitical instability, and economic uncertainty.

These results confirm that while GovTech contributes positively to social progress, its effects unfold within a broader temporal context shaped by global trends and disruptions. Social progress is therefore non-linear over time and sensitive to exogenous shocks, highlighting the importance of resilient governance systems.

Country fixed effects (Table A1) reveal substantial cross-country heterogeneity that cannot be explained solely by GovTech, economic conditions, or urbanisation. These effects capture persistent structural factors such as institutional quality, governance capacity, and historical development. Their wide dispersion, from strongly negative values (e.g., Somalia: −7.92; Angola: –5.58) to very high positive values (e.g., Slovenia: 36.78; Finland: 36.28; Norway: 35.01), indicates that structural differences account for a large share of the variation in social progress.

A clear pattern emerges across countries. Advanced economies, particularly in Europe and OECD members (e.g. Finland, Slovenia, Germany, Nordic countries), show consistently high positive effects, reflecting strong institutions and public services. Countries such as Estonia and Lithuania also perform strongly, highlighting successful digital and governance reforms. In contrast, many low-income and fragile states, especially in Sub-Saharan Africa and conflict-affected regions, exhibit negative or near-zero effects, indicating structural constraints. These findings emphasise that institutional and structural conditions remain decisive for social outcomes, beyond the measurable effects of GovTech.

DISCUSSION

The empirical findings support the conceptualisation of GovTech as a "Technological – Institutional – Human" system. Its impact on social progress depends not only on the level of digitalisation, but also on structural, institutional, and temporal conditions. The shift from insignificance in one-way models to significance in two-way specifications indicates that digitalisation effects emerge only when broader systemic factors are considered. This suggests that GovTech operates within a wider macro and institutional environment rather than as an isolated technological driver. These results align with studies emphasising that digital transformation outcomes are embedded in governance capacity, policy frameworks, and economic development (Valaskova et al., 2025b; Samarkhanov et al., 2025; Kuanaliyev et al., 2024).

The analysis also reveals strong heterogeneity across GovTech components. Infrastructure and human capital emerge as the most robust drivers once temporal effects are controlled for. This indicates that foundational capacities play a more stable role than service delivery alone. Improvements in online services appear more sensitive to global diffusion trends than to purely domestic reforms. This finding is consistent with research highlighting the role of international policy convergence and shared digital trajectories (Paraschiv et al., 2024; Pakhnenko et al., 2025). It also reinforces the argument that digital transformation requires complementary investments in infrastructure and skills (Kuzior et al., 2022; Kuzior & Sira, 2025).

Another important insight concerns the non-linear nature of GovTech effects. The results indicate that digitalisation does not generate uniformly increasing benefits. Instead, its impact depends on the stage of development. At higher levels of digital maturity, additional improvements yield smaller gains. At the component level, infrastructure and service delivery show diminishing returns, while human capital operates through a threshold mechanism. This means that digital skills become effective only after reaching a critical level. Such patterns are consistent with the literature on digital readiness and behavioural adoption (Budiyanto et al., 2025; Kowalska & Nguyen, 2025; Crăciun et al., 2025). They also reflect broader theories of welfare and system resilience (Oe & Yamaoka, 2025; Hakobyan et al., 2025).

One thing that holds across all specifications is that the coefficient on unemployment is positive and statistically significant. This too should be interpreted with caution. One explanation may be that this is capturing the ameliorating effect of social protection; countries with stronger institutions to deliver unemployment insurance, active labour market programs, and welfare support may have both higher measured unemployment and higher social progress outcomes. Alternatively, this may reflect structural transitions out of informal labour. Countries may experience rising measured unemployment as health outcomes, educational attainment and social infrastructure improve because workers leave informal labour markets. Finally, this may simply be an artefact of taking the log of unemployment; since this transformation compresses high values, the coefficient is identified almost exclusively off variation at low-to-moderate rates of unemployment and thus says less about the relationship at very high levels of labour market distress. Regardless of the reason, the point is that the association between unemployment and multidimensional well-being is more complex than any single coefficient can convey and should be explored further with better micro data on labour market outcomes.

Temporal dynamics further highlight that GovTech operates within an unstable global environment. The observed rise in social progress before 2020, followed by deterioration in later periods, suggests that digital systems enhance resilience but do not eliminate vulnerability

to external shocks. At the same time, substantial country-specific heterogeneity confirms that persistent institutional and economic differences remain decisive. These findings support the view that digital transformation is context-dependent and mediated by governance quality and public value management (Vasylieva et al., 2023; Sułkowski et al., 2025).

Important caveats are in order. First, EGDI is reported only every other year, so the time dimension of our data is relatively short, which rules out dynamic panel estimators that depend on overlaps in the time dimension (i.e. system GMM). The Driscoll–Kraay correction we use to account for cross-sectional dependence depends on a large time dimension asymptotically, and its finite-sample properties may suffer because of the uneven spacing between observations. Country-clustered standard errors are an alternative that could be reported here for robustness. Second, EGDI and SPI are indices. Indices can hide reverse movements within subindices, and the weights implied by indices assume that each component of social progress is valued equally by countries of different institutional quality (when benefits to each dimension may not accrue equally to those countries). Third, despite our two-way fixed effects, endogeneity may still be an issue; countries that happen to make gains in social progress may choose to invest more in digital government at the same time, and the fixed-effects specification cannot disentangle the direction of causality within these co-movements. Instrumental variable or quasi-experimental methods would be required to make causal claims. Fourth, we lack explicit measures of institutional quality or governance effectiveness, and do not account for digital inequality. All of these may be intervening variables that affect the strength of the relationship between GovTech and social variables. This should be addressed in future work, which could also leverage within-country variation and test for interactions between GovTech and institutional factors.

CONCLUSIONS

This study examined how GovTech development, conceptualised as a "Technological – Institutional – Human" system, influences social progress. The analysis demonstrates that the relationship between digitalisation and societal outcomes is conditional, non-linear, and strongly context-dependent.

Using panel data for 2003–2024 and applying two-way fixed-effects models with robust inference, the study shows that GovTech contributes positively to social progress when global dynamics are taken into account. The aggregate EGDI becomes statistically significant only after controlling for time effects ($\beta = 3.37$, $p = 0.036$), confirming that GovTech contributes positively to social progress when global dynamics are taken into account. The relationship is non-linear, with a turning point at approximately 0.61, indicating diminishing marginal returns at higher levels of digital development. The component-level analysis shows that telecommunications infrastructure exerts the strongest effect ($\beta = 14.09$, $p < 0.001$), followed by online services ($\beta = 4.16$, $p = 0.002$), while human capital displays a threshold effect with a turning point around 0.26. Fourth, GDP per capita remains the most influential control variable across all specifications ($\beta \approx 3.14$–6.45, $p < 0.001$), underscoring the central role of economic development. Finally, period effects indicate a strong upward trend in social progress until 2020 ($\beta \approx 6.10$), followed by a decline in 2022 ($\beta = 3.04$) and insignificance in 2024, reflecting the impact of recent global shocks.

These findings have important policy implications. First, GovTech strategies should shift from a focus on expansion to optimising the quality and integration of digital systems, particularly at advanced stages where diminishing returns emerge. Second, investments should prioritise telecommunications infrastructure and digital service delivery, as these components generate the most immediate and substantial societal benefits. Third, policies should recognise the threshold nature of human capital, ensuring that investments in digital skills and education reach a critical level before expecting measurable social outcomes. Fourth, digital transformation strategies must be embedded within broader socio-economic development frameworks, as economic capacity remains a fundamental determinant of social progress. Finally, given the sensitivity of social outcomes to global shocks, governments should design resilient, adaptive digital governance systems that sustain progress amid uncertainty. The study contributes to the literature by demonstrating that GovTech affects human well-being through complex, non-linear mechanisms. Its effectiveness depends on the interaction between technology, institutions, and human capabilities rather than on digitalisation alone.

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Appendix

Appendix A. Descriptive Statistics and Correlation Analysis

Table A1. Country Fixed Effects (Two-Way Fixed Effects Model)

Country	Fixed Effect	Country	Fixed Effect	Country	Fixed Effect
Afghanistan	-0.93	Georgia	25.592	Niger	10.717
Albania	25.846	Germany	34.572	Nigeria	6.674
Algeria	16.435	Ghana	17.618	North Macedonia	22.966
Angola	-5.579	Greece	30.611	Norway	35.006
Argentina	25.483	Guatemala	13.817	Oman	9.842
Armenia	23.5	Guinea	1.647	Pakistan	7.281
Australia	32.608	Guinea-Bissau	3.782	Panama	24.63
Austria	34.625	Guyana	22.405	Papua New Guinea	11.323
Azerbaijan	13.241	Haiti	2.368	Paraguay	19.672
Bahrain	7.275	Honduras	17.053	Peru	20.744
Bangladesh	9.596	Hungary	29.431	Philippines	22.632
Barbados	32.038	Iceland	33.417	Poland	32.437
Belarus	22.814	India	13.57	Portugal	34.22
Belgium	32.26	Indonesia	18.608	Qatar	7.009
Benin	13.899	Iran	12.86	Romania	28.428
Bhutan	20.567	Iraq	8.153	Russian Federation	19.244
Bolivia	18.025	Ireland	32.029	Rwanda	11.43
Bosnia and Herzegovina	24.929	Israel	27.791	São Tomé and Príncipe	15.289
Botswana	15.421	Italy	32.748	Saudi Arabia	3.681
Brazil	18.993	Jamaica	28.83	Senegal	16.323
Bulgaria	26.77	Japan	32.436	Serbia	26.429
Burkina Faso	11.753	Jordan	17.343	Sierra Leone	7.182
Burundi	9.074	Kazakhstan	18.528	Singapore	22.221
Cabo Verde	20.836	Kenya	15.312	Slovak Republic	33.142
Cambodia	12.891	Korea. Rep.	32.125	Slovenia	36.778
Cameroon	6.753	Kuwait	15.964	Solomon Islands	15.625
Canada	33.314	Kyrgyz Republic	25.675	Somalia	-7.922
Central African Republic	-4.179	Lao PDR	6.059	South Africa	17.715
Chad	-2.143	Latvia	32.521	Spain	31.184
Chile	26.686	Lebanon	16.436	Sri Lanka	25.773
China	13.956	Lesotho	12.667	Sudan	0.294
Colombia	17.439	Liberia	10.544	Suriname	21.614
Comoros	13.102	Libya	5.605	Sweden	33.604
Congo. Dem. Rep.	2.71	Lithuania	33.549	Switzerland	34.988
Congo. Rep.	-2.988	Luxembourg	29.108	Syrian Arab Republic	6.83
Costa Rica	29.92	Madagascar	9.433	Tajikistan	16.722
Cote d'Ivoire	8.802	Malawi	16.853	Tanzania	15.429
Croatia	31.471	Malaysia	19.419	Thailand	23.861
Cyprus	31.626	Maldives	20.592	Timor-Leste	18.35
Czechia	31.514	Mali	10.23	Togo	11.378
Denmark	34.281	Malta	27.571	Trinidad and Tobago	28.218
Djibouti	1.115	Mauritania	2.746	Tunisia	19.36
Dominican Republic	18.262	Mauritius	30.511	Turkiye	15.62
Ecuador	25.097	Mexico	18.2	Turkmenistan	13.169
Egypt	10.485	Moldova	30.049	Uganda	11.819
El Salvador	17.645	Mongolia	18.999	Ukraine	24.296
Equatorial Guinea	-4.707	Montenegro	25.072	United Arab Emirates	10.274

Estonia	34.704	Morocco	15.125	United Kingdom	32.777
Eswatini	3.87	Mozambique	9.573	United States	29.733
Ethiopia	7.352	Myanmar	11.383	Uruguay	25.999
Fiji	19.732	Namibia	16.917	Uzbekistan	15.407
Finland	36.275	Nepal	8.365	Vanuatu	20.774
France	32.221	Netherlands	32.214	Viet Nam	24.436
Gabon	7.531	New Zealand	33.523	Zambia	10.106
Gambia	6.013	Nicaragua	17.563	Zimbabwe	8.155