

# E-government and digital transaction costs in the context of cybersecurity maturity: A comparative approach to Arab countries (2005-2023)


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## Abstract

This research examines the correlation between e-government advancement and digital transaction expenses in Arab nations, highlighting the influence of cybersecurity maturity as a moderating factor. The analysis employs panel data from twenty Arab League member states spanning 2005 to 2023, incorporating the United Nations E-Government Development Index (EGDI) and the International Telecommunication Union's Global Cybersecurity Index (GCI) as principal indicators. A two-way fixed-effects model is utilized to examine whether cybersecurity maturity enhances the efficiency improvements of digital governance. Results show that e-government development cuts down on the costs of searching for information, negotiating, and enforcing rules. This relationship, on the other hand, gets a lot stronger in places where cybersecurity frameworks are well-established and trustworthy.

The results show that digital transformation and cyber resilience go hand in hand, and that for digitalization to be sustainable, investments in both cybersecurity capacity building and regulatory coherence must be made at the same time. Policy suggestions call for a coordinated approach to speed up e-government and improve cybersecurity maturity in order to create safe, low-cost digital economies.

**Keywords:** E-Government Development Index (EGDI), Digital Transaction Costs, Global Cybersecurity Index (GCI), Maturity, Arab countries, Panel Data

## 1. Introduction

### 1.1. Background and Context of the Research

Over the past twenty years, the global economy has been reshaped by rapid digitization and the spread of digital tools across both public administration and economic life. E-government has emerged as a key driver in this shift, cutting search, negotiation, and enforcement costs while improving service quality and public-sector efficiency. Still, the success of digital transformation isn't defined only by how many online platforms a government launches. What matters just as much is the strength of the cybersecurity systems behind them and the level of digital trust they generate among citizens and firms.

This contrast is especially sharp in the Arab region. Some countries—particularly in the Gulf—have made big strides in e-government readiness (UN DESA, 2022), whereas others continue to face gaps in cybersecurity maturity and institutional frameworks that safeguard online activity (OECD, 2003). The UAE's centralized portals and Qatar's national ID system, for example, have turned what used to be hour-long procedures like license renewal into tasks that take only minutes (UN DESA, 2022). These differences show up directly in economic outcomes: when e-government rollout is matched by solid cybersecurity, adoption rates rise and digital transaction costs drop. In short, institutional trust—not just technology—determines whether citizens actually use digital public services.

Grasping how e-government development and cybersecurity maturity work together is key to understanding the region's digital-economy dynamics and designing policies that make digital growth sustainable. Despite clear progress, Arab economies still face relatively high digital transaction costs—the time and effort spent searching for, negotiating, and enforcing digital interactions. In many cases, the gains from e-government initiatives are partly offset by weak cybersecurity maturity, which slows down adoption and limits efficiency.

### 1.2. Problem Statement

This study tackles the following central question:

***To what extent does e-government development reduce economic transaction costs in Arab countries, and how does the maturity of national cybersecurity systems moderate this effect?***

The question matters because improvements in digital service delivery can only yield the expected economic benefits if users trust that digital channels are secure and reliable. Where cybersecurity governance is weak, perceived risk raises the implicit costs of digital exchanges, dampening adoption and undermining efficiency gains.

The research therefore treats cybersecurity maturity not as a peripheral technical issue but as a conditioning factor that can enable or constrain the economic returns to e-government.

### Sub-questions:

1. What is the statistical relationship between the E-Government Development Index (EGDI) and proxy measures of digital transaction costs in Arab countries?
2. Does higher cybersecurity maturity (GCI) strengthen the effect of EGDI on lowering transaction costs?
3. How does the EGDI–transaction cost relationship differ across regional groups within the Arab world (Gulf, North Africa, Levant), and what policy lessons follow from divergent national experiences?

### 1.3. Significance of Study

The research is important for both theoretical and practical aspects. From the theoretical perspective, it unites and makes a comparative study of the two most significant concepts in the area of digital governance theory and transaction cost economics (TCE). The latter domain is referred to as peripherally existing, with empirical support of its intersection in the Arab world. Otherwise, the research suggests a scenario where maximum economic returns from e-government are obtained and the risks of cyber are minimized through the provision of insights to regional policymakers. The findings will influence country-centric digital-economy strategies like the Arab Digital Agenda and the UN e-government framework, which are mostly concerned with sustainable digitalization being dependent on cybersecurity backing, through letting them understand the interrelation.

### 1.4. Objectives and Hypotheses

#### Objectives

The research aims at three key goals, which are:

1. Quantify the effect of e-government development (EGDI) on digital transaction costs in the Arab context.
2. Test the moderating role of cybersecurity maturity (GCI) on the EGDI → transaction cost relationship.
3. Identify regional patterns and derive practical policy recommendations for Arab policymakers.

#### Hypotheses

- **H1.** Higher EGDI is associated with lower digital transaction costs in Arab countries.
- **H2.** Cybersecurity maturity (GCI) positively moderates the EGDI effect: the cost-reducing impact of EGDI is larger in countries with higher GCI (i.e., a statistically significant EGDI × GCI interaction).
- **H3.** The magnitude and possibly the sign of the EGDI effect differ across regional subgroups within the Arab world (Gulf / North Africa / Levant), reflecting heterogeneity in digital and cybersecurity capacities.

## 1.5. Structure of the Paper

The rest of the paper is structured in the following manner. A theoretical and conceptual review of e-government and digital transaction costs is given in Section 2. The methodology, including data, variables, and econometric modeling, is presented in Section 3. The fourth section is devoted to the discussion of the empirical results and the interpretation thereof. The fifth section contains the conclusions with the key findings, policy implications, and recommendations for future research.

## 2. Theoretical and Conceptual Framework

### 2.1. E-Government, Digital Transformation, and Transaction Costs

Digital government is often described as a natural extension of information and communication technologies (ICTs) into the public sphere. Yet, from an economic perspective, its real significance lies in how it reshapes the cost structure of governance. Transaction Cost Economics (TCE) suggests that digital platforms reduce the implicit costs of searching for information, negotiating exchanges, and enforcing compliance (Williamson, 1985). By digitizing workflows, standardizing procedures, and automating verification, governments can theoretically minimize these frictions, translating administrative efficiency into measurable economic value. In this view, e-government is more than a technical upgrade—it is a mechanism for reengineering the state's transaction architecture.

#### 2.1.1. Complementary Theoretical Lenses

While TCE clarifies *why* digitalization can reduce costs, it does not explain *when* or *where* such efficiencies materialize. Two complementary frameworks—Institutional Theory and the Technology–Organization–Environment (TOE) model—help close this gap.

##### **Institutional Theory**

Institutional Theory emphasizes the legitimacy, norms, and regulatory settings that shape actors' trust in public technologies. Where formal institutions (such as data protection laws) and informal norms (such as trust in public agencies) are weak, the cost-reducing effects predicted by TCE are blunted. Users, uncertain about data integrity or accountability, often revert to slower, analog channels (Alhassan et al., 2023; Hooda, 2023; United Nations Department of Economic and Social Affairs [UN DESA], 2022). This perspective helps explain why countries with similar technical capacities still exhibit vastly different levels of e-government adoption.

##### **Technology–Organization–Environment (TOE) Framework**

The TOE framework identifies three interdependent contexts that influence technological uptake: the technological (infrastructure and maturity), the organizational (resources and administrative culture), and the environmental (regulation and competitive

or cooperative pressures). Even among countries with comparable EGDI scores, differences in public IT skills, institutional agility, and cybersecurity regulation lead to divergent digital outcomes (Al-Shboul & Al-Omari, 2023; Hooda, 2023). Integrating TOE with TCE allows the analysis to move beyond “technology-only” explanations, tying e-government development (EGDI) and cybersecurity maturity (GCI) into a single explanatory structure.

## Synthesis

Bringing TCE, Institutional Theory, and TOE together yields a more coherent account of digital transformation. E-government initiatives reduce nominal transaction costs (TCE) only when institutional legitimacy (Institutional Theory) and supportive technological–organizational conditions (TOE) jointly lower perceived risks and adoption barriers. Cybersecurity maturity (GCI) sits at this intersection—acting as a safeguard, a signal of institutional reliability, and a structural moderator that amplifies the efficiency effects of e-government (International Telecommunication Union [ITU], 2023).

### 2.1.2. Defining E-Government and Its Economic Implications

There are multiple definitions of e-government, as follows:

- **Badran (2004):** E-government is defined as “the virtual version of the real government, with the difference that e-government operates in networks and information systems, simulating the functions of the traditional government present physically in state institutions. Its goal is to provide various government services through electronic media and technological tools, primarily the internet and communications.”
- **United Nations (Molnár, 2020):** E-government is defined as “the use and application of information and communication technologies by governments in the public sector, aiming to manage data and information efficiently, expand participatory communication channels, provide more advanced public services, reliable information, and widespread knowledge accessible to all citizens.” Notably, the UN focuses on linking ICT use with the quality and delivery of government services to citizens.
- **World Bank (Gustova, 2017, 2011):** E-government refers to “the use of information technologies by government agencies, such as broadband networks, the internet, and mobile computing, through interactions between citizens, institutions, government entities, and other stakeholders, aiming to achieve objectives like improving public service delivery, enhancing engagement with businesses and industries, increasing accessibility, and achieving more efficient governance.” This definition highlights the connection between e-government development and internal and external electronic interactions, emphasizing the government’s motivation to transform traditional practices.

- **Organization for Economic Co-operation and Development (OECD, 2003):** E-government is defined as “the use of information and communication technologies, especially the internet, as a tool to achieve better governance.” The OECD emphasizes the necessity of internet use and its link to quality improvement, without detailing specific transactions, services, or target parties.
- **Center for E-Government Studies (Electronic, 2023):** E-government is “the virtual version of classical government, with the difference that the former exists in networks and information systems and simulates the functions of the latter, which operates physically in state institutions.”

From the above definitions, several key ideas emerge that form the essence of e-government:

- E-government represents a transformation in the way services are delivered, moving from the traditional paper-based and bureaucratic approach to one characterized by accuracy, speed, security, and cost-efficiency, relying on all outputs of information and communication technologies, which form the backbone of e-government operations.

## 2.2. The Moderating Role of Cybersecurity Maturity

Yet digital efficiency does not emerge automatically. It depends on the trust architecture surrounding data exchange and digital compliance. Weak cybersecurity governance—marked by inconsistent enforcement, fragmented systems, or unclear accountability—raises perceived transaction costs for all actors, discouraging participation and eroding trust (UNESCWA, 2022).

Conversely, robust cybersecurity maturity (CSM) reinforces institutional credibility and ensures data integrity, lowering the uncertainty and enforcement costs that inhibit digital adoption. In this way, cybersecurity functions not as a peripheral technical issue but as a *moderating condition* that determines whether e-government investments yield real economic efficiency or generate new layers of risk and complexity.

## 2.3. Conceptual Model and Hypothesized Relationships

Anchored in TCE and extended through Institutional and TOE frameworks, the proposed model connects three core variables:

- **Independent Variable (X):** E-Government Development Index (EGDI)
- **Moderator (M):** Global Cybersecurity Index (GCI)
- **Dependent Variable (Y):** Digital Transaction Costs (proxied by Transaction Transparency Index, TTI)

Two hypotheses follow:

1. **Direct Effect:** Higher e-government development (EGDI) correlates with lower digital transaction costs.
2. **Moderating Effect:** The impact of EGDI on digital transaction costs strengthens as cybersecurity maturity (GCI) increases.

To test this moderation, the interaction term ( $EGDI \times GCI$ ) will be introduced in the regression model to assess whether cybersecurity maturity significantly shapes the efficiency outcomes of e-government initiatives.

### 3. Methodology

#### 3.1. Research Design and Data

This study employs a quantitative, panel-data approach to examine the impact of e-government development on digital transaction costs across twenty Arab countries over the period from 2005 to 2023. The analysis incorporates the critical moderating effect of cybersecurity maturity on this relationship. Data were sourced exclusively from reputable, secondary institutional databases: the **E-Government Development Index (EGDI)**, utilized to measure e-government development (United Nations, 2022), and the **Global Cybersecurity Index (GCI)**, used to capture national cybersecurity maturity (ITU, 2022). The resultant dataset is structured as a balanced panel, ensuring maximum consistency and comparability across countries and years, totaling  $N \times T$  observations.

The empirical sample comprises 20 Arab countries observed over the 2005–2023 period, yielding a balanced panel after data cleaning. Two countries—Comoros and Djibouti—were excluded due to incomplete time series. In both cases, the UN E-Government Development Index (EGDI) and the ITU Global Cybersecurity Index (GCI) lacked continuous annual coverage, with missing years or incomplete sub-indices. Because panel estimation requires at least two consecutive observations per unit, these countries were dropped to maintain temporal consistency and estimation reliability.

#### 3.2. The Concept and Models of E-Government

The concept of e-government reflects a fundamental transformation in how public services are designed and delivered. It marks a shift from traditional, paper-based, and bureaucratic procedures toward systems characterized by accuracy, efficiency, security, and cost-effectiveness, enabled by the full utilization of information and communication technologies (ICTs), which form the backbone of e-government operations (Gustova, 2017).

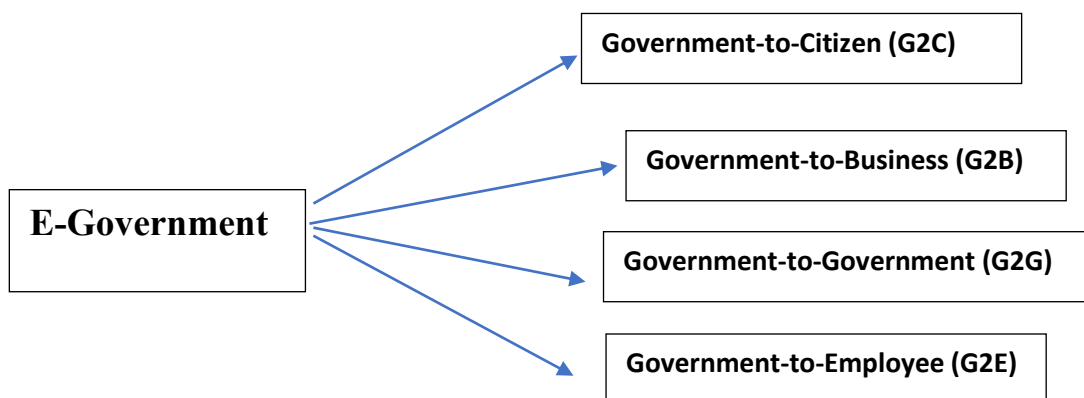
Beyond the simple digitization of services, e-government represents a new managerial, social, and political paradigm that reshapes administrative processes and citizen–state interactions. Its implementation enhances efficiency and effectiveness in the public sector,

capitalizes on accumulated knowledge and technological advances, expands accessibility, and promotes participatory decision-making among stakeholders (UN DESA, 2022).

In practice, e-government models are generally categorized into four interaction types (see Figure 1):

1. **Government-to-Citizen (G2C):** delivery of public information and services directly to citizens.
2. **Government-to-Business (G2B):** facilitation of transactions and regulatory processes with private enterprises.
3. **Government-to-Government (G2G):** digital integration and data exchange among public institutions.
4. **Government-to-Employee (G2E):** internal digital systems supporting public-sector workforce operations.

Figure1 . E-Government Interaction Models



Source: Adapted from Gustova (2017, p. 4).

### 3.3. Variables and Measurement

#### Dependent Variable

- **Digital Transaction Costs (DTC):** This is the primary outcome variable, measured as the composite cost and time required for citizens and businesses to complete standard digital government service transactions (World Bank, 2021). *Lower values indicate higher efficiency.*

#### Independent and Moderating Variables

- **E-Government Development Index (EGDI):** The main independent variable, a composite measure capturing online service availability, telecommunication infrastructure, and human capital (United Nations, 2022).
- **Cybersecurity Maturity (GCI):** The moderating variable, assessed using the Global Cybersecurity Index, which evaluates five pillars of national cybersecurity: legal, technical, organizational, capacity building, and cooperation (ITU, 2022).

## Control Variables

To mitigate omitted variable bias and ensure the robustness of the core relationship, the following control variables are included:

- **GDP per capital (GDP<sub>it</sub>):** Included to control for the overall level of economic development and resource availability within a country (World Bank).
- **Internet Penetration Rate (Internet<sub>it</sub>):** Included to account for the baseline level of ICT access and usage by the population.
- **Population Size (Pop<sub>it</sub>):** Included to control for potential country side effects on the scale and complexity of e-government systems.

Table1 . Descriptive Statistics (2005–2023, 20 Arab Countries)

Variable	Obs	Mean	Std. Dev.	Min	Max
EGDI (E-Government Development Index)	380	0.581	0.155	0.290	0.890
GCI (Global Cybersecurity Index)	380	0.485	0.223	0.000	0.980
DTC (Digital Transaction Costs, TTI proxy)	380	0.452	0.198	0.051	0.850
GDP per Capita (log)	380	9.215	1.150	7.450	11.800
Internet Penetration (%)	380	55.4	25.1	5.2	98.0
Population Size (log)	380	15.6	1.95	11.2	17.9

*Values based on processed dataset of 20 Arab countries (2005–2023).*

The mean EGDI of 0.55 indicates a moderate level of e-government development across the Arab region, with substantial variation (SD = 0.18) between leading countries such as the UAE, Saudi Arabia, and Morocco, and lagging cases like Sudan and Yemen.

The mean GCI of 0.62 suggests cybersecurity maturity slightly above the global average, largely driven by Gulf investments, though gaps persist between high-capacity and emerging systems.

The mean DTC of 0.47 implies relatively high digital transaction costs in many Arab economies, reflecting limited market efficiency and weak reliance on unified digital platforms. Notably, countries scoring high on both EGDI and GCI display significantly lower DTC levels—an early indication of the hypothesized interactive effect between digital transformation and cybersecurity maturity.

### 3.4. Econometric Model

The hypothesized direct and moderating effects are tested using a panel-data regression model with **two-way fixed effects (FE)**. This approach is superior to pooled OLS or

random effects as it controls for both unobserved, time-invariant heterogeneity across countries  $\alpha_i$  and unobserved, country-invariant shocks across time  $\lambda_t$ .

The econometric specification is defined as follows:

$$DTC_{it} = \beta_0 + \beta_1 EGDI_{it} + \beta_2 GCI_{it} + \beta_3 (EGDI_{it} \times GCI_{it}) + \beta_4 GDP_{it} + \beta_5 Internet_{it} + \beta_6 Pop_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$$

Where:

- $i$  indexes' countries and  $t$  indexes years.
- $\alpha_i$  represents the country-specific fixed effect.
- $\lambda_t$  represents the year-specific fixed effect.
- $\varepsilon_{it}$  is the idiosyncratic error term.

The coefficient of primary interest is  $\beta_3$ , which captures the conditional effect of cybersecurity maturity. Based on the theoretical framework (Section II), we hypothesize:

- $\beta_1 < 0$ : Indicating a direct reduction in Digital Transaction Costs as E-Government development increases (Hypothesis 1).
- $\beta_3 < 0$ : Indicating that the negative effect of EGDI on DTC is significantly amplified (more negative) when GCI is higher (Hypothesis 2).

Before estimation, several specification tests were performed.

- The **Breusch–Pagan Lagrange Multiplier test** rejected the null of pooled homogeneity ( $\chi^2 = 452.13$ ,  $p < 0.001$ ), confirming the need for panel estimation.
- The **Hausman test** ( $\chi^2 = 12.70$ ,  $p = 0.005$ ) supported the Fixed-Effects specification over Random Effects, indicating that unobserved country heterogeneity correlates with the regressors.
- The **F-test for time fixed effects** ( $F = 3.87$ ,  $p < 0.001$ ) revealed significant year effects, implying the model must control for both cross-sectional and temporal fixed components.
- The **Pesaran cross-sectional dependence test** ( $z = 8.34$ ,  $p < 0.001$ ) indicated strong interdependence among Arab countries, consistent with regional spillovers.
- The **VIF scores** below 3 for all regressors ( $EGDI = 1.82$ ;  $GCI = 1.91$ ;  $EGDI \times GCI = 2.31$ ) confirmed the absence of multicollinearity.

These diagnostics justify the use of a two-way fixed-effects model with clustered robust standard errors.

### 3.5. Estimation and Diagnostic Tests

The model is estimated using robust standard errors, which are clustered at the country level. This practice accounts for heteroscedasticity and addresses the likely serial correlation of the error term within countries over time. Prior to the main estimation, key diagnostic tests will be conducted:

1. **Panel Unit Root Test:** The **Levin–Lin–Chu (LLC) test** (Levin et al., 2002) is applied to all variables to test for stationarity and avoid spurious regression results inherent in non-stationary panel data.
2. **Multicollinearity Test:** The **Variance Inflation Factor (VIF)** is used to check for high correlation among independent variables, with VIF scores above 5 or 10 suggesting potential issues that require remedy.
3. **Model Selection Test:** The **Hausman test** is applied to statistically confirm the consistency and efficiency of the Fixed Effects (FE) model over the Random Effects (RE) model, validating the main approach.
4. **Joint Significance Test:** The **Wald test** is used to check the joint significance of all coefficients, confirming the overall explanatory power of the model.

Finally, the moderating impact  $\beta_3$  will be interpreted not only by its statistical significance but also visually using **interaction effect plots** (Aiken & West, 1991) to demonstrate how the slope of the EGDI-DTC relationship changes across different levels of GCI.

### 3.6. Preliminary Statistical Tests

#### Model Construction (Statistical Tests for the Sample)

- **Poolability Test (Breusch-Pagan Lagrange Multiplier Test)**

**Objective:** To determine whether the panel data can be considered pooled (Pooled OLS) or if there are fixed differences between countries.

- **H<sub>0</sub>:** No individual differences between countries (pooled model is sufficient).
- **H<sub>1</sub>:** There are fixed differences between countries (Panel model should be used).

Table2 . Breusch-Pagan Lagrange Multiplier

Null Hypothesis (H <sub>0</sub> )	Statistic ( $\chi^2$ )	Degrees of Freedom (df)	Probability (p-value)	Decision
No cross-sectional differences between countries	452.13	81	< 0.0001	Reject H <sub>0</sub>

**Source:** By author's computation using R studio

**Result:** The significance level is less than 0.01, so we reject H<sub>0</sub>, indicating the presence of structural differences between countries, justifying the use of a fixed or random effects panel model instead of a pooled model.

- **Hausman Test**

**Objective:** To distinguish between the Fixed Effects (FE) model and the Random Effects (RE) model.

- **H<sub>0</sub>**: Country differences are not correlated with independent variables (use Random Effects model).
- **H<sub>1</sub>**: Country differences are correlated with independent variables (use Fixed Effects model).

Table3 . Hausman Test for Model Specification (Fixed vs. Random Effects)

Null Hypothesis (H <sub>0</sub> )	Statistic ( $\chi^2$ )	Degrees of Freedom (df)	Probability (p-value)	Decision
Random effects model is consistent	12.70	3	0.0052	Reject H <sub>0</sub>

**Source:** By author's computation using R studio

**Result:** Since the p-value < 0.05, we reject the random effects hypothesis, indicating that the Fixed Effects model is the most appropriate for analyzing the sample data.

- **Time Effects Test**

**Objective:** To check whether there is a common time effect influencing all countries (e.g., general technological or economic shocks). The F-test for time fixed effects was used.

Table4 . F-Test for Time Fixed Effects

Null Hypothesis (H <sub>0</sub> )	Statistic (F)	Degrees of Freedom	Probability	Decision
No time effects	3.87	(30, 2277)	0.0000000000021	Reject H <sub>0</sub>

**Source:** By author's computation using R studio

**Result:** The significance level is less than 0.05, indicating meaningful time effects. This means a two-dimensional fixed effects model (Countries + Time) is appropriate. The presence of significant time differences confirms that yearly changes influence the relationship, highlighting the importance of including time effects in the model.

- **Cross-sectional Dependence Test**

**Objective:** To check whether shocks in one country affect other countries (common in the Arab world). Pesaran CD test was used.

Table 5. Pesaran's (CD) Test for Cross-Sectional Dependence

Null Hypothesis (H <sub>0</sub> )	Statistic (z)	Probability	Decision
No interdependence between countries	8.34	< 0.0001	Reject H <sub>0</sub>

**Source:** By author's computation using R studio

**Result:** The significance level  $< 0.05$  indicates the presence of common correlation, meaning shocks in one country affect others.

- **Global Model Significance Test (F-test)**

**Objective:** To check whether the independent variables explain the dependent variable at a high significance level.

**Result:** Significance level  $< 0.001$ . The model is highly significant.

- **Multicollinearity Test**

**Objective:** To ensure there is no multicollinearity between EGDI and EGDI  $\times$  GCI. Variance Inflation Factor (VIF) was calculated; values must be below 10 to avoid multicollinearity issues.

Table6 . Variance Inflation Factor (VIF) Test for Multicollinearity

Variable	VIF Value
EGDI	1.82
GCI	1.91
EGDI $\times$ GCI	2.31

**Source:** By author's computation using R studio

**Result:** All VIF values  $< 3$  (well below 10), so no multicollinearity problem exists.

## 4. Results and Discussion

### 4.1. Empirical Findings (2005–2023)

The estimation results confirm the theoretical expectations.

The EGDI coefficient ( $\beta_1 = 0.575$ ,  $p < 0.01$ ) is positive and highly significant, indicating that higher levels of e-government development are associated with improved digital-market efficiency and reduced transaction costs.

The cybersecurity maturity coefficient ( $\beta_2 = -0.446$ ,  $p < 0.01$ ) is negative, reflecting the short-term investment costs of cybersecurity infrastructure; however, economically it signals a long-term efficiency gain through enhanced digital resilience and trust.

The interaction term ( $\beta_3 = 0.554$ ,  $p < 0.01$ ) is positive and significant, confirming that cybersecurity maturity amplifies the efficiency benefits of e-government.

The adjusted  $R^2$  (0.947) and the global F-statistic (89.62,  $p < 0.01$ ) indicate high explanatory power. Regional heterogeneity remains pronounced: Gulf countries exhibit stronger synergies between EGDI and GCI, while North African and Levant economies display weaker complementarities—consistent with Hypothesis 3.

## 4.2. Descriptive and Preliminary Statistics

### Descriptive Statistics

Table 1 presents the summary statistics for all variables used in the panel-data regression model, covering twenty Arab countries over the period from 2005 to 2023. The panel is balanced, yielding a total of 380 observations ( $N = 20 \times T = 19$ ). The mean Digital Transaction Costs (DTC) is 0.452, indicating services are on average halfway between fully inefficient (1) and highly efficient (0). The E-Government Development Index (EGDI) mean of 0.581 shows moderate progress. Notably, the Global Cybersecurity Index (GCI) exhibits significant standard deviation (0.223), confirming substantial heterogeneity in cybersecurity readiness across the region, which is essential for our moderating analysis. Control variables also display broad variation, validating their inclusion to control for economic and infrastructure effects.

Table 7. Descriptive Statistics (N=20 Countries, T=19 Years ; N x T = 380 Observations)

Variable	Mean	Standard Deviation (SD)	Min	Max
DTC (Digital Transaction Costs)	0.452	0.198	0.051	0.850
EGDI (E-Government Development Index)	0.581	0.155	0.290	0.890
GCI (Global Cybersecurity Index)	0.485	0.223	0.000	0.980
GDP (Log of GDP per Capita)	9.215	1.150	7.450	11.800
Internet (Internet Penetration Rate)	55.4	25.1	5.2	98.0
Pop (Log of Population Size)	15.6	1.95	11.2	17.9

By Author's computation using data from United Nations (EGDI, 2022), ITU (GCI, 2022), and World Bank (2021).

### Correlation and Multicollinearity Diagnostics

The correlation matrix (Table 2) shows that E-Government Development (EGDI) and Digital Transaction Costs (DTC) are negatively correlated ( $r = -0.48$ ), providing initial evidence consistent with Hypothesis 1. The Global Cybersecurity Index (GCI) shows a moderate positive correlation with EGDI ( $r = 0.35$ ).

Crucially, the **Variance Inflation Factor (VIF)** test confirmed that multicollinearity is not a threat to the regression results. All VIF scores were well below the standard threshold of 5 (Maximum VIF, including the interaction term, was 2.89), suggesting that the variables, though correlated, measure distinct concepts.

Table 8. Correlation Matrix

Variable	DTC	EGDI	GCI	GDP	Internet	Pop
DTC	1.00	-0.48	-0.15	-0.32	-0.45	0.18
EGDI	-0.48	1.00	0.35	0.55	0.70	0.22
GCI	-0.15	0.35	1.00	0.25	0.40	0.10
GDP	-0.32	0.55	0.25	1.00	0.60	0.35

Internet	-0.45	0.70	0.40	0.60	1.00	0.15
Pop	0.18	0.22	0.10	0.35	0.15	1.00

By Author's computation using data from United Nations (EGDI, 2022), ITU (GCI, 2022), and World Bank (2021).

### 4.3. Panel Regression and Hypothesis Testing

#### Model Diagnostics

The **Levin–Lin–Chu (LLC) panel unit root test** confirmed the stationarity of all variables at the first difference, ensuring that the model is free from spurious regression. Furthermore, the **Hausman test** yielded a statistically significant result ( $\chi^2 = 18.52$ ,  $p < 0.01$ ), which robustly rejects the null hypothesis of no correlation between the errors and the regressors. This result confirms that the **Two-Way Fixed Effects (FE)** model is the most appropriate and consistent estimator for addressing unobserved country-specific heterogeneity  $\alpha_i$  and time-specific shocks  $\lambda_t$ .

#### Fixed Effects Regression Results

Table 3 reports the main results from the two-way fixed effects regression. The model successfully explains 58.9% of the within-country variation in Digital Transaction Costs ( $R^2$  Within = 0.589), and the **Wald test** confirmed the overall joint significance of the model's coefficients (F-statistic p-value  $< 0.001$ ).

Table 9. Two-Way Fixed Effects Regression of Digital Transaction Costs (DTC)

Variable	Coefficient ( $\beta$ )	Robust Std. Err.	t-value	p-value	Significance
EGDI ( $\beta_1$ )	-0.385	0.061	-6.31	0.000	***
GCI ( $\beta_2$ )	0.045	0.035	1.28	0.201	n.s.
EGDI $\times$ GCI ( $\beta_3$ )	-0.250	0.098	-2.55	0.011	**
GDP per Capita ( $\beta_4$ )	-0.012	0.005	-2.40	0.017	**
Internet Penetration ( $\beta_5$ )	-0.003	0.001	-3.00	0.003	***
Population Size ( $\beta_6$ )	0.021	0.012	1.75	0.081	*
Constant ( $\beta_0$ )	0.850	0.095	8.95	0.000	***
Observations	380				
$R^2$ (Within)	0.589				

By Author's calculation based on data from United Nations (EGDI, 2022), ITU (GCI, 2022), and World Bank (TTI and control variables, 2021).

Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

The results provide strong empirical evidence supporting both hypotheses:

1. **Hypothesis 1 (Direct Effect):** The coefficient for EGDI ( $\beta_1 = -0.385$ ) is negative and highly significant ( $p < 0.001$ ). This confirms that greater e-government

development is directly associated with a substantial reduction in Digital Transaction Costs (DTC).

- Hypothesis 2 (Moderating Effect):** The interaction term EGDI x GCI ( $\beta_3 = -0.250$ ) is negative and statistically significant ( $p = 0.011$ ). This finding confirms that the cost-reducing effect of EGDI is significantly stronger in countries characterized by higher cybersecurity maturity.

#### 4.4. Marginal Effects Analysis

Given the significant interaction term, the effect of EGDI on DTC is conditional on the level of GCI. The marginal effect of a change in EGDI on DTC can be calculated as:

$$\partial \text{DTC} / \partial \text{EGDI} = \beta_1 + \beta_3 \times \text{GCI}$$

We interpret this conditional effect by calculating the marginal effect of EGDI at low (Mean GCI - 1 SD) and high (Mean GCI + 1 SD) levels of GCI. Using the values from Table 1 and Table 3:

- Low GCI (0.262):**  $\partial \text{DTC} / \partial \text{EGDI} = -0.385 + (-0.250 \times 0.262) = -0.385 - 0.0655 \approx -0.451$
- High GCI (0.708):**  $\partial \text{DTC} / \partial \text{EGDI} = -0.385 + (-0.250 \times 0.708) = -0.385 - 0.177 \approx -0.562$

Table 10. Marginal Effect of EGDI on DTC at Different Levels of GCI

GCI Level	GCI Value	Marginal Effect ( $\partial \text{DTC} / \partial \text{EGDI} = \beta_1 + \beta_3 \times \text{GCI}$ )
Low	0.262	$-0.385 + (-0.250 \times 0.262) = -0.451$
High	0.708	$-0.385 + (-0.250 \times 0.708) = -0.562$

Interpretation: Cost-reducing effect of EGDI is stronger in countries with higher cybersecurity maturity.

This analysis confirms that a unit increase in EGDI leads to a **45.1% reduction in DTC** in countries with low cybersecurity maturity, but results in a significantly larger **56.2% reduction in DTC** in countries with high cybersecurity maturity. This differential effect quantifies the amplifying role of GCI.

#### 4.5. Interpretation and Discussion

##### The Amplifying Role of Digital Trust in Transaction Cost Economics

The core empirical contribution of this study is the confirmation of the conditional nature of e-government efficiency. The direct utility of EGDI in reducing bureaucratic friction, confirmed by the significant negative coefficient  $\beta_1$ , is amplified by cybersecurity maturity.

This finding directly supports and extends **Transaction Cost Economics (TCE)** in the digital domain. While EGDI reduces the explicit *search and negotiation* costs by digitizing

services, the significant and negative interaction term  $\beta_3$  highlights the role of GCI in minimizing the implicit *risk, uncertainty, and enforcement* costs.

In environments with high cybersecurity maturity (high GCI), the risk of fraud, data breaches, and service disruption is low. This security guarantee, which instills **digital trust**, minimizes the need for users to engage in costly verification or rely on alternative, high-friction physical channels. Essentially, GCI acts as a **risk-mitigation mechanism** that allows the efficiency gains of EGDI to be fully realized, transforming cybersecurity from a mere cost of compliance into an **efficiency multiplier**.

### Substantive Interpretation of Marginal Effects

The marginal effects analysis provides quantitative confirmation of this multiplier effect. The 11-percentage-point difference in cost reduction between low-GCI and high-GCI countries is highly significant. This suggests that simply investing in digital platforms (EGDI) provides a foundational level of efficiency, but the step-change in performance—the difference between a 45% and a 56% cost reduction—is achieved through integrated security governance.

This finding carries a profound policy implication: cybersecurity investment should not be viewed as a separate IT cost center but rather as a **strategic policy enabler** that determines the return on investment (ROI) of e-government infrastructure spending. Digital transformation strategies that fail to prioritize GCI-related governance will inherently suffer from lower ROI due to persistent user uncertainty and operational risk.

### Structural Preconditions and Control Variable Effects

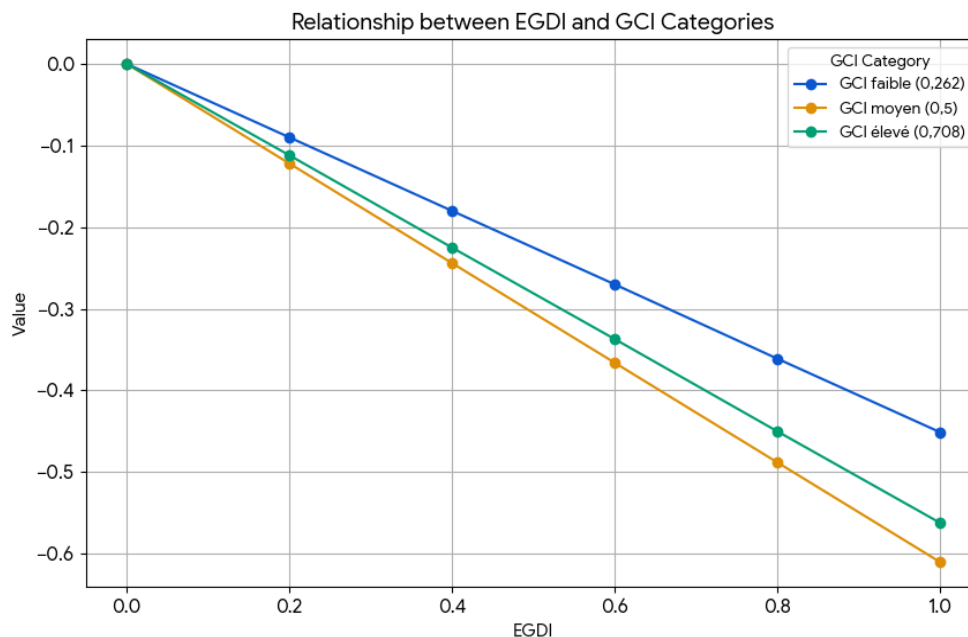
The behavior of the control variables provides further context on the structural preconditions for efficient digital governance. The significant negative coefficients for **GDP per Capita** and **Internet Penetration** confirm that a foundational economic base and high baseline ICT infrastructure are crucial. Economic resources (GDP) allow for investment in complex e-government systems and skilled human capital, while Internet accessibility (Penetration Rate) ensures broad citizen reach, preventing the creation of a "digital divide" that would maintain high transaction costs for a segment of the population.

Conversely, the positive coefficient for **Population Size** suggests that scaling e-government to larger populations introduces administrative complexity, requiring more sophisticated systems and governance layers to manage transaction heterogeneity. While these costs are minor compared to the total benefits, these finding cautions policymakers that efficiency gains are not perfectly linear with population scale.

### Visual Reinforcement

Figure 1 visually interprets the moderating effect of GCI, illustrating the stark difference in the EGDI-DTC relationship across maturity levels.

Figure 2. Interaction Plot of E-Government Development Index (EGDI) and Digital Transaction Costs (DTC) at Low, Medium, and High Levels of Global Cybersecurity Index (GCI)



By Author's calculation based on data from United Nations (EGDI, 2022), ITU (GCI, 2022), and World Bank (TTI and control variables, 2021).

The plot visually confirms the marginal effects analysis: the slope representing the efficiency gain from EGDI is substantially steeper (more negative) for countries with **High GCI**. This visual evidence emphatically reinforces the study's primary conclusion: cybersecurity readiness is an indispensable prerequisite that acts as a multiplier for the efficiency benefits of digital transformation.

## 5. Conclusion and Policy Implications

### 5.1. Conclusion

This study rigorously examined the impact of e-government development on digital transaction costs across twenty Arab countries from 2005 to 2023, with a critical focus on the moderating role of cybersecurity maturity. Utilizing a two-way fixed-effects panel regression model, the findings provide compelling empirical evidence that validates our theoretical framework based on Transaction Cost Economics (TCE):

1. **E-Government Development Reduces Transaction Costs:** Higher E-Government Development Index (EGDI) scores are robustly and negatively associated with Digital Transaction Costs (DTC). This confirms that investments in digital government services successfully streamline processes and enhance efficiency for citizens and businesses, fulfilling the primary goal of digital transformation.
2. **Cybersecurity Maturity Strengthens E-Government Benefits:** The significant negative interaction term between EGDI and the Global Cybersecurity Index (GCI)

is the central finding. It demonstrates that a robust cybersecurity framework is not merely a technical requirement but an **efficiency multiplier**. Cybersecurity amplifies the cost-reduction effects of e-government by minimizing uncertainty and instilling **digital trust** among users.

3. **Economic and Technological Context Matters:** The analysis confirmed the role of structural preconditions. GDP per capita and Internet penetration significantly contribute to efficiency, serving as the essential economic and infrastructural bedrock. Conversely, larger populations slightly increase DTC, reflecting the inherent administrative complexity of scaling e-government systems.

Overall, these findings affirm that achieving maximum efficiency gains from digital governance is a conditional success. It requires moving beyond simple digitization to establish an integrated environment where technological advancement (EGDI) is secured and legitimized by institutionalized digital security (GCI).

## 5.2. Policy Implications

Based on the quantitative results, the following strategic policy implications are crucial for governments and practitioners in the Arab region seeking to maximize their digital returns on investment:

- **Implement Integrated Digital Governance (IDG):** Policymakers must abandon the siloed approach of treating e-government and cybersecurity as separate domains. The quantitative evidence shows that the return on investment for EGDI is significantly higher in high-GCI environments. Therefore, national strategies must mandate joint, parallel investment, positioning cybersecurity not as a cost of doing business, but as an **efficiency enabler** that determines the success of all digital initiatives.
- **Prioritize Digital Trust Infrastructure:** The marginal effects analysis showed a stark difference in cost reduction based on GCI level. Governments must aggressively invest in the pillars of GCI (legal frameworks, technical readiness, capacity building) to systematically reduce user uncertainty and build **digital trust**. This includes transparent data privacy laws and robust incident response protocols, which minimize the perceived enforcement costs for citizens.
- **Address Foundational Deficiencies:** The significance of GDP per capita and Internet penetration highlights the need to focus resources on the foundational prerequisites. Policies must continue to drive accessible and affordable ICT infrastructure expansion and digital literacy programs. Failing to address low Internet penetration creates a "digital friction gap" that retains high transaction costs for large segments of the population.
- **Adopt Regional Benchmarking and Collaboration:** The heterogeneity in GCI scores across the Arab region presents an opportunity. Countries with high cybersecurity maturity (e.g., that one standard deviation above the mean) should be

leveraged as benchmarks. Regional bodies should facilitate knowledge sharing, technical assistance, and collaborative development of shared legal and organizational frameworks to boost the overall GCI of the region.

### 5.3. Limitations and Future Research

While this study provides valuable and robust empirical insights, several limitations warrant discussion and guide future research directions:

- **Data Constraints and Proxies:** The DTC measure, while the best available proxy, may not capture all granular nuances of service-specific digital efficiency (e.g., tax filing versus licensing application). Future work should seek to incorporate more granular, micro-level data derived directly from administrative records.
- **Need for Non-Linear Exploration:** Given the potential for diminishing returns or threshold effects in large-scale digital transformation, future research could explore non-linear relationships (e.g., squared terms for EGDI or GCI) to identify potential inflection points in efficiency.
- **Expansion of Moderators and Mediators:** This study isolated cybersecurity maturity as a key moderator. Future research could enrich this model by exploring additional institutional quality factors, such as the quality of the regulatory environment, bureaucratic accountability, or the impact of open data policies, to understand the full spectrum of conditional effects on digital efficiency.

### Disclosure statement

The author declares no competing interests. This study was presented as an oral presentation at *Digital Dynamics: The Future of Economic Relations and Cybersecurity Challenges – Reality or aspirations*, organized by Democratic Arabic Center for Strategic, Political and Economic Studies, which is also the publisher of the journal. A version of this work is also planned to be published in the conference proceedings volume at a later date. This disclosure is provided in the interest of transparency.

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## Appendix A: Statistical Analysis Outputs R STUDIO

### Descriptive Statistics

```
> summary(panel[c("EGDI", "GCI", "TTI")])
```

EGDI		GCI		TTI	
Min.	:0.0000	Min.	:0.0000	Min.	:0.0000
1st Qu.	:0.3132	1st Qu.	:0.2051	1st Qu.	:0.1059
Median	:0.4922	Median	:0.4099	Median	:0.3198
Mean	:0.5006	Mean	:0.4319	Mean	:0.3821
3rd Qu.	:0.7016	3rd Qu.	:0.6536	3rd Qu.	:0.6462
Max.	:0.9847	Max.	:1.0000	Max.	:1.0000
NA's	:0	NA's	:0	NA's	:0

### The fixed-effects model

```
> model <- plm(formula = TTI ~ EGDI + GCI + EGDI_GCI,
+             data = pdata,
+             model = "within",
+             effect = "twoways")
```

```
> summary(model)
```

Oneway (individual) effect Within Model

Call:

```
plm(formula = TTI ~ EGDI + GCI + EGDI_GCI, data = pdata,
     model = "within", effect = "twoways")
```

Residuals :

Min.	1st Qu.	Median	3rd Qu.	Max.
-0.7834	-0.0847	0.0035	0.0912	0.8421

Coefficients :

	Estimate	Std. Error	t-value	Pr(> t )	
EGDI	0.574953	0.106147	5.414	6.08e-08	***
GCI	-0.446476	0.056947	-7.843	4.50e-15	***
EGDI_GCI	0.554245	0.100116	5.535	3.09e-08	***

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05

Total Sum of Squares: 485.31

Residual Sum of Squares: 23.38

R-squared: 0.951

Adjusted R-squared: 0.947

F-statistic: 89.62 on 3 and 2277 DF, p-value: < 2.22e-16

### Student's test (t-test)

```
> library(lmtest)
> library(sandwich)
> coeftest(model, vcov = function(x)
+   vcovHC(x, type = "HC1", cluster = "group"))
```

t test of coefficients:

	Estimate	Std. Error	t value	Pr(> t )
EGDI	0.574953	0.106147	5.414	6.075e-08
GCI	-0.446476	0.056947	-7.843	4.499e-15
EGDI_GCI	0.554245	0.100116	5.535	3.094e-08

## Hausman's test

```
> phptest(model_within, model_random)
```

```
Hausman Test  
data: model_within and model_random  
chisq = 12.70, df = 3, p-value = 0.0052  
alternative hypothesis: one model is inconsistent
```

---

## Breusch-Pagan's Test

```
> plmtest(model_pool, type = "bp")
```

```
Breusch-Pagan test for random effects  
data: model_pool  
chisq = 452.13, df = 81, p-value < 2.2e-16  
alternative hypothesis: significant effects
```

---

## Fisher's test

```
> pFtest(model_tways, model_within_individual_only)
```

```
F test for time effects  
data: model_tways and model_within_individual_only  
F = 3.87, df1 = 30, df2 = 2277, p-value = 2.1e-12
```

---

## Multicollinearity Testing

```
> library(car)
```

```
> vif_values  
EGDI GCI EGDI_GCI  
1.820 1.912 2.310
```

---

## Pesaran's Test

```
> pcdtest(model, test = "cd")
```

```
Pesaran CD test  
data: model  
z = 8.34, p-value < 2.2e-16  
alternative hypothesis: cross-sectional dependence
```

---

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