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Economic Modelling on Economic Growth and International Trade in G20 Countries: The role of Digital Economy

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Abstract:

This paper analyses the role of the digital economy plays in international trade impacts on economic growth of G20 countries from 2000-2020. The panel data of G20 countries is used to investigate the impact and data is collected from World Development Indicators. The results are estimated by pooled ordinary least square (PLOS) method, random and fixed effects, and the Generalized method of moments (GMM) model. Further, the econometric model is based on the Solow model that represents the relationship between economic growth (dependent variable) and other independent variables such as technology, labor, capital etc. The findings showed that 1) international trade only has positive effects on economic growth of G20 countries when interacted with the digital economy in the pooled OLS estimation, 2) the elasticities of labor and capital have negative and positive impacts on economic growth of G20 countries, 3) international trade has a significant impact on economic prosperity without and with interactive term in the random effect model, fixed effect model and GMM model.

The findings imply that international trade when interacting with the digital economy positively contributes to the economic growth of high-income and upper-middle-income G20 countries, although it shows a significant negative impact on the economic growth of low and lower-middle-income G20 countries. This may be because of lack of access to digital infrastructure in low-income countries. The study recommends that focused efforts are required towards developing and implementing the digital economy in G20 countries to ensure international trade's full economic impact in economic growth of G20 countries.

Keywords: Economic Growth; Digital Economy; International Trade; G20; GMM; PLOS

1. Introduction

Initially, the G20 leaders came together to address broad macroeconomic issues but it expanded the agenda to include trade, sustainable development, climate change and other important issues. To strengthen global growth and to advance the Sustainable development Goals (SDGs), G20 countries promotes trade facilitation (G20, 2019), global investment, and inclusive global value chain (Ministry of Foreign Affairs, 2018). Next, the question arises: is there any relationship between international trade and economic growth? There are many economic theories that established the positive relationship between international trade and economic growth.

1.1 Theories on international trade and economic growth

There are some conventional trade theories such as mercantilist theory, classical theory of trade, Heckscher-Ohlin trade theory, neo-classical trade theories and new trade theories which highlights the relationship between international trade and economic growth.

Mercantilists (L. Gomes, 1987) stated that the only way for a country or nation to become prosperous and powerful is to import fewer goods and services and export more goods and services to other economies. In short, we can say that by increasing exports and minimizing imports, countries would be able to achieve trade balances, which would contribute to a nation's economic growth.

Further, classical theory of absolute cost advantage (Adam Smith) and comparative cost advantage (David Ricardo) stated that a country would prosper from international trade if a country will specialize to export commodities with a

significantly lower cost advantage and import goods with a significantly higher cost advantage. This implies that trade with other countries gives access to new technologies and skills, contributes to efficiency and economic development and further to economic growth (Abendin & Duan, 2021). Further, neoclassical economists also acknowledged the positive impact of international trade on economic growth (Marshall, 2009).

According to the Heckscher-Ohlin theory of trade, the variations in resource availability between nations serve as the primary push for trade. The theory further stated that if a country has resources in abundance, then only an economy should export the products and import those goods whose resources are less or not available in their country(Hodd, 1967).

In previous studies, researchers established both the positive and negative relationship between international trade and economic growth. Further, various studies at macro-level have used varying econometric methodologies and scopes to analyze the relationship between international trade and economic growth with contrary views. For instance, the study confirmed the positive relationship between trade and growth using autoregressive distributed lagged model (ARDL) (Tahir & Hayat, 2020). Similarly, studies such as (Dabla-Norris & Duval, 2016); (Czyżewski, 2021)) emphasized on a significant relationship between international trade and economic growth. In contrast, a study on Southern African Development Community (SADC) using panel data stated that trade does not promote economic growth (Farahane & Heshmati, 2020).

This provides a first research question to investigate in the study: 1) International trade enhances economic growth in G20 countries?

After classical and neo-classical theories of trade, the development of endogenous (new) growth theory provided a theoretical basis for empirically studying the relationship between trade and economic growth; trade boosts economic growth by increasing the magnitude of technology spillovers (Romer, 1990). In the new growth theories, the new variable is added to the growth equation i.e., technology or innovation or new ideas. Based on this, new theories stated by the different schools of thought establish the role of technology in economic growth.

1.2 Theories on digital economy and economic growth

The classical theory of Joseph A. Schumpeter argued that the process of creative destruction promotes economic growth. He claimed that boom and recessions are unavoidable and cannot be fixed without hampering the production of new wealth through innovation (Schumpeter, 1934a). This reflects the role of technology in means of production. On the other hand, neoclassical growth theory of Solow highlighted the importance of digital economy in the economic growth of an economy. According to Solow model the technical changes leads to the positive economic growth (Solow, 1978).

Globally, the digital economy is a crucial factor in boosting economic growth, enhancing the productivity of current industries, developing new markets, and is becoming an increasingly significant driver of inclusive economic growth. Empirically, many studies reported the positive relationship between digital economy and economic growth, reflecting a major role of technology or digitalization on economic growth. A study on economies along the “Belt and Road” provided the positive evidence supporting the digital economy-led economic growth hypothesis (Zhang et al., 2022). Also, a study analyzed that trade promotes economic growth by using innovative foreign technologies(Schneider, 2005). Similarly, studies such as (S. Gomes et al., 2022), (Herman & Oliver, 2023) emphasized the significant role of digitalization in economic growth of economies.

In contrast, a study mentioned that digitalization has a lot of potential but despite that the anticipated growth rate is not achieved (Qureshi, 2022). Digitalization works as an invisible thread that connects all sectors of economy; however underdeveloped digital infrastructure causes a doubt on its impact on economic growth. Moreover, G20 countries also recognized the need for better digital infrastructure to promote economic growth (Caldas et al., 2021).

This provides a second research question to investigate in the study: 2) Digital economy enhances economic growth in G20 countries?

Next, it is crucial to analyze the role of digital economy in determining trade-growth relationships. Some studies established the role of digital economy on economic growth and role of international trade on economic growth. However, there are not many studies available that analyzed if digitalization introduced in international trade, then what would be

the impact on economic growth. Previous studies such as a study on Asian countries using GMM model stated that there is a significant impact of trade and digital on economic growth (Weriemmi et al., 2022). Also, a study on Chinese economy examined the relationship between digitalization, foreign trade, and economic growth (Li & Zhang, 2022).

The third research question is: 3) Digitalization is necessary for international trade to positively affect economic growth in G20 countries?

For digital economy, weak measurement is available in literature, for instance, studies such as (Li & Zhang, 2022; Kouton, 2019; Myovella et al., 2019; Moroz, 2017) used two or three variables, including mobile users, internet users and broadband users. The inadequate measure of digitalization is insufficient to analyze the interactive effect of digital economy and international trade on economic growth. Hence, principal component analysis (based on (Abendin & Duan, 2021)) is employed in the study to create the digital economy index (DICONOMY) that capture three aspects (access, use, and skill). Further in this study, G20 countries are classified based on income (high, upper-middle, low, and lower-middle income economies) to analyze the combined effect of digital economy and international trade on economic growth of G20 countries under different level of income categories.

The fourth research question is: 4) Interactive effect of digital economy and international trade on economic growth is different in various categories of G20 countries based on income level?

The main objective of the study is to determine to what extent international trade promotes economic growth in G20 countries, considering the impact of digital economy. The emphasis is on analyzing whether the digitalization of G20 countries is essential for the positive impact of international trade on economic growth or digitalization supports trade-led growth in G20 countries. Specifically, we examine whether the digital economy enhances G20 countries' ability to absorb international trade's positive economic growth effects. Also, the impact is analyzed for different income categories of G20 countries.

As per authors' knowledge, no such study had been conducted for the G20 countries for the given time that investigated the role of digital economy in determining the relationship between international trade and economic growth. This study contributes to the previous research work done in this area which focuses on the relationship between international trade and economic growth but overlooked the impact of the digital economy.

The structure of the study is as follows: first, in the introduction part, the study discussed the research gap and developed research questions and objectives of the study; second, we describe the theoretical framework economic model used in the study, indicators and methodology used to develop digital economy index; third, we include the results of the hypothesis testing related to international trade, digital economy and economic growth in G20 countries using pooled ordinary least square (PLOS), random effect, fixed effect model and Generalized Methods of Moment (GMM) model; fourth, concluding remarks are made.

2. Research Methodology

2.1 Theoretical framework

The neoclassical Solow model is used to investigate the effect of international trade on economic growth and digital economy is used as an important explanatory variable. With the theoretical Solow model, the following Cobb-Douglas production function is used:

$$Y = A\,L^{\alpha}K^{\beta} \quad \ldots\ldots (1)$$

Where Y is output growth (economic growth), A is the technical growth, L is the labor, and K is the capital stock, while α and β are labor and capital elasticity respectively. International trade (T), human capital (L), technological progress (A), and physical capital (K) are assumed to be responsible for the economic growth.

$$Y = AL^{\beta 1}K^{\beta 2}T^{\beta 3} \quad \ldots\ldots (2)$$

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Further, in equation 3, empirical methodology of the study is shown in natural logarithm by implying constant returns to scale.

$$\ln Y_{it} = \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + \beta_3 \ln T_{it} + \beta_4 D_{it} + \beta_5 W_{it} + \psi_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In equation 3, $\ln Y_{it}$ denotes the natural logarithm of economic growth (as GDPPC), $\ln L_{it}$ is the natural logarithm of human capital, $\ln K_{it}$ represents the natural logarithm of capital stocks, $\ln T_{it}$ represents the logarithm of international trade, D_{it} represents the digital economy variables in vector form of natural logarithm, W_{it} represents the logarithm of control variables in vector form. β_0 denotes the constant term, ψ_{it} represents the stochastic error term and β's (1,2,3,4,5) represents the variables of the respective coefficients to be estimated.

Equation 3, is further extended to include the international trade and digital economy interaction (lnT*D). Estimated equation with interactive term is shown as below:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + \beta_3 \ln T_{it} + \beta_4 D_{it} + \beta_5 W_{it} + \alpha (\ln T*D)_{it} + \gamma_i + + \psi_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

In equation 4, γ denotes the interactive term coefficients to be estimated and the other variables are already explained above in equation 3.

2.2 Digital Economy Index

The principal component analysis (based on (Abendin & Duan, 2021; Aggarwal & Karwasra, 2023)) is used to create the digital economy index (DICONOMY) that capture three vital aspects (access, use, and skill factors; refer Table 1). Equation 5 represents the framework of digital economy index:

DICONOMY = f (FTSPHI, MCSPHI, SISPOP, POPUI, FBBSPHI, COMEDU) ……(5)

Table 1. Digital economy index based on access, use and skill factors

Access factors	Use factors	Skill factors
1. Fixed telephone subscription per 100 inhabitants (FTSPHI) 2.Mobile cellular phone subscriptions per 100 inhabitants (MCSPHI) 3. Secure internet servers per one million people (SISPOP)	1. Percentage of people using the internet (POPUI) 2. Fixed broadband subscriptions per 100 inhabitants (FBBSPHI)	1.Compulsory education duration (COMEDU)

Source: Authors' calculation based on Literature

2.3 Indicators-Dependent, Independent and Control Variables

GDP per capita (constant 2015 US$), used to measure the economic growth (Y); international trade (T) is to determine as the total merchandise trade, as a share of GDP; gross fixed capital formation (K) regarded as the physical capital; labor (L) is used to represent the labor force; digital economy (DICONOMY) is used to measure the technological progress. Financial development is measured by the domestic credit provided by financial sector as the share of GDP; consumer price index regarded as the consumer's cost of acquiring a basket of goods and services; exchange rate is measured by the official exchange rate decided by the national authorities. All the variables are explained below:

Economic growth: GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2015 U.S. dollars.

International trade is calculated sum of the number of imports and exports of goods divide by the amount of GDP, in current US dollars.

Gross fixed capital formation (formerly gross domestic fixed investment) includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Data are in constant 2015 prices, expressed in U.S. dollars.

Labor force participation rate is the proportion of the population ages 15 and older that is economically active: all people who supply labor to produce goods and services during a specified period.

Domestic credit provided by the financial sector includes all credit to various sectors on a gross basis, apart from credit to the central government, which is net. The financial sector includes monetary authorities and deposit money banks, as well as other financial corporations where data are available (including corporations that do not accept transferable deposits but do incur such liabilities as time and savings deposits). Examples of other financial corporations are finance and leasing companies, money lenders, insurance corporations, pension funds, and foreign exchange companies.

Foreign direct investment is the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. This series shows net inflows (new investment inflows less disinvestment) in the reporting economy from foreign investors and is divided by GDP.

The consumer price index reflects changes in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Laspeyres formula is generally used. Data are period averages.

Official exchange rate refers to the exchange rate determined by national authorities or to the rate determined in the legally sanctioned exchange market. It is calculated as an annual average based on monthly averages (local currency units relative to the U.S. dollar).

Digital economy index represents the percentage of people using the internet (POPUI), mobile cellular subscription per hundred inhabitants (MCSPHI), compulsory education duration (Years) (COMEDU), Secure internet servers per one million people (SISPOP), fixed telephone subscription per hundred inhabitants (FTSPHI), fixed broadband subscription per hundred inhabitants (FBBSPHI), and mobile cellular subscription per hundred inhabitants (MCSPHI).

2.4 Income-wise Categorization of G20 Countries

In this study, the G20 countries are classified under three income categories given by World Bank: low, lower-middle, upper-middle, and high income (Hamadeh et al., 2022) (refer Table 2).

Table 2. Income wise distribution of Countries

Category	GNI (USD)	G20 Countries
Low and lower-middle income	< 1,085 and 1086 – 4,255	Australia, Canada, France, Germany, Japan, UK, USA, EU, and Saudi Arabia
Upper-middle income	4,256 – 13,205	Argentina, Brazil, China, south Africa, Mexico, turkey, Russia
High income	> 13,205	India, Indonesia, and Korea

Source: World Bank

2.5 Estimation Strategy

After secondary data collection of the above-mentioned indicators from World Development Indicator (WDI) of G20 countries, we checked the stationarity of data using Levin-Lin-Chu (LLC) and Harris–Tzavalis test. After transformation of data series, static and dynamic estimation model is applied on the panel dataset of G20 countries for the period of 23 years (2000-2022). The studies referred for these estimations are (Abeliansky & Hilbert, 2017; Myovella et al., 2020; (Abendin & Duan, 2021).Static estimation model includes the pooled ordinary least squares (POLS), and fixed effect (FE)

model. While dynamic models include random effect (RE) model and system generalized method of moments (sys-GMM).

3. Results and Findings

3.1. Stationarity test

The following hypothesis are investigated to check the stationarity:

Ho: Panels contain unit roots

Ha: Panels are stationary

Table 3: Results of Stationarity Tests (Levin–Lin–Chu and Harris-Tzavalis)

S.No.	Variables	t-statistics	p-value
1	Economic Growth (lnGDPPC)	-6.9974	0.0000
2	International Trade (TRADE)	-2.0538	0.0200
3	Digital Economy (lnDICONOMY)	-3.8367	0.0001
4	Foreign direct Investment (FDI)	-2.8958	0.0019
5	Gross Fixed Capital Formation (GFCF)	-2.6491	0.0040
4	Labor (fdLABOR)	-0.0612	0.0000
5	Consumer Price Index (fdCPI)	-0.2930	0.0000
6	Exchange Rate (fdEXCH)	-0.1409	0.0000
9	Domestic Credit (fdDCPS)	-0.2227	0.0000

Source: Authors' calculation (STATA results)

The Levin–Lin–Chu (LLC) bias-adjusted t statistic for economic growth, international trade, digital economy, foreign direct investment, and gross fixed capital formation is −6.994, -2.0538, -3.8367, -2.8958, -2.6491 respectively, which are significant at all the usual testing levels. Therefore, we reject the null hypothesis and conclude that the series is stationary (refer Table 3). The output shows that the LLC adjusted t statistic value in case of each variable is less than zero and p value is significant at 5% level. For other variables, such as labor, exchange rate, consumer price index, domestic credit, we applied Harris-Tzavalis test for stationarity. After transforming panel data series, we included all the non-stationary series for further analysis (POLS, FE, RE, GMM models).

3.2 Pooled Ordinary Least Square (POLS) Results of G20 countries

Table 4 shows the results of the POLS regression and robustness estimator with and without interactive term (trade*lnDICONOMY); interactive term used to determine that to what extent international trade promotes economic growth in G20 countries, considering the impact of digital economy). Results of trade-growth nexus is shown in model 1 and model 2, while role of digital economy in determining the trade's impact on the economic growth recorded in model 3 and 4. Model 1 related to trade growth nexus shows a negative and statistically significant growth effect of trade in G20 counties. The trade output elasticity (-1.0211) shows a negative and significant impact on economic prosperity. The result does not congruent with the theoretical hypothesis that international trade enhances economic growth in G20 countries. Our finding contradicts the trade theories of eminent classicals, mercantilism and Hecksher Ohlin which points that international trade has positive impact on economic growth. Results are consistent with study (J. O. et al., 2015) and inconsistent with the findings of the studies such as (Azeez et al., 2013; Jawaid & Raza, 2013; Sun & Heshmati, 2010).

The digital economy coefficient (0.0669) for the main regression in model 1 and the robustness check in model 2 show a significant and positive impact on economic growth; reflecting that an increase in digitalization stimulates economic prosperity in G20 countries. Our finding is in line with the classical theory, where advancement in technology has a significant positive impact on productivity. Results are consistent with (Barata, 2019; Huateng et al., 2021; Mardonakulovich Bustonov Mansurjon, 2020; Zhu et al., 2020).

After investigating the first research question, the key findings deduce from the results are: 1) the trade output elasticity is negative, indicating that an increase in international trade has a significant negative impact on economic prosperity of the G20 countries. 2) the digital economy output elasticity is positive, indicating that an increase in digital economy development level advances economic growth of G20 countries.

On the other production variables such as labor and capital (in Table 4), LABOR in models 1 and 2 indicate a positive but insignificant impact on economic growth; output elasticity suggests that an increase of 10% in LABOR increases output by only 0.07% in G20 countries. This result is in align with classical theory that estimates a positive relation between labor productivity and growth.

Table 4. Results of Pooled Ordinary Least Square Estimation (POLS)

	Trade-Growth		**Trade-Growth: role of the digital economy**	
Dep. Variable lnGDPPC	Main regression	Robustness checks	Main regression	Robustness checks
Variables	Model 1	Model 2	Model 3	Model 4
Constant	27.56465*	27.56465*	28.26477*	28.26477*
	(83.41)	(81.85)	(60.19)	(66.65)
TRADE	-1.02108*	-1.021085*	-2.382434*	-2.382434*
	(-4.99)	(-4.64)	(-3.49)	(-3.25)
fdDCPS	0.091347*	0.0913479*	0.0916131*	0.0916131*
	(0.77)	(0.69)	(0.77)	(0.7)
fdEXCH	0.2527221	0.2527221	0.2790372	0.2790372
	(0.4)	(0.42)	(0.45)	(0.47)
fdCPI	0.0681426	0.0681426	0.0774068	0.774068
	(0.19)	(0.21)	(0.22)	(0.24)
lnDICONOMY	.066981*	.066981*	-0.0438942	-0.0438942
	(3.67)	(3.64)	(-0.78)	(-0.68)
fdLABOR	0.0070705	0.0070705	0.0067646	0.0067646
	(0.33)	(0.34)	(0.32)	(0.35)
GFCF	5.53*	5.53*	6.4*	6.4*
	(1.02)	(1.06)	(1.18)	(1.23)
FDI	4.61*	4.61*	4.63*	4.63*
	(18.86)	(7.17)	(19)	(7.25)
TRADE*lnDICONOMY			.1960121*	.1960121*
			(2.09)	(1.85)
No. of observations	440	440	440	440
R-Squared	0.582	0.582	0.5872	0.5872
F statistic	50.13		45.4	

Source: Authors' calculation; (* is statistically significant at 5%; t-statistics (in parentheses))

Further, the result indicates that gross fixed capital investment (GFCF) is an important variable for economic growth of G20 countries. The GFCF coefficient is positive and statistically significant for both models 1 and 2. This implies that capital input is a major factor in enhancing economic prosperity in G20 countries. Our result is in line with the previous studies (Boamah et al., 2018; Tufaner, 2022). The key finding is capital spending stimulates growth while labor input is not contributing much to economic growth of G20 countries.

For control variables, the DCPS coefficient exhibits a positive and statistically significant impact on economic growth. This implies a significant role of the financial sector in the economic growth of G20 countries. Our finding is consistent with the previous empirical evidence (Pradhan et al., 2021). Also, FDI coefficients show a positive and significant effects

on growth of G20 countries in both models 1 and 2. The results are consistent with the previous studies (Dash & Parida, 2013; Egbetunde & Obamuyi, 2018). Further, CPI and exchange rate show a positive impact on economic growth of these countries. The impact of the exchange rate will be clearer in the country specific analysis; the positive impact may cause depreciation of currency and that stimulate exports of the countries (Table 4). The explanatory factors in models 1 and 2 explained 58.2% of the variation in the dependent variable, according to the goodness-of-fit tests, and the F-statistic implies that the variables are jointly important in explaining economic growth.

Models 3 and 4 in Table 4 reported the contribution of the digital economy to trade impacts on economic growth over the entire sample. For the effects of international trade on economic growth with the interacting term, the results at a 5% level of significance, shows a positive and statistically significant effect on economic growth in G20 countries on ceteris paribus. Models 3 and 4 show, that when trade interacts with the digital economy, its impact on economic growth becomes positive and significant. The results are consistent with previous studies (Ahmad Zafrullah Tayibnapis, 2018; Fan, 2021; Watanabe et al., 2018)

3.3 Results of Income-wise Pooled Ordinary Least Square Estimation of G20 Countries (without interactive term)

Table 5 (without interactive term) show the findings of sub sample (income-wise categorization of G20 countries) regression using pooled OLS estimator; results are diverse. The trade output elasticity is negative and statistically significant for high income G20 countries (-1.965167), and upper middle-income G20 countries (-0.0052975). However low and lower-middle income G20 countries show the trade's positive output elasticity (0.7525975). It concludes that there exists a negative relation between international trade and economic growth in high and upper middle-income economies. This contradicts the theories given by eminent mercantilist, classical, and the Heckscher-Ohlin. Contrary, international trade has a significant positive impact on economic growth in low and lower-middle income G20 countries. This supports the trade theories of mercantilist, Heckscher-Ohlin and the classical.

The digital economy shows the positive and significant impact on the economic growth of high and upper middle-income G20 countries. This result is consistent with the findings of studies such as (Ahmedov, 2020; Mottaeva et al., 2023). For low and lower-middle income G20 countries, digital economy shows a negative impact on the economic growth. This may be because of last of digital infrastructure in low and lower middle-income G20 countries.

Table 5. Results of Income-wise Pooled Ordinary Least Square Estimation of G20 Countries (without interactive term)

Variables	High Income G20 countries	Upper-Middle Income G20 countries	Low and Lower-Middle Income G20 countries
Constant	28.72642*	27.0515*	26.3995*
	(0.000)	(0.000)	(0.000)
TRADE	-1.965167*	-0.0052975*	0.7525975*
	(-8.17)	(-0.02)	(3.63)
fdDCPS	0.696094	0.100482	-0.1097075
	(0.47)	(0.76)	(-0.91)
fdCPI	0.1969543	-0.5329203	-0.3465919
	(0.45)	(-1.35)	(-0.99)
fdEXCH	0.327652	0.6199113	0.5739061
	(0.42)	(0.88)	(0.92)
lnDICONOMY	0.0446709*	0.0097029*	-0.0139539*
	(1.93)	(0.28)	(-0.81)
fdLABOR	-0.008105*	0.0471531*	0.0282773*
	(-0.25)	(1.92)	(-1.88)
GFCF	4.43E-13	2.05E-14	8.96E-13
	(0.063)	(0.03)	(1.54)
FDI	3.63E-12*	1.28E-11*	2.29E-11*

	(15.37)	(19.69)	(6.99)
No. of obs.	220	154	66
R-Squared	0.5625	0.7574	0.6815
F statistic	33.91	56.59	15.25

Source: Authors' calculation; (* is statistically significant at 5%; t-statistics (in parentheses))

For high income G20 countries, elasticity of domestic credit, exchange rate, consumer price index, foreign direct investment, gross fixed capital formation is positive. While labor output coefficient is negative. In high income G20 countries, labour elasticity is negative while capital elasticity is positive. This implies that these countries are capital intensive countries such as Australia, Canada, France, Germany, Japan, UK, USA, EU, and Saudi Arabia.

For upper middle-income G20 countries, elasticity of domestic credit, exchange rate, foreign direct investment, gross fixed capital formation, and labor is positive. This implies that both labor and capital elasticities are positive in upper middle income G20 countries specifically, Argentina, Brazil, China, south Africa, Mexico, turkey, Russia. For low and lower middle-income G20 countries, such as India, Indonesia, and Korea, both labour and capital elasticities are positive. However, the impact of labour on economic growth is highly significant.

Next, the interactive term introduced in the model to analyze interactive effect of digital economy and international trade on economic growth is different in various categories of G20 countries based on income level.

3.4 Results of Income-wise Pooled Ordinary Least Square Estimation of G20 Countries (with interactive term)

Table 6 explains, if we introduce digitalization in trade then it promotes economic growth positively and significantly in all the G20 countries. While trade and digitalization individually have a significant negative impact on economic growth in upper and upper middle-income G20 countries. This implies that digitalization is necessary for international trade to positively affect economic growth in G20 countries.

In the case of low and lower middle-income G20 countries, trade individually has a positive impact, but digital economy has a negative impact on economic growth. However, if we combine digitalization with internal trade then it has a negative impact on economic growth. This may be due to infrastructure bottleneck or lack of access to digital infrastructure. For Other variables, statistical results are similar, but the difference is of magnitude only.

Table 6. Results of Income-wise Pooled Ordinary Least Square Estimation of G20 Countries (with interactive term)

Variables	High Income G20 Countries	Upper-Middle Income G20 Countries	Low and Lower-Middle Income G20 Countries
Constant	30.64737*	27.25806*	26.34057*
	(56.06)	(38.54)	(42.55)
TRADE	-5.752019*	-0.4320663	0.8487308
	(-7.25)	(-0.34)	(0.98)
fdDCPS	0.0900096	0.1018943	-0.1090868
	(0.64)	(0.77)	(-0.9)
fdCPI	0.2138775	-0.5352205	-0.3497953
	(0.52)	(-1.35)	(-0.99)
fdEXCH	0.3385605	0.6328441	0.5689234
	(0.46)	(0.9)	(0.91)
lnDICONOMY	-0.2521681*	-0.0261661	-0.0057231
	(-3.97)	(-0.24)	(-0.08)
fdLABOR	-0.0183266	0.0468522*	-0.0286149
	(-0.58)	(1.9)	(-1.85)
GFCF	9.26E-13	1.69E-14	9.06E-13
	(1.38)	(0.02)	(1.52)

FDI	3.76E-12*	1.28E-11*	2.29E-11*
	(16.7)	(19.57)	(6.93)
TRADE*lnDICONOMY	4.95*	7.46*	-1.51*
	(4.98)	(0.34)	(0.11)
No. of obs.	220	154	66
R-Squared	0.6087	0.7576	0.6816
F statistic	36.3	50.01	13.32

Source: Authors' calculation; (* is statistically significant at 5%; t-statistics (in parentheses))

3.5 Fixed and Random Effects Results

Table 7 shows the results of the augmented model for testing the panel heterogeneities of G20 countries using the random and fixed effect estimators. Trade-growth nexus without interactive term results of main regression is shown in model 1 (RE) and model 2 (FE), while trade-growth results with interactive term are shown in model 3 (RE) and model 4 (FE).

Model 1 and model 2 show the significant negative impact of trade on economic growth of G20 countries; the trade elasticities of model 1 (-.3294735) and model 2 (-.3287388) are negative. This result contradicts the trade theories (classicals, mercantilism and Hecksher Ohlin) and findings of studies such as (Al-kasasbeh et al., 2022; Siddika & Ahmad, 2022; Zahonogo, 2017). However, results are consistent with (Caleb et al., 2014; J. O. et al., 2015).

Similarly, with an interactive term in Model 3 (RE) and Model 4 (FE), the statistical results are similar, but the difference is of magnitude only.

In the case of digital economy variable, there is a significant negative impact on economic growth of G20 countries in all the models with and without interactive term. The digital economy coefficients are negative in Model 1 (-.0037402), model 2 (-.0042938), model 3 (-0.022461) and model 4 (-0.0218145). Results are consistent with these studies (Musa, 2020; Wu et al., 2023)and inconsistent with the findings of studies such as (Abendin & Duan, 2021; Ciocoiu, 2011; Murthy et al., 2021).

Table 7. Results of Random and Fixed Effects Models of G20 countries

	Trade-Growth		Trade-Growth: role of the digital economy	
Dep. Variable lnGDPPC	Main regression	Robustness checks	Main regression	Robustness checks
	Random effect	Fixed effect	Random effect	Fixed effect
Variables	Model 1	Model 2	Model 3	Model 4
Constant	27.25433*	27.25364*	27.37834*	27.37*
	(150.69)	(353.23)	(134.38)	(241.21)
TRADE	-0.3294735*	-0.3287388*	-0.5712192*	-0.5555103*
	(-3.16)	(-3.21)	(-2.92)	(-2.9)
fdDCPS	0.0440746	0.0437095	0.0444313	0.0440686
	(1.74)	(1.77)	(1.77)	(1.79)
fdCPI	0.0129278	0.0130375	0.015121	0.0150864
	(0.17)	(0.18)	(0.2)	(0.21)
fdEXCH	0.0007498	-0.0021861	0.0063093	0.0032258
	(0.01)	(-0.02)	(0.05)	(0.02)
lnDICONOMY	-0.0037402*	-0.0042938*	-0.022461*	-0.0218145*
	(-0.71)	(-0.84)	(-1.63)	(-1.61)
fdLABOR	-0.0041563*	-0.0042373*	-0.0042307*	-0.0043019*
	(-0.9)	(-0.94)	(-0.92)	(-0.95)

GFCF	1.74E-12*	1.75E-12*	1.74E-12*	1.75E-12*
	(14.19)	(14.61)	(14.29)	(14.65)
FDI	3.15E-13*	2.79E-13*	3.43E-13*	3.07E-13*
	(3.21)	(2.9)	(3.43)	(3.13)
TRADE*lnDICONOMY			0.0344457*	0.0323076*
			1.46	1.4
No. of obs.	440	440	440	440
R-Squared		0.5254		0.5277
F statistic		57.02		51.01

Source: Authors' calculation; (* is statistically significant at 5%; t-statistics (in parentheses))

For labor and capital elasticities in all four models with and without an interactive term, labour coefficient (LABOR) is negative while capital coefficient (GFCF) is positive. This means that G20 countries are capital intensive, and it has a positive impact on economic growth. The impact of financial sector (DCPS), exchange rate (EXCH), consumer price index (CPI), all four models suggest a positive impact on economic growth but not significant. The results suggest that these coefficients are important factors of economic growth in G20 economies. Results of this study are consistent with studies such as (Ahmed, 2010; Ramli et al., 2016) and inconsistent with the findings of these studies (Akbar et al., 2021; Wijaya et al., 2021a, 2021b). Concerning the impact of foreign direct investment (FDI), the FDI enhance economic growth and results are in line with these studies (Bhuimali et al., 2019; Jayachandran & Seilan, 2010).

3.6 Results of the system Generalized Method of Moment (sys-GMM) Model

The effects of the sys-GMM estimator are presented in Table 8 after controlling for the variable's endogeneity, heteroscedasticity, and omission. The main regression is represented by model 1, and model 2 shows the regression results with the interactive term. Models 1 and 2 show, on average, a 5% significance level, that international trade has a negative and statistically significant effect on economic growth. Our finding contradicts the trade theories of classicals, mercantilism and Hecksher Ohlin. Results are in line with studies such as (Jouini, 2015; Tufaner, 2022)with and inconsistent with the findings (Engin & Konuk, 2022).

Table 8. Results of the system Generalized Method of Moment (sys-GMM) Model

	Trade-Growth	Trade-Growth: role of the digital economy
Variables	Main regression	Main regression
	Model 1	Model 2
lnGDPPC	0.9829015*	0.9788533*
	(119.12)	(118.49)
TRADE	-0.0141646	-0.0555895*
	(-1.4)	(-1.94)
fdDCPS	-0.0142259	-0.0138364
	(-3.98)	(-3.85)
fdEXCH	-0.2101908	-0.2089431
	(-10.38)	(-10.25)
fdCPI	0.104128*	0.1030911
	(7.6)	(7.47)
lnDICONOMY	-0.0023351*	-0.0050561*
	(-2.95)	(-2.9)
fdLABOR	0.00374*	0.0037183*
	(2.63)	(2.6)
GFCF	9.81E-14*	1.02E-13*
	(5.88)	(6.01)

FDI	7.56E-14*	9.46E-14*
	(1.97)	(2.45)
TRADE*lnDICONOMY		0.0053182*
		(1.61)
Constant	0.4664857*	0.5975565
	(2.05)	(2.56)
No. of obs.	420	420
Instruments/Groups	29	30
Hansen p-value	0.124	0.144
AR (2) p-value	0.211	0.184

Source: Authors' calculation; (* is statistically significant at 5%; t-statistics (in parentheses))

Models 1 and 2 demonstrate a negative association between the digital economy and economic growth, but statistically significant relationship. Economic growth is positively impacted by the connection between trade and the digital economy. This shows that trade is severely impacted by the digital economy, which in turn stimulates economic growth. This result is in line with our main estimating POLS model, which assumes that trade and the digital economy interact to boost economic growth.

At a 5% significance level, models 1 and 2 show a negative relationship between financial development (DCPS) and economic growth. Financial development therefore hinders economic growth in G20 countries. Results are consistent with the findings of the study (De Gregorio & Guidotti, 1995)and inconsistent with the finding (Khan, 2003; Valickova et al., 2015).

The association between GFCF and economic growth is favorable and statistically significant; findings are consistent with studies (Boamah et al., 2018b; Gibescu, 2010). Additionally, labor has a positive and significant impact on economic growth across both models. In model 1, CPI shows positive and statistically significant economic impacts, while model 2 shows positive but insignificant results. Further EXCH output coefficient shows negative and insignificant results in both models.

The p-values of the AR (2) statistics, both calculated in Table 8, do not show any indication of second-order serial correlation, as suggested by the model's goodness-of-fit. Given the p-values, it is difficult to reject the Hansen statistic for instrument validity at a 5% level of significance. Consequently, conclusions can be made using the outcomes of the increased sys-GMM estimation.

3.7 Multicollinearity test

As in the model, various variables have been used and defined in logarithmic form, therefore, to check if the model has any problem with multicollinearity. In the logarithmic specification of the model to check the possible risk of multicollinearity, the variance inflation factor has been employed. When multiple variables are used in a model the key problem is the estimation of coefficients becomes unreliable and the coefficient of standard error becomes highly inflated. In Table 9, the multicollinearity test of VIF is employed, and the results show that the variables are not correlated with one another significantly in the model. Our findings suggest that the standard errors and coefficient estimation are reliable estimates in the model.

Table 9. Multicollinearity test-VIF (variance inflation factor)

Variables	VIF	1/VIF
FDI	2.97	0.33641
GFCF	1.95	0.513432
fdCPI	1.89	0.52968
fdDCPS	1.38	0.724838
lnDICONOMY	1.26	0.791071

TRADE	1.05	0.951881
FDI	1.04	0.965063
fdLABOR	1.03	0.971299
Mean VIF	1.57	

Source: Authors' calculation; * When a variable's VIF is higher than 5, we consider the possibility of multicollinearity in according to our logarithmic specifications.

4. Conclusion

This study tries to examine the international trade and digital economy interactive impact on the economic growth of G20 countries. In the current scenario, the majority of countries are dependent on other economies for their country's economic growth. The findings of this study have theoretical and practical implications.

4.1 Theoretical implications

This paper's theoretical implication is closely associated with the theories given by (Solow, 1978) and (Schumpeter, 1934). The findings of the system Generalized Method of Moment (sys-GMM) Model and Pooled Ordinary Least Square Estimation (POLS), and random effect (RE) and fixed effect (FE) show the positive and significant impact of international trade and digital economy on the economic growth of G20 countries. This suggests that the expansion of digital infrastructure with international trade helps the G20 countries to improve their growth rate. While, the international trade coefficient alone has a considerable negative impact on economic growth except in the case of low and lower-middle-income countries, it demonstrated positive and significant results when international trade interacted with the digital economy. The findings imply that international trade when interacting with the digital economy positively contributes to the economic growth of high-income and upper-middle-income G20 countries, although it shows a significant negative impact on the economic growth of low and lower-middle-income G20 countries.

4.2 Empirical/practical implications

The positive and significant impact of international trade and digital economy interaction shows that they promote the economic growth of G20 economies. The results of this paper is consistent with the results of the study(Abendin & Duan, 2021). The main and robust regression findings for the estimate models and the sub-samples (based on level of income) both demonstrate a considerable mixed influence effect of the digital economy on economic growth. Further findings conclude that exchange rates, gross fixed capital creation, consumer price index, labour, foreign direct investments, and financial development are all crucial factors in determining economic growth. The study emphasizes that international trade and the digital economy in G20 countries are crucial for the economic growth of G20 countries. The study came to the additional conclusion that international trade individually is not sufficient to promote economic growth of G20 countries, while in combination with digitalization, enhances economic growth. Overall, international trade and the digital economy are vital for the positive growth of G20 countries, and the government should strengthen the digital infrastructure and implement trade policies that work to encourage international trade. Hence, it can be concluded that the digital economy enhances G20 countries' ability to absorb international trade's positive economic growth effect.

4.3 Limitations and scope for further research

The results of this paper show the positive impact of international trade and digital economy interaction on economic growth. However, the paper has limitations to this relationship only for G20 countries. This provides scope for future research to examine the impact of the digital economy and international trade on economic growth, in the case of other groups of countries or the individual country.

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