THE ENHANCEMENT OF CYBERSECURITY AND ECONOMIC GROWTH: PANEL DATA ANALYSIS

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Declaration*

Abstract

This study aims to comprehensively analyze how economic growth influences cybersecurity investments and policies in contemporary economies where digitalization is spreading at an accelerated pace. In an era characterized by mounting direct and indirect expenses stemming from cyber threats to the global economy, there is a pressing need to elucidate the correlation between cybersecurity and macroeconomic performance quantitatively. The present study examines the relationship between cybersecurity capacity and economic growth using a multidimensional nested panel data analysis method, which utilizes annual data for 171 countries in the IDI. The study also reveals that cybersecurity isn't just a technical issue but one of the main determinants of macroeconomic stability. In nations undergoing digital transformation, cybersecurity infrastructure is as strategically significant as traditional infrastructure investments. This study examines the relationship between economic growth and cybersecurity. The findings suggest that there is a statistically significant and positive relationship between cybersecurity and economic growth. The objective of this study is to provide policymakers with strategic recommendations by highlighting the critical role of economic growth in cybersecurity, supported by quantitative data.

Keywords: Cybersecurity, economic growth, panel data analysis, digital economy, macroeconomic effects.

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Introduction

In the contemporary era, characterized by the accelerated adoption of digital technologies, the drivers of economic growth are undergoing a profound transformation. In addition to factors such as physical capital, human capital, and technological development, which are prominent in traditional growth models, a new one has now been added: cybersecurity. In the contemporary era of increasing digitalization, economic activities have become increasingly dependent on information and communication technologies. This paradigm shift has transformed cybersecurity from a purely technical issue to a strategic element that has a direct impact on economic performance. In this context, systematic analysis of the effects of cybersecurity on economic growth is of great importance at both academic and political levels (Rudnev et al., 2024; Ünver, 2024; Ahmed, 2021, pp. 413, 416-417).

It is becoming increasingly evident that global cyberattacks represent a threat not only to digital systems but also to entire economic cycles (Kırtıllı, 2019). Attacks in strategic areas, such as finance, healthcare, energy, and critical infrastructure, can lead to the cessation of production, disruption of services, a decline in consumer confidence, and an increased risk perception among international investors. A prime example of this phenomenon is the WannaCry ransomware attack of 2017, which not only disrupted information systems but also public health services, production facilities, and transportation systems, resulting in economic losses amounting to billions of dollars. According to McAfee, the global cost of cybercrime has exceeded $1.5 trillion. This compelling data unveils the direct impacts of cybersecurity on economic stability (Zaiats & Kytsyuk, 2024; Miliefsky, 13.03.2025; ISACA, 2022).

It is essential to adopt a nuanced perspective on cybersecurity, one that transcends the conventional defence-based approach. Instead, it should be conceptualized as a proactive investment domain that fosters growth and development. In this context, three fundamental mechanisms have been identified as explanatory of the relationship between cybersecurity and growth. These measures have been shown to enhance the investment environment, ensure uninterrupted production processes, and safeguard innovation capacity (Akyeşilmen, 2022). The presence of secure digital infrastructures has been demonstrated to be a contributing factor to the observed increase in foreign direct investments, particularly within the technology and finance sectors. The 30% increase in investments in the technology sector following Israel's national cybersecurity strategy implementation in 2018 provides concrete support for this situation (Benaichouba et al., 2024, pp. 3-7; Falevich, 2018). Conversely, IBM Security (2023) data indicates that the average cyberattack results in approximately 200 hours of operational downtime and losses exceeding $3.5 million for businesses, directly impacting total factor productivity. Furthermore, the preponderance of digital infrastructure in R&D underscores the indispensability of cybersecurity for sustaining innovation processes (IBM Security, 2023). The primary objective of this study is to ascertain the ways and the extent to which an augmentation in cybersecurity capacity affects economic growth, employing panel data analysis as a methodological framework. The main questions of the study are shaped within the following framework: (1) Do cybersecurity investments significantly and positively affect economic growth? (2) How does this effect differ between developed and developing countries? The analyses conducted in line with these questions are also supported by heterogeneity tests, and the behavioral patterns of different country groups in the cybersecurity-growth relationship are comparatively evaluated. The contribution of the study to the existing literature can be summarized as follows. This study, which encompasses 171 countries based on IDI data, has developed a comprehensive cybersecurity index. In addition, it has empirically tested how the structural differences between developed and developing country groups modify the effect of cybersecurity on economic growth.

Literature Review

The relationship between cybersecurity and economic growth has emerged as an interdisciplinary field of research with the transformation created by digitalization in global economies. In the extant literature, three fundamental theoretical approaches have been advanced to elucidate this relationship, namely, endogenous growth theory, institutional economics and network effects, and the systemic risk approach. The extant literature on this subject posits that cybersecurity exerts a dual effect on economic growth, both direct and indirect. However, studies examining the relationship between ICT and economic growth emphasize the critical role of cybersecurity in this process (Albimana & Sulongb, 2018).

The theory of endogenous growth posits that technological progress is the primary catalyst for economic growth. In this context, cybersecurity is a vital element in terms of protecting the stock of knowledge and sustaining innovation processes. The Estonian case demonstrates that investments in cybersecurity can yield an annual growth rate of 1.2% in the digital economy (Skierka, 2022). Furthermore, studies examining the contribution of ICT to economic growth (Dewan & Kraemer, 2000; Ahmed & Ridzuan, 2013) have revealed that technological infrastructure increases efficiency, but the lack of cybersecurity measures can reduce this effect. Albiman and Sulong (2018) and Suzuki (2024) have asserted that, within the paradigm of network effects theory, the proliferation engendered by digitalization can only be perpetuated through the implementation of security measures.

Institutional economics theory (North, 1987) posits that the presence of secure digital infrastructure is conducive to economic growth by virtue of the manner in which it protects property rights and serves to reduce transaction costs. Regulations such as the Cybersecurity Information Sharing Act (CISA) in the United States have aimed to reduce the potential impact of cyberattacks and strengthen overall market confidence by increasing the sharing of cyber threat information between the public and private sectors (Yang et al., 2020). A body of research has been conducted that examines the impact of ICT infrastructure on growth (Pradhan et al., 2022). The findings of these studies have emphasized the critical role of institutional regulations on financial stability and investment climate. As posited by Singh and Alshammari (2020), the absence of adequate digital security policies in developing countries serves to curtail the potential for ICT to exert its impact on growth.

In accordance with Metcalfe's Law, the proliferation of digital networks has been demonstrated to engender economic value, whilst concomitantly giving rise to an augmentation in cyber risks. A notable example of this phenomenon is the 2018 Aadhaar data breach in India, which compromised the personal data of approximately 1.1 billion individuals. This incident has been categorized as one of the most significant data breaches ever documented, yet the precise total of the confirmed economic loss resulting from this breach remains ambiguous (Pimenta et al., 2023). A body of research has been conducted on the impact of ICT on growth (Niebel, 2018; Appiah-Otoo & Song, 2021). The findings of these studies indicate that cybersecurity investments have a beneficial effect on macroeconomic stability in developed countries. However, the effect is limited in developing countries due to a lack of infrastructure. Convergence Theory (Barro & Sala-i-Martin, 1992) posits that digital infrastructure and cybersecurity levels will converge across countries over time. However, subsequent theories (Stephens et al., 2008) contend that cyber threats necessitate a continuous adaptation process due to their dynamic nature.

The impact of investments in cybersecurity on economic growth is subject to variation depending on factors such as the development level of countries, their digital infrastructure, and their institutional capacity. A body of research has been conducted on the relationship between ICT and growth (Saba et al., 2024). The findings of this research indicate that the impact of cybersecurity investments in developing countries can only be observed after a certain digital infrastructure threshold is exceeded. Despite the confirmation provided by extant literature that cybersecurity supports economic growth, the effects of such measures are considered to be inadequate, particularly in the context of developing countries. A number of studies examining the relationship between ICT and growth (Shiu & Lam, 2008; Pradhan et al., 2016) have argued that the causality relationship is unclear, whereas others (Fernández-Portillo et al., 2020) have emphasized that ICT triggers growth and that the effect of this is strengthened by cybersecurity measures. Consequently, comparative studies that will be conducted by taking into account the digital infrastructure and institutional capacities of countries with panel data analyses will reveal the effect of cybersecurity on growth more clearly.

Method

This study examines the relationship between economic growth and IDI. 171 nations that are part of the ICT Development Index (IDI) are covered in this study for the period of 2023-2024. The focus on these years stems from the fact that the IDI, which was published between 2009 and 2017 by ITU, underwent significant changes in 2017. As a result of these changes, data limitations forced the index computation to be done for all countries as of 2023.

Some of the countries, namely Bhutan, Liberia, Liechtenstein, Monaco, Palestine, San Marino, Sierra Leone, the Syrian Arab Republic, Tonga, Venezuela, and Yemen, are excluded from the sample due to data limitations. In some of the mentioned countries, there are no data for GDP per capita, while in others, there are no available data for IDI**.** Predictions are made by using the multidimensional panel data analysis method. Table 1 presents the dataset used in this study.

Table 1. Data Set

Variables	Dimensions	Representation	Source
IDI	Country	μi	ITU Reports
GDP per capita			World bank
Europe, Asia- Pacific, Arab States, Africa, Common Wealth of Independent States, America	Region	γj	ITU Reports
	Time	λt	

The countries included in IDI are classified according to their geographic region. Unit dimensions presented in the table represent country, region, and time unit dimensions. Therefore, the overall trend of the groups created based on their geographic regions may be seen in addition to country effects. Yerdelen Tatoğlu (2016) used all of the specifications for unnested multidimensional panel data models proposed by different academics to build fixed and random effect estimators for nested multidimensional panel data models. The three-dimensional and two-effect panel data specification is shown in equation (1).

$$Y_{ijt} = \alpha + \beta X_{ijt} + \mu i + \gamma j + \lambda t + u_{ijt} \quad i=1,\ldots,N,\ j=1,\ldots M,\ t=1,\ldots T \qquad (1)$$

Here, Y_{ijt} represents the dependent variable, α represents the model fixed term, β represents the independent variable coefficient, X_{ijt} represents the independent variable, u_{ijt} represents the error term, and μi, γj, and λt represent country, region, and time unit effects, respectively.

Two distinct methods are used under the assumption of fixed effects: the within-group estimator and the least squares dummy variable estimator (LSDV). Because of multicollinearity, the findings of the LSDV estimator are biased and unable to reveal information about nested units within one another. In this study, the fixed-effects within-group estimators were used under the assumption of fixed effects. Equation (2) displays the within-group transformation for equation (1).

$$\left(Y_{ijt} - \overline{Y_i} - \overline{Y_j} - \overline{Y_t} + 2\bar{Y}\right) = \beta\left(X_{ijt} - \overline{X_i} - \overline{X_j} - \overline{X_t} + 2\bar{X}\right) + \left(u_{ijt} - \overline{u_i} - \overline{u_j} - \overline{u_t} - 2\bar{u}\right) \quad (2)$$

Here, $\bar{X}$ represents the overall average, $\overline{X_i}$ represents the average according to unit i, $\overline{X_j}$ represents the average according to unit j, $\overline{X_t}$ represents the average according to unit t, and similar representations are valid for the error term as well. The model loses all effects and fixed parameters due to the transformation. Using pooled ordinary least squares (OLS) to estimate equation (2) yields the fixed-effect within-group estimator for three-dimensional panel data models.

There are two alternative estimators in terms of random-effects, namely generalized OLS and the maximum likelihood estimator. Under the assumption of random effects, the maximum likelihood estimator has been employed in this study.

GDP per capita, which is the model's independent variable, is derived from World Bank data, while the IDI data, which is the dependent variable, is derived from ITU reports (ITU, 2023; ITU, 2024). The dimensions of the region consist of six groups: Europe, Asia-Pacific, Arab

States, Africa, the Commonwealth of Independent States, and the Americas. All variables are included in the model in the form of natural logarithms. The LR test is used to examine the existence of unit effects.

Table 2. Results of the LR Test

Null Hypothesis	LR Statistic	P Value
H0= μi=γj=λt=0	414.56	0.000
id(i)	333.69	0.000
region(j)	54.27	0.000
year (t)	0.17	0.3381

The LR test results are shown in Table 2. According to the results, the joint significance of each unit effect on the null hypothesis was rejected. To ascertain which effect is significant, each effect was investigated separately under the alternative hypothesis, which states that at least one unit effect is significant. The unit effects of country and region are statistically significant, whereas the unit effect of time is not, in terms of LR test results, which examine the separate significance of unit effects. In light of this information, the time unit effect was removed from the model in equation (1) in order to obtain the three-dimensional two-unit effect panel data model employed in this study and shown in equation (3).

$$\mathrm{LIDI}_{ijt} = \alpha + \beta\,\mathrm{LGDP}_{ijt} + \mu i + \gamma j + u_{ijt} \quad (3)$$

i=1,…..,N, j=1,…M , t=1,….T

In this case, all variable explanations are the same as above. The within-group transformation for the model in equation (3) is shown in equations (4) and (5).

$$\widetilde{\mathrm{LIDI}}_{ijt} = \mathrm{LIDI}_{ijt} - \overline{\mathrm{LIDI}_{i}} - \overline{\mathrm{YLIDI}_{j}} + \overline{LIDI} \quad (4)$$

$$\widetilde{\mathrm{LGDP}}_{ijt} = \mathrm{LGDP}_{ijt} - \overline{\mathrm{LGDP}_{i}} - \overline{\mathrm{LGDP}_{j}} + \overline{LGDP} \quad (5)$$

Under the assumption of fixed effects, the within-group estimators are generated by these transformations. $\overline{LIDI}$ represents the overall average, $\overline{\mathrm{LIDI}_{j}}$ represents the average according to unit j, $\overline{\mathrm{LIDI}_{i}}$ represents the average according to unit i, and $\widetilde{\mathrm{LIDI}}_{ijt}$ represent the within-group estimators. The transformation process and explanation for variable GDP are the same as IDI.

Findings

Fixed and random effects model estimations were performed following the selection of the panel data model to be employed in the analysis.

Table 3. Fixed Effects and Random Effects Estimator Results

	Fixed Effects – Within Group Estimator	F statistic	Random Effects - Maximum Likelihood Estimator	Wald Statistic
LGDP	0.2383***	2344.17***	0.1568***	217.58***
AIC	-667.2633		-557.1812	
BIC	-663.5013		-534.6089	

Note: ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

The results of the fixed and random effects estimators for the multidimensional panel data model are shown in Table 3. The Wald and F tests have been used to evaluate the models' overall significance for random-effect and fixed-effect estimators, respectively. Both the fixed effect within-group estimator and the random effect maximum likelihood estimator clearly show that GDP per capita has a positive and statistically significant impact on IDI. The findings indicate that economic development has a statistically significant and positive effect on IDI, with an increase in per capita GDP leading to an increase in IDI. A 1% increase in economic growth leads to approximately a 0.24% and 0.16% increase in the IDI according to fixed-effect and random-effect, respectively.

Table 4. Test of homoscedasticity, parameter heterogeneity and model selection.

Name of test	Test Statistics	p-value
Hausman test	218.85	0.000
Breush-Pagan/Cook-Weisberg test	265.28	0.000
S test (Swamy, 1970)	1892.62	0.000

The results of the parameter heterogeneity test, the model selection criteria, and the existence of heteroscedasticity are shown in Table 4. The Breusch-Pagan/Cook-Weisberg (1980-1983) test was used to determine the presence of heteroscedasticity. The parameter heterogeneity was tested by Swamy's (1970) S test. The null hypothesis was rejected, which demonstrated that the parameters are not homogeneous. The Hausman test is used for model selection. The alternative hypothesis, which states that the fixed effects model is consistent and the random effect model is inconsistent, was accepted based on the results of the Hausman test. A 1% rise in per capita income is roughly associated with a 0.24% increase in IDI, in terms of the results of the fixed effects estimator.

The results of the LR test demonstrate the impact of both the country and the region of the country. In addition, the results of the S test (Swamy, 1970) indicate parameter heterogeneity.

A two-dimensional panel data model estimation based on regions is made due to this heterogeneity. Europe (region 1), Africa (region 4), America (region 6), Arab countries (region 3), Asia and the Pacific (region 3), and the Commonwealth of Independent States (CIS) (region 5) are the six dimensions of the regional distinction.

Table 5. Two-Dimensional Panel - Fixed Effects and Random Effects Estimation Results According to Geographic Region

	Variables	Fixed Effects	Random Effects	Hausman Test Statistic	F Test Statistic	Wald Statistic
Region 1 (Europe)	LGDP	-0.1006	**0.0421*****	2.76*	1.37	45.82***
	constant	5.4993	**4.0656*****			
Region 2 (Asia-Pacific)	LGDP	0.0622	**0.1641*****	2.01	0.69	61.95***
	constant	3.7551***	**2.8547*****			
Region 3(Arab Countries)	LGDP	0.2947	**0.2125*****	0.03	0.33	41.00***
	constant	1.7133	**2.4245*****			
Region 4 (Africa)	LGDP	**1.4338*****	0.3416***	4.97**	8.52***	108.11***
	constant	**-6.7133***	1.3162***			
Region 5 (Commonwealth of Independent States)	LGDP	**0.4922*****	0.0339	13.03***	14.07***	1.05
	constant	**0.2499**	4.1635***			
Region 6 (America)	LGDP	0.0885**	**0.1328*****	1.72	5.56**	66.85***
	constant	3.5137***	**3.1053*****			

Note: The models shown in dark colour are the ones recommended according to the Hausman test statistics. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

The fixed effects and random effects estimators for the groups according to the region of countries are shown in Table 5. The fixed effect estimators have a negative sign for Europe and are statistically insignificant for the European region, Asia-Pacific, and Arab states. In addition, the random effects model estimators are statistically significant and have a positive sign for all regions. The model selection for each group was made by using the Hausman test statistic. The fixed effects estimations are consistent for the regions of Africa and the Commonwealth of Independent States, while the random effects estimator is effective for Europe, Asia-Pacific, Arab States, and the Americas regions, according to the Hausman test results. A one per cent increase in per capita income raises the ICT Development Index by 1.43% for African region countries and by 0.49% for the Commonwealth of Independent States region countries, depending on the country's geographic region. A 1% increase in per capita income causes the ICT Development Index to rise by 0.21% for Arab nations, 0.16% for the Asia-Pacific region, and 0.13% for American countries, respectively. The lower amount of increase is observed in European countries, where a 1% increase in GDP leads to only a 0.04% increase in IDI for this region's countries. The reason for this issue might be that the European region generally consists of developed countries, and compared to regions with developing and relatively less developed countries, financial development and stability have been achieved.

Conclusion

The present study aims to reconceptualize the multi-layered relationship between cybersecurity and economic growth in today's world, where digitalization is accelerating, by analyzing it theoretically and empirically. Cybersecurity, a factor that has thus far been overlooked by traditional growth theories, is considered a fundamental production factor. This is due to the fact that it both protects the fragile infrastructure of the information society and secures macroeconomic stability.

This study addresses cybersecurity from three different perspectives. Firstly, it is evident that cybersecurity investments have a significant impact on total factor productivity. This is due to the fact that such investments serve to preserve the integrity of digital infrastructure. Secondly, within the context of the institutional regulatory framework, the implementation of effective cybersecurity regulations has been demonstrated to reinforce investor confidence and to reduce market failures, thereby ensuring efficiency in resource allocation. Thirdly, with regard to systemic risk management, cybersecurity provides resilience against macroeconomic shocks and strengthens financial stability. In developing countries, the simultaneous development of these three dimensions is a critical requirement for the sustainability of the digital economy. The findings indicate that economic growth has a statistically significant and positive effect on cybersecurity, as expected theoretically.

The most fundamental contribution of this study is that it addresses the relationship between cybersecurity and economic growth as a multidimensional, reciprocal, and dynamic interaction network, rather than a unidirectional causality. This approach provides structural contributions to academic literature and national and international policy-making processes. This is particularly evident in economies undergoing digital transformation, where cybersecurity investments have become as important as traditional infrastructure investments. In some contexts, these investments have even assumed a more strategic role.

In the future, as digital technologies become more central to economic systems, we anticipate that the macroeconomic effects of cybersecurity will become more apparent. Consequently, there is an imperative for both academia and public policy to adopt interdisciplinary, data-based and forward-looking approaches. The objective of this study is to establish a theoretical, empirical, and methodological foundation that will contribute to this transformation and to the establishment of a new paradigm in this field.

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Annex 1: List of the Group of Countries Based on Geographical Region.

Europe (EUR)	Asia-Pacific (ASP)	Arab States (ARB)	Africa (AFR)	Commonwealth of Independent States (CIS)	America (AMS)
Albania	Afghanistan	Algeria	Angola	Armenia	Antigua and Barbuda
Andorra	Bangladesh	Bahrain	Benin	Azerbaijan	Argentina
Austria	Bhutan	Comoros	Botswana	Belarus	Australia
Belgium	Brunei Darussalam	Djibouti	Burkina Faso	Kazakhstan	Bahamas
Bosnia and Herzegovina	Cambodia	Egypt	Burundi	Kyrgyzstan	Barbados
Bulgaria	China	Iraq	Cabo Verde	Russian Federation	Bolivia (Plurinational State of)
Croatia	Hong Kong, China	Jordan	Cameroon	Uzbekistan	Brazil
Cyprus	Indonesia	Lebanon	Chad		Canada
Czech Republic	Iran (Islamic Republic of)	Libya	Congo (Rep. of the)		Chile
Denmark	Japan	Mauritania	Côte d'Ivoire		Colombia
Estonia	Kiribati	Morocco	Dem. Rep. of the Congo		Costa Rica
Finland	Korea (Rep. of)	Oman	Equatorial Guinea		Cuba
France	Kuwait	Palestine	Eswatini		Dominica
Georgia	Lao P.D.R	Qatar	Ethiopia		Dominican Rep.

Germany	Macao, China	Saudi Arabia	Gabon	Ecuador
Greece	Malaysia	Somalia	Ghana	El Salvador
Georgia	Maldives	Syrian Arab Republic	Guinea-Bissau	Fiji
Hungary	Pakistan	Tunisia	Kenya	Guatemala
Iceland	Philippines	United Arab Emirates	Liberia	Grenada
Ireland	Samoa	Yemen	Lesotho	Honduras
Israel	Singapore		Madagascar	Jamaica
Italy	Sri Lanka		Malawi	Mexico
Latvia	Thailand		Mali	Mongolia
Liechtenstein	Timor-Leste		Mauritius	Myanmar
Lithuania	Tonga		Mozambique	New Zealand
Luxembourg	Vanuatu		Namibia	Nicaragua
Malta	Viet Nam		Nigeria	Panama
Moldova			Rwanda	Paraguay
Monaco			São Tomé and Príncipe	Peru
Montenegro			Senegal	Saint Kitts and Nevis
Netherlands (Kingdom of the)			Seychelles	Saint Lucia
North Macedonia			Sierra Leone	Saint Vincent and the Grenadines
Norway			South Africa	Suriname
Poland			Tanzania	Trinidad and Tobago
Portugal			Togo	United States
Romania			Uganda	Uruguay
San Marino			Zambia	Venezuela
Serbia			Zimbabwe	
Slovakia				
Slovenia				
Spain				
Sweden				
Switzerland				
Türkiye				
Ukraine				
United Kingdom				