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DIGITALIZATION, FINANCIAL DEVELOPMENT, AND LONG-RUN GROWTH: STRUCTURAL EVIDENCE FROM ADVANCED G20 ECONOMIES

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ABSTRACT

This study examines the structural determinants of long-run economic growth in advanced economies, with a particular focus on digitalization, financial development, and human capital. Drawing on annual panel data for eleven G20 countries spanning 2011–2022, the analysis employs a Panel Autoregressive Distributed Lag (ARDL) framework to estimate both short-run dynamics and long-run relationships. Preliminary unit root and cointegration tests confirm that the variables are integrated of order one and exhibit a stable long-run equilibrium. Empirical results indicate that financial development, gross fixed capital formation, and life expectancy have a statistically significant and positive impact on GDP growth, highlighting the central importance of efficient financial systems, sustained capital investment, and population health in promoting long-term economic performance. In contrast, government consumption expenditure is negatively associated with growth, reflecting potential inefficiencies in resource allocation. Although digitalization and foreign direct investment exhibit positive but statistically insignificant effects in the short run, these patterns may reflect time lags or saturation effects in digitally advanced economies. Overall, the findings reinforce the importance of coherent policy strategies that advance financial inclusion, enhance human capital, and harness digital transformation to support resilient and innovation-led growth across advanced G20 nations.

KEYWORDS: Digitalization; Financial Development, Human Development, Economic Growth, G20.

1. INTRODUCTION

In the pursuit of sustained economic growth, structural transformation has emerged as a central theme in modern macroeconomic discourse. Classical and endogenous growth theories, most notably those of Solow (1956), Romer (1990), and Lucas (1988) – have long emphasized the significance of capital accumulation, technological progress, and human capital in determining long-run output trajectories. More recently, the digital revolution and the expansion of financial systems have redefined the channels through which economies accumulate knowledge, allocate resources, and enhance productivity. In high-income countries, digital infrastructure and financial deepening are increasingly recognized as critical enablers of innovation-led growth (Aghion et al., 2005; Beck et al., 2020). Simultaneously, improved health outcomes and rising life expectancy have reinforced the importance of human capital as both a productive input and a driver of demographic dividends (Bloom et al., 2004). Despite this growing consensus, empirical analyses that jointly examine the contributions of digitalization, financial development, and human development to economic performance, especially in the context of advanced economies, remain limited. This research is motivated by the need to empirically disentangle these structural drivers and assess their long-run and short-run implications for output growth within a unified econometric framework.

Economic growth remains a cornerstone of macroeconomic inquiry, serving as a vital indicator of national prosperity and long-term developmental progress. Within this domain, the G20 economies hold a pivotal role, collectively contributing over 80% of global GDP and approximately 75% of international trade (World Bank, 2023). Despite their shared influence, G20 countries encompass a wide spectrum of structural characteristics, institutional capacities, and stages of economic development. This diversity makes the G20 a compelling context for analyzing how macroeconomic and structural drivers shape heterogeneous growth outcomes.

While an extensive body of literature has examined the determinants of economic growth, much of this research has traditionally concentrated on either standard macroeconomic variables or select structural indicators in isolation. Foundational studies emphasize the role of capital accumulation (Levine & Renelt, 1992), the efficiency of financial markets (King & Levine, 1993), and the accumulation of human capital (Barro, 2001) as fundamental drivers of long-term economic expansion. In more

recent years, digitalization has emerged as a transformative force, with scholars linking information and communication technology (ICT) adoption to enhanced productivity, innovation diffusion, and overall economic dynamism (Niebel, 2018; Vu, 2020). These contributions have been especially salient in the context of developed economies, where technological penetration and financial depth are significantly more advanced.

Despite these valuable insights, several critical gaps remain. First, the empirical literature tends to treat these determinants in a fragmented manner, seldom integrating digitalization, financial development, and human capital within a unified empirical framework. Second, while cross-country studies abound, many employ heterogeneous global samples, which often obscure structural differences and institutional characteristics specific to advanced economies. As such, the specific mechanisms through which structural drivers influence growth in high-income settings, particularly within the G20 bloc, remain underexplored. Third, most studies prioritize either short-run dynamics or long-run equilibrium relationships, without jointly modeling both adjustment processes over time.

Furthermore, the rapidly evolving global economic landscape, shaped by technological disruption, demographic shifts, and pandemic-induced volatility, has highlighted the limitations of conventional growth models. The COVID-19 crisis revealed structural vulnerabilities in global trade, investment flows, and public finance systems, prompting renewed interest in resilient and inclusive growth strategies (Taylan et al., 2022). Simultaneously, the rise of the digital economy and growing recognition of the centrality of human development to national competitiveness demand a broader, more integrated policy lens. This study addresses critical empirical and conceptual gaps by employing a Panel ARDL methodology to examine the joint long-run and short-run effects of digitalization, financial development, and human capital on GDP growth across eleven high-income G20 countries over the period 2000–2023. Focusing exclusively on advanced economies within the G20 enables the analysis to capture a relatively homogeneous institutional and developmental setting, thereby improving the precision of inference. The research offers a holistic and policy-relevant perspective on structural transformation in mature economies and contributes to the broader discourse on building resilient, innovation-driven growth trajectories in an increasingly digital and interconnected world.

Building on established theoretical foundations and recent empirical evidence, this study offers a comprehensive evaluation of the long-run macroeconomic and structural determinants of economic growth. It focuses particularly on digitalization, financial development, and human capital—dimensions increasingly acknowledged as pivotal to fostering sustained economic expansion. Digitalization, represented by internet usage, contributes to productivity growth and innovation by enhancing information flows, facilitating knowledge diffusion, and lowering transaction costs. Financial development, captured through a multidimensional composite index, supports efficient capital allocation, reduces financing constraints, and stimulates entrepreneurial activity. Human capital, proxied by life expectancy, serves as an indicator of labor force quality and the long-term viability of economic participation, underscoring the role of health and longevity in sustaining productive capacity. In addition to these core structural drivers, the model incorporates gross fixed capital formation, foreign direct investment (FDI), and government consumption expenditure as control variables, representing key channels of domestic investment, external capital inflows, and fiscal policy, respectively. Rather than evaluating these factors in isolation, the analysis seeks to uncover their interdependencies and the mechanisms through which they influence long-run economic performance within advanced G20 economies. By analyzing the structural linkages among key macroeconomic variables, the study offers deeper insights into how structural transformation, technological diffusion, and institutional development collectively shape economic performance. The resulting evidence is intended to inform the design of policy frameworks that promote resilience, inclusivity, and long-term productivity in an increasingly complex global economic environment.

The rest of the paper is structured as follows: Section 2 reviews the theoretical foundations and empirical literature on economic growth determinants, focusing on digitalization, financial development, and human capital. Section 3 outlines the data sources, variable definitions, and econometric methodology, including the Panel ARDL framework. Section 4 presents the empirical results and provides a detailed interpretation of both the short-run and long-run dynamics. Finally, Section 5 concludes the study by summarizing key findings, discussing policy implications, and suggesting avenues for future research.

2. LITERATURE REVIEW

The literature on economic growth has undergone a profound transformation, evolving from the early neoclassical models to more nuanced endogenous growth theories that place structural and institutional factors at the heart of development.

a. Neoclassical Growth Theory

The neoclassical growth model, primarily associated with Solow (1956), emphasizes capital accumulation, labor force expansion, and exogenous technological progress as the key determinants of long-term economic growth. Within this framework, economies converge to a steady-state growth path determined by savings rates, population growth, and the rate of technological change. One of the central tenets of the model is that increases in capital per worker yield diminishing marginal returns, implying that without continual technological advancement, growth will eventually stagnate. This mechanism supports the notion of conditional convergence, where poorer countries catch up to richer ones provided, they share similar savings behavior, population growth, and access to technology. However, the Solow model assumes that technological progress occurs independently of economic policy or institutional quality, treating it as an exogenous “black box.” This limits the model’s capacity to account for endogenous drivers of innovation, structural change, and institutional development factors that are increasingly recognized as crucial in explaining sustained productivity growth and cross-country divergence. Moreover, the model does not capture feedback loops between economic output and human capital accumulation, innovation, or digital infrastructure, all of which are vital in today’s advanced economies.

For G20 countries, many of which have matured beyond the early stages of industrial development, the constraints of the neoclassical model become particularly evident. These economies now face new challenges tied to digital transformation, demographic shifts, and environmental sustainability. Thus, while the Solow model offers valuable baseline intuition about capital accumulation and the role of technology in sustaining growth, it falls short of explaining the complex and dynamic structural adjustments shaping modern economic performance. This theoretical limitation has led to the development of more comprehensive models, such as those offered by endogenous growth theory, which embed innovation, human capital, and institutional quality directly within the growth-generating process.

b. Endogenous Growth Theory

In response to the limitations of the neoclassical model, endogenous growth theories emerged, incorporating technology, human capital, and innovation as internal drivers of long-term economic performance. Romer (1990) introduced a framework in which knowledge accumulation and research and development (R&D) are central to sustaining growth, emphasizing the role of policy incentives and spillover effects from innovation. Lucas (1988) highlighted the accumulation of human capital as a key mechanism for productivity enhancement, drawing attention to education and skill development as endogenous sources of growth. Aghion and Howitt (1992) further advanced this literature by conceptualizing innovation as a process of creative destruction, wherein new technologies continuously replace obsolete ones, thereby generating productivity gains. Building on these foundations, recent empirical research underscores the transformative role of digitalization and financial development in driving modern growth trajectories. Digital infrastructure not only accelerates information dissemination and market access but also complements human capital and innovation systems, consistent with the predictions of endogenous models. Likewise, a well-functioning financial system facilitates efficient resource allocation, mobilizes savings for investment in innovation, and mitigates risks—all of which are essential for sustaining long-run growth. These insights provide a strong theoretical rationale for examining how internet usage and financial development, alongside structural macroeconomic controls, influence economic growth patterns within G20 economies.

c. Technological Change and Digitalization

Within the endogenous growth framework, digitalization is increasingly recognized as a transformative force that fundamentally reshapes production structures, innovation dynamics, and institutional efficiency. Far from being a passive input, digital technology actively reorganizes economic processes by lowering information asymmetries, compressing transaction times, and enabling scalable innovation. As firms and governments integrate digital platforms into communication, service delivery, and logistics, the productivity effects of digitalization spill over across sectors and borders. Digital infrastructure—often proxied by internet penetration rates, mobile broadband subscriptions, and ICT capital

formation—facilitates knowledge diffusion, enhances firm competitiveness, and raises total factor productivity (TFP). These mechanisms are consistent with endogenous growth theory's emphasis on intangible capital, learning-by-doing, and cumulative technological advancement.

Empirical research substantiates the macroeconomic significance of digitalization. Niebel (2018), using cross-country panel data, finds that ICT investments positively affect labor productivity, particularly in advanced economies. Similarly, Vu (2011) documents a significant and sustained contribution of digital connectivity to GDP growth, with more pronounced effects in countries that have complementary investments in education and governance. The growth-enhancing potential of digitalization is not uniform; however, it is moderated by institutional capacity, the absorptive ability of labor markets, and the depth of financial intermediation. For instance, digital technologies require robust financial systems to fund innovation and expand access to digital tools among firms and households. This interdependence between digital infrastructure, financial development, and human capital highlights the importance of a coordinated structural environment for maximizing the economic returns to digital transformation. In the context of G20 economies, these dynamics are particularly relevant, as countries vary widely in their digital maturity and financial inclusion, influencing their respective patterns of economic development.

d. Financial Development and Growth

Financial development constitutes a fundamental pillar in both theoretical and empirical analyses of economic growth. Seminal work by King and Levine (1993) argues that well-functioning financial systems mobilize domestic savings, allocate capital efficiently, and facilitate risk diversification, thereby stimulating entrepreneurship and innovation. Such systems reduce transaction costs and information asymmetries, which in turn enhance productive investment and long-term output. Within the endogenous growth framework, financial development is considered a driver of sustained capital accumulation and technological advancement, playing a key role in moving economies beyond reliance on physical input expansion (Greenwood & Jovanovic, 1990; Aghion et al., 2005).

Empirical evidence further supports this relationship. Beck et al. (2007) demonstrate that financial deepening contributes significantly to long-run GDP growth, particularly in countries with

robust institutional structures. In the context of the G20, Beck et al. (2020) emphasize that financial development fosters both investment efficiency and innovation, acting as a transmission channel for growth-enhancing policies. Furthermore, Levine (2005) underscores the importance of financial institutions and markets in shaping macroeconomic performance, highlighting the role of financial development in fostering inclusive and resilient economic systems.

Taken together, the literature establishes financial development not merely as a supporting factor, but as an active agent in driving productivity, innovation, and long-run growth, especially in structurally advanced and institutionally mature economies such as those of the G20.

e. Human Capital and Long-Term Growth

The literature on economic growth increasingly emphasizes the critical role of human capital, defined in terms of education, health, and skill formation, in sustaining long-term development. Seminal contributions by Lucas (1988) and Barro (2001) identify human capital accumulation as a central mechanism within endogenous growth models, highlighting its ability to enhance labor productivity, facilitate technological diffusion, and generate dynamic knowledge spillovers. These theoretical frameworks stress that the quality of human capital is not merely a supplementary input, but a fundamental driver of a country's capacity to innovate and adapt to structural change. Life expectancy at birth, often used as an indicator of human development, has been consistently linked to labor market efficiency and macroeconomic stability. For instance, Bloom et al. (2004) show that increased longevity contributes to growth by extending working lives and improving workforce quality. Similarly, Weil (2007) provides empirical evidence that health improvements are strong predictors of long-run economic performance, particularly when supported by investments in education.

In the contemporary global economy, marked by rapid digital transformation and demographic transitions, the relevance of cognitive and adaptive skills has become even more pronounced. Hanushek and Woessmann (2012) contend that differences in learning outcomes – rather than years of schooling – explain much of the observed variation in long-term economic growth across countries. For G20 economies, sustained investment in high-quality education and healthcare systems is therefore essential not only for inclusive development but also for preserving global competitiveness in an era of

technological disruption.

f. Unified Growth and Structural Transformation

Contemporary advancements in growth theory, particularly the Unified Growth Theory developed by Galor and Weil (2000), offer an integrated framework for understanding the long-run evolution of economies. This theoretical approach seeks to reconcile disparate phases of economic development, ranging from pre-industrial stagnation to modern sustained growth, by endogenizing the roles of demographic transition, human capital accumulation, and institutional change. Central to this perspective is the notion that economic growth is shaped by the dynamic interplay between population dynamics, technological progress, and educational expansion. By capturing how these endogenous mechanisms co-evolve over time, Unified Growth Theory provides a comprehensive lens through which to interpret the structural transformation of economies and the emergence of persistent growth patterns.

A central insight of this literature is that structural transformation characterized by shifts from agriculture to industry and subsequently to services plays a pivotal role in productivity enhancement and long-run development. Unified growth models account for how such transitions are conditioned by the expansion of human capital, the diffusion of technological change, and improvements in governance and institutions. The framework is particularly pertinent for G20 economies, which, while having largely completed their industrial transitions, now confront second-generation structural challenges such as demographic aging, climate change, digital inequality, and institutional rigidities. For these advanced and emerging economies, sustaining growth necessitates adaptive and forward-looking policy responses that foster complementarities between education systems, technological infrastructure, and institutional capacity. As highlighted by Galor (2011), inclusive and innovation-driven development depends on a society's ability to endogenously generate and equitably distribute both knowledge and opportunity. Within this context, digital transformation, if aligned with human capital development and responsive institutions, offers a critical lever for ensuring inclusive and sustainable growth in the decades ahead.

In summary, the existing body of literature highlights that sustained economic growth is shaped by a complex interaction among digital

transformation, financial development, human capital investment, and broader structural dynamics. Classical and endogenous growth theories offer foundational insights by emphasizing the roles of capital accumulation, technological progress, and education, while more comprehensive frameworks—such as Unified Growth Theory—underscore the importance of demographic transitions and institutional change. Empirical evidence further confirms the vital roles of digital infrastructure, well-developed financial systems, and human capital in enhancing productivity and promoting inclusive development.

However, within the context of G20 economies characterized by heterogeneity in institutional capacity, technological advancement, and demographic composition, there is a clear research gap concerning the combined influence of digitalization, financial development, and human capital, especially when examined alongside key macroeconomic variables. This study addresses that gap by offering a comprehensive, policy-relevant analysis of structural determinants of economic growth across both advanced and emerging G20 nations. Its distinct contribution lies in the integrated assessment of digitalization, financial development, and human capital within a unified empirical framework. Whereas prior studies have often considered these drivers in isolation or within limited regional contexts, this research captures their interconnected long-run and short-run effects using a panel Autoregressive Distributed Lag (ARDL) model, specifically the Pooled Mean Group (PMG) estimator. This methodological approach is well-suited to the G20 setting, where considerable

differences exist in terms of institutional quality, digital readiness, and financial development. The panel ARDL model allows for mixed orders of integration and accommodates dynamic adjustment mechanisms through the inclusion of an error correction term, thus enabling robust estimation of long-term equilibrium relationships while accounting for short-term country-specific variations. As such, this study provides valuable insights into how digital, financial, and human capital factors collectively influence growth dynamics in a complex and globally interdependent economic environment.

3. DATA AND METHODOLOGY

To assess the impact of digitalization and financial development on economic growth, this study employs annual panel data from 2000 to 2023 for eleven G20 countries: Canada, China, Indonesia, Mexico, the Russian Federation, Saudi Arabia, South Africa, Türkiye, the United Arab Emirates, the United Kingdom, and the United States. The dependent variable is the real GDP growth rate. Core explanatory variables include internet usage (% of population) and a financial development index. Control variables comprise FDI inflows, exports, imports, final consumption expenditure, government consumption expenditure, and gross fixed capital formation (all as % of GDP). Life expectancy at birth, included as a proxy for human development, captures long-term investments in health and education. All data are sourced from the World Bank's World Development Indicators (Table 1).

Table 1: Variable Description Table.

Variable Name	Description	Unit / Scale	Source
GDP	Real GDP growth rate, annual % change in output	Percentage	World Bank
Digital	Internet users as % of population, proxy for digital penetration	Percentage	World Bank
FDI	Net Foreign Direct Investment inflows	% of GDP	World Bank
EX	Exports of goods and services	% of GDP	World Bank
FCE	Final Household Consumption Expenditure	% of GDP	World Bank
GCE	Government Consumption Expenditure	% of GDP	World Bank
GFCF	Gross Fixed Capital Formation (	% of GDP	World Bank
IM	Imports of goods and services	% of GDP	World Bank
Findevindx	Financial Development Index	Index (0–1 scale)	World Bank
LifeExp	Life Expectancy at birth	Years	World Bank

3.1. Model Specification

To examine the dynamic relationship between economic growth, digitalization, and financial development, this study adopts a panel Autoregressive Distributed Lag (ARDL) framework. The choice of ARDL is motivated by its suitability for

handling variables that are integrated of mixed order, i.e., $I(0)$ and $I(1)$, and its capacity to distinguish between short-run dynamics and long-run equilibrium relationships.

The general form of the panel ARDL (p, q) model can be expressed as:

$$\Delta GDP_{it} = \alpha_i + \lambda_i GDP_{it-1} + \sum_{k=0}^{p-1} \beta_{1ik} \Delta Digital_{it-k} + \sum_{k=0}^{p-1} \beta_{2ik} \Delta Findevindx_{it-k} + \sum_{k=0}^{p-1} \gamma_{1ik} \Delta Z_{it-k} + \varepsilon_{it} \quad (1)$$

In Equation (1), GDP_{it} denotes the real GDP growth rate for country i in year t , serving as the dependent variable of interest. The variable *Digital* represents internet usage as a percentage of the population and serves as a proxy for the extent of digitalization. Digitalization is increasingly recognized as a transformative force in modern economies, enhancing productivity through improved access to information, reduced transaction costs, and the emergence of new economic sectors. Higher internet penetration is expected to stimulate innovation, support entrepreneurship, and increase labor market efficiency, all of which can contribute positively to long-term economic performance. Whereas, *Findevindx* refers to the financial development index, which captures the depth, access, and efficiency of the financial system. A well-functioning financial sector can mobilize savings, allocate capital more efficiently, and provide risk management tools, thereby fostering private investment and facilitating inclusive economic growth. In G20 economies, where capital markets are relatively developed but uneven in inclusivity, financial development remains a critical driver of sustained growth, especially when combined with digital infrastructure. The vector Z_{it} comprises a set of control variables, including foreign direct investment (FDI) inflows, exports (EX), imports (IM), final consumption expenditure (FCE), government consumption expenditure (GCE), gross fixed capital formation (GFCF), and life expectancy at birth (LifeExp). Foreign direct investment (FDI) inflows often bring not only capital but also technology transfer and managerial expertise, which can enhance productivity in host countries. Exports (EX) and imports (IM), as components of trade openness, are crucial for integrating into global value chains and accessing new markets and technologies. Final consumption expenditure (FCE) and government consumption expenditure (GCE) reflect domestic demand dynamics and public sector involvement in the economy, respectively. Gross fixed capital formation (GFCF) captures investment in physical infrastructure and productive assets, which are essential for capacity expansion. Life expectancy at birth (LifeExp) serves as a proxy for human development, reflecting the cumulative impact of health, education, and living standards on labor productivity and economic potential.

The term α_i captures unobserved, country-specific fixed effects, such as institutional quality,

geographic characteristics, or policy frameworks, that remain constant over time.

The coefficient λ_i denotes the error correction term, indicating the speed at which short-run deviations are corrected toward the long-run equilibrium. Finally, ε_{it} represents the idiosyncratic error term, accounting for unobservable shocks or transitory disturbances that are not captured by the included explanatory variables.

This study employs the Panel ARDL model to analyze the dynamic effects of structural determinants on GDP growth across G20 countries. The model is suitable when variables are integrated of order $I(0)$ or $I(1)$, but not $I(2)$. Estimation uses the Pooled Mean Group (PMG) estimator, which allows for heterogeneity in short-run dynamics while imposing homogeneity on long-run relationships. Stationarity is verified using the Augmented Dickey-Fuller (ADF) panel unit root test to confirm the absence of $I(2)$ variables. To establish long-run relationships, the study applies the Johansen cointegration test using multiple selection criteria, including the Sequential t-test, MAIC, MSIC, and Schwarz criterion. These tests evaluate whether non-stationary series move together over time, providing the basis for valid long-run estimation. The Panel ARDL framework thus enables a comprehensive assessment of both short-run adjustments and long-run equilibrium linkages among digitalization, financial development, and macro-structural drivers of growth.

4. RESULTS AND ANALYSIS

To assess the impact of digitalization, financial development, and structural macroeconomic variables on economic growth, this research begins its empirical investigation with a descriptive statistical analysis. This preliminary step provides a foundational understanding of the central tendencies, dispersion, and distributional characteristics of the selected variables. Table 2 presents key summary measures, including means, standard deviations, and interquartile ranges. The GDP growth rate (GR) has a mean of 3.5%, with the interquartile range spanning from 1.79% to 5.57%, reflecting variation across countries and time. Digitalization shows the highest dispersion, with a mean of 53.4% and values ranging from 23.8% (25th percentile) to 80.3% (75th percentile), highlighting the digital divide. The financial development index averages 0.56, with 50% of observations between 0.40 and 0.79. Export and import shares show moderate variation, with interquartile ranges of 23.92–35.23 and 21.81–31.99, respectively. Final consumption

expenditure is more stable, ranging from 65.85 to 81.16, while life expectancy lies between 70.78 and 79.72 years. These percentiles indicate considerable

heterogeneity across countries, supporting the use of panel data methods to examine growth dynamics.

Table 2: Descriptive Statistics.

Variable	Mean	Median	Std. Dev.	Min	Max	25th Percentile	75th Percentile
EX	33	28.58	18.28	9.04	98.34	23.92	35.23
FCE	71.5	74.62	11.27	40.78	86.28	65.85	81.16
FDI	2.36	2.03	2.04	-2.76	12.08	1.15	3
GDP	3.5	3.15	3.76	-10.36	14.23	1.79	5.57
GCE	15.73	15.88	4.66	6.53	29.32	11.97	19.24
GFCF	23.31	21.61	6.82	13.18	44.52	18.74	24.41
IM	28.99	26.7	12.3	13	74.46	21.81	31.99
Findevindx	0.56	0.49	0.21	0.26	0.96	0.4	0.79
LifeExp	74.34	75.72	6.38	53.91	82.6	71.05	78.75
Digitalization	53.4	59.5	31.38	0.93	100	23.8	80.3

Figure 1 highlights the relationship between internet usage and GDP growth for eleven G20 countries in 2000 and 2023. It shows a significant rise in internet penetration across all countries, with several, such as the United Arab Emirates and Saudi Arabia, reaching near-universal access by 2023. However, the increase in digitalization is not consistently associated with higher GDP growth.

While countries like China and India maintained strong growth alongside rising internet usage, others, such as the Russian Federation and the United Kingdom, experienced weaker growth despite high digital connectivity. This suggests that the growth impact of digitalization depends on broader structural and institutional conditions.

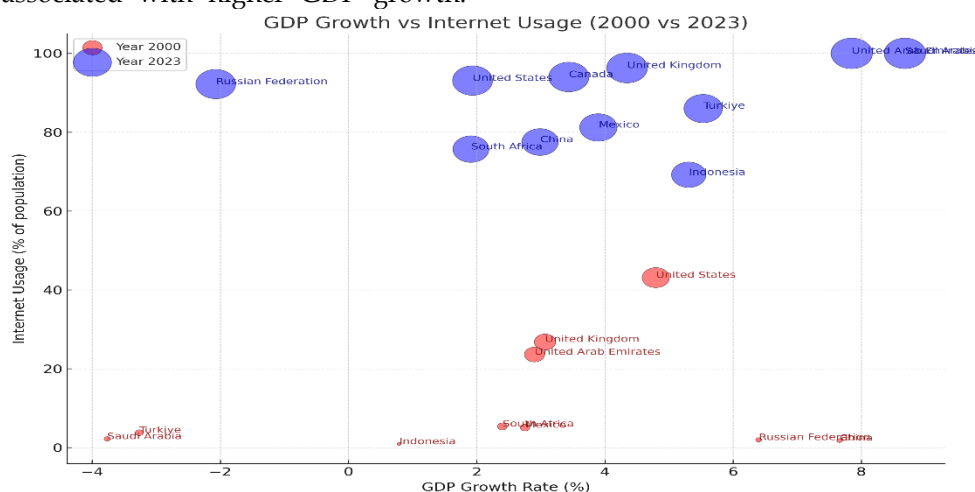


Figure 1: GDP Growth Vs Internet Usage (2000 Vs 2023).

Table 3 reports the Augmented Dickey-Fuller (ADF) unit root test results for all variables across the eleven G20 countries. Most variables are non-stationary at levels but become stationary after first differencing, indicating they are integrated of order one, I (1). GDP, digitalization, and financial development consistently reject the null hypothesis

of a unit root at first difference, with test statistics significant at the 1% or 5% levels in nearly all cases. For example, GDP is stationary at first difference across all countries, with values such as -6.26 (Saudi Arabia) and -4.92 (Canada). These results validate the use of panel ARDL and cointegration approaches in the empirical estimation.

Table 3: Unit Root Test Results (ADF Test).

Country	Test	GDP	Digital	FDI	EX	FCE	GCE	GFCF	IM	Findevindx	LifeExp
Canada	Level	-4.15***	-3.03**	-3.62**	-2.82*	-2.06	-2.01	-1.99	-2.97*	-2.60*	-2.72*
	1st Diff	-4.92***	-2.65*	-3.31**	-3.20**	-3.64**	-3.96***	-2.49	-3.01**	-3.19**	-1.91
China	Level	-0.72	-0.74	-0.51	-1.54	-3.35**	-1.76	-2.11	-1.49	-3.10**	-1.91
	1st Diff	-4.05***	-2.16	-4.46***	-2.15	-1.5	-2.47	-3.40**	-2.64*	-3.82***	-1.69
Indonesia	Level	-2.74*	0.95	-3.28**	-2.63*	-0.51	-2.46	-1.77	-2.1	-1.7	-1.54
	1st Diff	-4.79***	-1.31	-4.49***	-5.75***	-4.27**	-3.21**	-2.18	-6.99***	-4.76***	-5.47**
Mexico	Level	-4.23***	-4.23**	-4.29***	-4.74***	-1.07	-3.21**	-2.18	-4.89***	-4.76***	-5.47***

	1st Diff	-4.34***	-5.71**	-9.16***	-4.74***	-2.67*	-3.05**	-4.86***	-4.89***	-5.49***	-6.83**
Russian Fed	Level	-2.5	-1.48	-1.05	-3.84***	-3.55**	-3.88***	-2.36	-0.59	-1.69	-1.15
	1st Diff	-4.94***	-3.16**	-3.58**	-5.32***	-3.88**	-3.55**	-5.16***	-1.76	-3.03**	-3.55**
Saudi Arabia	Level	-3.73**	-0.65	-2.15	-1.6	-5.00***	-2.13	-1.93	-1.53	-3.03**	-1.88
	1st Diff	-6.26***	-2.83*	-2.61*	-3.34**	-3.44**	-3.67**	-3.11**	-2.71*	-3.31**	-2.09
South Africa	Level	-2.42	-0.59	-2.71*	-2.17	-1.55	-1.08	0.24	-2.57	-1.54	-0.68
	1st Diff	-4.69***	-3.38**	-3.92***	-5.15***	-4.85***	-3.24**	-3.08**	-3.51**	-3.65**	-4.61**
Turkiye	Level	-2.89*	-0.32	-3.13**	-0.08	-0.14	-0.22	-1.56	-0.89	-2.64*	-1.63
	1st Diff	-4.27***	-3.38**	-3.92***	-5.15***	-4.85***	-3.24**	-3.08**	-3.51**	-3.65**	-4.61**
UAE	Level	-3.14**	-1.72	-2.83*	-1.52	-1.42	-0.69	-2.66*	-1.63	-2.32	-2.84*
	1st Diff	-4.49***	-3.51**	-3.61**	-3.44**	-2.90*	-3.83***	-3.34**	-3.65**	-3.34**	-2.73*
UK	Level	-3.79***	-3.55**	-5.03***	-3.48**	-3.95***	-3.63**	-2.28	-4.19***	-4.12***	-3.07**
	1st Diff	-4.54***	-3.81**	-5.04***	-3.48**	-3.95***	-3.63**	-2.28	-4.19***	-4.12***	-3.07**
USA	Level	-3.84***	-1.89	-4.47***	-1.41	-2.92*	-2.26	-2.92*	-2.92*	-2.97*	-1.6
	1st Diff	-4.68***	-3.29**	-3.56**	-3.44**	-3.10**	-2.68*	-3.10**	-4.19***	-6.77***	-4.15**

After establishing that most variables are integrated of order one, the analysis proceeds to examine long-run relationships among them. Table 4 reports results from the Pedroni, Kao, and Westerlund panel cointegration tests, all of which provide strong evidence of cointegration across the eleven G20 countries. The Pedroni test reveals statistically significant Phillips-Perron and Augmented Dickey-Fuller t-statistics, rejecting the null of no cointegration at the 1% level. The Kao test reinforces this conclusion, with all variants of the

Dickey-Fuller statistic confirming a common long-run relationship. Accounting for cross-sectional heterogeneity, the Westerlund test yields a significant variance ratio statistic (-2.5917 , $p = 0.0048$), indicating cointegration in at least some countries. These consistent findings affirm the existence of long-run equilibrium dynamics among the macroeconomic and structural variables, supporting the use of cointegration-based econometric techniques in the subsequent analysis.

Table 4: Panel Cointegration Tests.

Test	Statistic	p-value
Pedroni: Phillips-Perron t	-10.3832	0.0000
Pedroni: Augmented Dickey-Fuller t	-8.4454	0.0000
Kao: Modified Dickey-Fuller t	-14.0652	0.0000
Kao: Dickey-Fuller t	-11.7219	0.0000
Kao: Augmented Dickey-Fuller t	-9.3004	0.0000
Kao: Unadjusted modified Dickey-Fuller t	-19.3810	0.0000
Kao: Unadjusted Dickey-Fuller t	-12.3718	0.0000
Westerlund: Variance ratio	-2.5917	0.0048

Table 5 presents the long-run estimation results from the Panel Autoregressive Distributed Lag (ARDL) model, shedding light on the dynamic relationship between GDP and its key macroeconomic and structural determinants across the sample of G20 economies. The statistically significant negative coefficient on the lagged dependent variable confirms the existence of a stable long-run adjustment mechanism, suggesting that deviations from equilibrium are corrected over time.

Among the independent variables, government consumption expenditure exhibits a statistically significant negative association with GDP at the 1% level. This finding supports classical fiscal theory, which posits that excessive or inefficient government consumption can displace private sector activity and signal misallocation of public resources. In the context of advanced economies represented in the sample, where government sectors are already

sizable, further increases in consumption expenditure may constrain productivity and long-term output growth. Recent empirical literature substantiates this view. Afonso and Jalles (2015) demonstrate that higher government consumption relative to GDP tends to hinder growth, particularly in high-income economies. Égert (2017) similarly finds that the composition of public spending plays a critical role, with consumption expenditure exerting a contractionary effect on output, in contrast to capital investment, which tends to promote growth. Woo and Kumar (2015) identify threshold effects, wherein the negative impact of government size on growth becomes more pronounced beyond certain levels of public expenditure. Complementing this evidence, Gemmell et al. (2011) and Acosta-Ormaechea and Morozumi (2015) show that reallocating spending from consumption to infrastructure, education, or health can yield more

sustainable and inclusive growth outcomes in developed economies.

In contrast, gross fixed capital formation is positively associated with GDP, with the coefficient being statistically significant, underscoring the critical role of productive investment in sustaining long-term output growth. This finding is consistent with the neoclassical growth framework, which emphasizes capital accumulation as a fundamental driver of economic expansion. The result also reflects the capacity of capital investment to enhance physical infrastructure, stimulate private sector activity, and raise productivity through technology adoption and scale economies. Empirical literature offers strong support for this relationship. Levine and Renelt (1992), in one of the earliest systematic sensitivity analyses, identified investment in physical capital as a robust correlate of growth across a wide range of countries and model specifications. More recent evidence by Égert et al. (2022) confirms that gross fixed capital formation significantly contributes to GDP growth, particularly in OECD economies, where investment efficiency and institutional quality support the effective translation of capital accumulation into output gains. Similarly, Furceri and Mourougane (2012) demonstrate that public investment, especially in transport and communication infrastructure, yields substantial long-run output multipliers in developed economies, reinforcing the importance of capital formation beyond short-term cyclical effects.

Moreover, the financial development index emerges as a statistically significant and positive contributor to GDP growth, reinforcing recent evidence from high-income countries that deeper and more inclusive financial systems enhance capital allocation and stimulate economic activity (Svirydzenka, 2016; Beck et al., 2020). This finding highlights the crucial role of well-functioning financial institutions in promoting long-term economic growth. In advanced economies, efficient financial systems support capital mobilization, lower transactions and information costs, and direct savings toward productive investment, mechanisms that collectively strengthen macroeconomic performance. The results are consistent with Svirydzenka (2016), who develops a comprehensive index of financial development and identifies a robust positive association with output growth across a wide cross-country sample. Similarly, Beck et al. (2020) report that improvements in financial access and intermediation are positively linked to productivity and innovation in high-income countries. Cihak et al. (2016) emphasize that financial

sector soundness and institutional quality significantly enhance the growth effects of financial development. More recently, Degryse et al. (2014) find that traditional banking systems in developed countries play a stabilizing and growth-promoting role, particularly when supported by prudent regulation. These studies collectively affirm that the benefits of financial development are most effectively realized in settings where institutional frameworks and market structures are conducive to inclusive and efficient financial intermediation.

Similarly, life expectancy, as a proxy for human development, shows a positive and statistically significant effect on GDP growth. This result is consistent with pioneering contributions by Bloom et al. (2004), who argue that increased longevity fosters economic growth by improving labor productivity, extending working years, and encouraging greater investments in education and skills. As a key dimension of human development, longer life expectancy reflects not only improved health outcomes but also broader gains in living standards, social welfare, and economic resilience. Weil (2007) further supports this link, providing robust cross-country evidence that better health, as reflected in life expectancy, contributes significantly to income growth. These findings highlight the importance of integrating human development indicators into macroeconomic analysis, especially in advanced economies where institutional capacity enables the full realization of demographic dividends.

Interestingly, digitalization and foreign direct investment exhibit positive but statistically insignificant effects in the short run. This finding may reflect transitional dynamics, wherein the benefits of digital adoption and capital inflows take time to materialize. Moreover, the stage of development of the countries under study could play a pivotal role in shaping these outcomes. In more advanced economies, digital infrastructure is often mature and integrated, which may reduce the marginal short-run impact of further digitalization. Similarly, the growth effects of FDI may be less pronounced in developed economies where domestic capital markets are already deep and technological capabilities well established. These results align with findings by Borensztein et al. (1998) and Alfaro et al. (2004), who emphasize that the absorptive capacity—shaped by human capital, institutional quality, and development level—conditions the growth-enhancing potential of FDI. Likewise, studies such as Niebel (2018) suggest that the productivity gains from digitalization are more significant in lower-income settings, where digital transformation can

overcome infrastructure and efficiency gaps. Thus, the lack of short-run significance may indicate

diminishing returns in high-income economies or a lagged realization of structural benefits.

Table 5: Panel Ardl Estimation Results.

Variable	Coefficient	Std.error	t statistic	p.value
L1_GDP	-0.861***	0.054	-15.802	0.000
D_EX	-0.161	0.126	-1.273	0.204
D_FCE	-0.178	0.126	-1.404	0.162
D_FDI	0.038	0.087	-0.440	0.660
D_GCE	-1.503***	0.209	-7.198	0.000
D_GFCF	0.381**	0.166	2.291	0.023
D_IM	0.233*	0.120	1.951	0.052
D_Findevir	16.394***	5.997	2.734	0.007
D_Digital	0.018	0.052	0.339	0.735
D_LifeExp	0.705***	0.215	3.285	0.001

Overall, the Panel ARDL results substantiate the hypothesis that structural determinants, namely domestic investment, financial development, and human capital, exert statistically significant and enduring effects on long-run economic growth. The consistent positive contributions of gross fixed capital formation, the financial development index, and life expectancy underscore the pivotal role of productive capital accumulation, well-functioning financial systems, and improved health outcomes in fostering sustained output expansion. In contrast, the observed negative association between government expenditure and GDP growth suggests that the effectiveness of public spending is contingent upon its efficiency, allocation quality, and institutional context. These findings align with a broad corpus of empirical literature from advanced economies (e.g., Égert et al., 2022; Beck et al., 2020), which emphasizes the structural underpinnings of economic performance. Collectively, the results lend robust empirical support to the integration of structural transformation priorities—such as financial sector deepening, strategic public investment, and human capital development—within long-term economic planning frameworks aimed at enhancing resilience, competitiveness, and productivity growth in developed contexts.

5. CONCLUSION

This study investigates the long-run and short-run determinants of economic growth across a panel of eleven G20 economies over the period 2000 to 2022, with a specific focus on the structural roles of digitalization, financial development, foreign direct investment, and human capital. By employing the Panel Autoregressive Distributed Lag (Panel ARDL) model using the Pooled Mean Group estimator, the analysis accommodates heterogeneity in short-run dynamics while capturing common long-run equilibrium relationships. The empirical framework

includes key macroeconomic and structural variables: real GDP growth as the dependent variable, and gross fixed capital formation, financial development index, foreign direct investment (FDI), government consumption expenditure, digitalization (measured as internet usage), imports, and life expectancy as explanatory variables. Prior to estimation, panel unit root tests confirm that most series are integrated of order one, justifying the use of cointegration techniques. Subsequent Pedroni, Kao, and Westerlund cointegration tests provide robust evidence of long-run relationships among the variables. The findings reveal that gross fixed capital formation, financial development, and life expectancy exert statistically significant positive effects on GDP in the long run, indicating the crucial role of domestic investment, financial system efficiency, and human development in driving sustainable economic expansion. Government consumption, by contrast, is negatively associated with GDP, suggesting that the growth impact of public expenditure depends on its composition and efficiency. In the short run, digitalization and FDI exhibit positive but statistically insignificant effects, implying that their growth-enhancing impacts may manifest more prominently over time or under specific institutional and developmental conditions. These results align with existing literature on the structural drivers of growth in advanced economies and offer several policy implications for policymakers in these economies seeking to reinforce the structural foundations of long-term growth. The strong and consistent positive association between gross fixed capital formation and GDP underscores the pivotal role of domestic investment in driving productive capacity. Encouraging private investment and ensuring the efficiency of public capital expenditure—especially in infrastructure, innovation, and green technologies—should remain a core policy priority.

Equally, the significance of the financial development index affirms the growth-enhancing role of deep, inclusive, and well-regulated financial systems. Financial sector policies that improve intermediation, expand access to credit and capital markets, and promote fintech integration can enhance resource allocation and stimulate innovation. Ensuring macroprudential oversight and institutional stability remains essential for maintaining long-term financial system effectiveness. The positive contribution of life expectancy, serving as a proxy for human capital and population health, highlights the strategic value of sustained investment in health and education. Policies aimed at improving healthcare access, increasing educational attainment, and promoting labor force skills development are likely to yield high returns in terms of productivity and economic resilience. Conversely, the negative relationship observed between government consumption expenditure and GDP suggest that the growth impact of fiscal spending depends on its efficiency and composition. Rather than emphasizing the scale of

public expenditure, governments should focus on improving their quality, prioritizing investments in public goods and growth-enabling services while minimizing inefficiencies, misallocations, and administrative overheads.

Although digitalization and foreign direct investment do not exhibit statistically significant short-run effects in this analysis, their positive signs suggest that they may exert greater influence over longer horizons. To unlock their growth potential, policymakers should invest in digital infrastructure, reduce regulatory frictions, foster a conducive business climate, and strengthen institutional frameworks that align FDI inflows with national development objectives. Overall, these results support a holistic policy approach that integrates structural transformation through investment, finance, human capital, and digital readiness within a stable macroeconomic and institutional context. Ensuring transparency, governance effectiveness, and policy coherence will be crucial for translating structural reforms into sustained and inclusive economic growth across advanced economies.

Declarations

Author Contributions: IA conceptualized the study, conducted the literature review, collected the data, performed the empirical analysis, and led the drafting of the manuscript. RS provided critical input in shaping the research framework, supported the analytical process, and contributed substantially to the revision and refinement of the final manuscript. Both authors reviewed and approved the submitted version.

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