

Population Size, Market Size, and Digital Technology Innovation

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Abstract

The digital economy has become an important driving force for global economic development, and competition among countries around the world in the field of the digital economy is becoming increasingly fierce. Given that digital technology and digital economy have obvious economies of scale effects, population size and market size are of special importance for digital technology innovation. Based on the panel data of OECD and BRICS countries from 1996 to 2020, this paper empirically examines the impact of population size and market size on digital technology innovation using the fixed effect model. The results show that: market size will have a significant positive impact on digital technology innovation; different ages of population size will have different impacts on digital technology innovation, the population size of 20-44 years old will have a promotional effect on technological innovation, and the population size of more than 45 years old will inhibit technological innovation. Heterogeneity analysis shows that there are significant differences in the impact of population size and market size on digital technology innovation in countries with different levels of economic development, and the size of the young population aged 20-44 has a facilitating effect on digital technology innovation in low-income countries, and the market size has a facilitating effect on digital technology innovation in high-income countries. Therefore, population size and market size are the key carriers of digital technology breeding, low-income countries need to increase the advantage of market size, and high-income countries should increase the fertility rate while maintaining the market size, so as to promote the continuous innovation and development of digital technology.

Keywords: Population size; Market size; Digital technology innovation

1.0 Introduction

The digital economy has become a critical driver of global economic development. In 2020, the global digital economy reached a market size of 11 trillion USD and is projected to double to 23 trillion USD by 2025 (International Monetary Fund, 2021). Competition in the digital economy is intensifying globally, with significant disparities in development among countries. Developed countries have a digital economy nearly three times the size of that in developing countries, though the latter are growing at a faster pace (China Academy of Information and Communications Technology, 2022).

Digital technology encompasses a series of technologies based on modern electronic computers. According to reports from the Organisation for Economic Co-operation and Development

(OECD) and others, digital technology primarily includes digital manufacturing technologies, software, and communications. Today, big data, cloud computing, the Internet of Things, blockchain, and artificial intelligence constitute the main components of digital technology. Extensive research emphasizes that information and communication technology (ICT), particularly the new generation of ICT, is a crucial part of digital technology. Therefore, digital technology can be considered an extension of ICT (Li & Liu, 2024).

Existing research on the factors influencing digital technology innovation predominantly analyzes aspects like information and communication infrastructure (Gholami et al., 2010; Marston et al., 2011; Forman et al., 2012), data (Manyika et al., 2011), algorithms, computational power (Zheng, 2023), and scenarios (Dubey et al., 2019). However, there is limited research examining the unique characteristics of digital technology innovation in relation to population size and market size.

The digital economy is characterized by its scale and interactivity. The development and use of digital technology are closely related to the population size using information technology. A larger population generally indicates a vast market demand, providing a broad market foundation for digital products and services. Moreover, a large market and user base can generate massive amounts of data, which are the bedrock for the development of artificial intelligence and big data analytics. In summary, digital technology and the digital economy exhibit imbalances in global development, with developed countries in the lead, though developing countries are growing faster. Given the scale and user participation characteristics of the digital economy, does population size and market size promote digital technology innovation? And do these effects differ among countries? This study aims to explore the impact of population size and market size on digital technology innovation through an analysis of data from OECD and BRICS countries between 1996 and 2020.

2.0 Theoretical Framework and Research Hypotheses

2.1 Market Size and Digital Technology Innovation

Firstly, the theory of demand inducing innovation suggests that a large market size can induce innovation through scale effects, competition effects, and specialization effects. The expansion of market size increases the certainty of returns on enterprise innovation investment, shortens the amortization period of R&D costs, reduces production and R&D costs and risks, and enhances expected returns on innovation activities. Market expansion also intensifies competition, prompting enterprises to increase R&D investment, improve product quality and technical content, thereby enhancing the competitiveness of the industrial and innovation chains and overall industry innovation efficiency (Wei&Feng, 2024). Labor division depends on market size, and market size is determined by labor division (Arlin&Jia, 1996). A large market size can promote the

continuous deepening and refinement of specialized division of labor, thereby improving enterprises' technical R&D efficiency. Large economies are more likely to simultaneously achieve both "specialization" and "economies of scale" making the two compatible and promoting economic development.

Secondly, the diversity of market size can promote digital technology innovation through economies of scope, the long-tail effect, and network effects. A complex and diverse market demand structure covers multi-level differentiated demands for product types, functions, quality, performance, price, etc., leading to the long-tail effect where even niche technologies have sufficient demand support, thereby enhancing enterprises' motivation for technological R&D. Additionally, the diverse demand structure means that the same new technology can be used to produce a variety of differentiated products, facilitating economies of scope and enhancing innovation returns.

H₁: Market size has a positive impact on digital technology innovation.

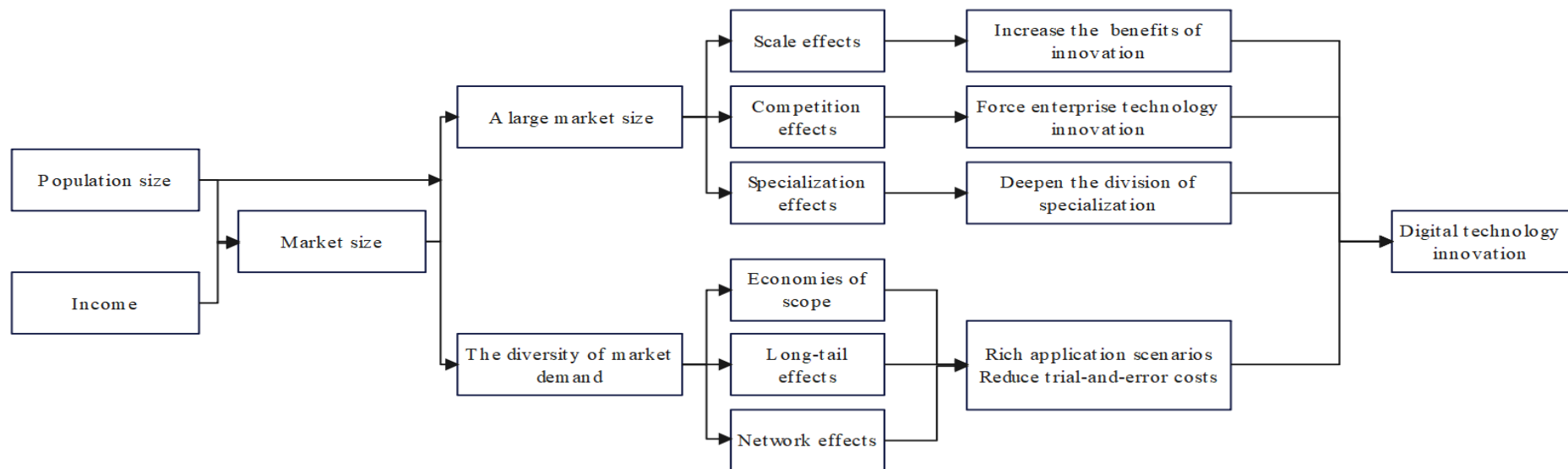


Fig 1: Theoretical Logic

2.2 Population Size and Digital Technology Innovation

Market size is jointly determined by population size and income level, with population size being the fundamental determinant of market size. The actual size of the market is also constrained by income level and consumption capacity. Although population size does not equate to current consumers, a large population base signifies an increase in potential demand scale, demand diversity, and data generation, resulting in network effects. This provides diverse application scenarios, data, and model foundations for digital technology innovation, making population size more crucial in digital technology innovation compared to other technology fields.

H₂: Population size, especially the young population, promotes digital technology innovation, whereas an older population inhibits digital technology innovation.

2.3 Population Size, Market Size, and Digital Technology Innovation in Economies with Different Development Levels

For countries with different income levels, the impact of population size and market size on digital technology innovation may vary. In low-income countries, a large population generates vast amounts of data crucial for algorithm training and improvement. A large population base makes the economic and social systems more complex and diverse, providing rich application scenarios, data, and model foundations for digital technology. In high-income countries, consumers have higher purchasing power and technology acceptance, offering a stable and large market that can support high R&D costs and commercialization of new technologies, thereby driving continuous digital technology innovation. Additionally, high consumption capacity results in higher profit margins, allowing enterprises to reinvest these profits in further R&D and innovation activities, creating a virtuous cycle.

H₃: In low-income countries, the young population promotes digital technology innovation; in high-income countries, market size promotes digital technology innovation.

3.0 Methods

3.1 Sample Selection

Considering data availability and completeness, this study selects 38 OECD member countries and 5 BRICS countries (Brazil, China, India, Russia, South Africa) from 1996 to 2020 for empirical analysis. The selected data are from the World Bank database, OECD database, United Nations World Population Prospects database (WPP2022), etc., with a few missing data points completed using interpolation.

3.2 Variables

3.2.1 Measuring Digital Technology Innovation

Following the literature, we use patent applications to measure innovation. ICT covers all communication equipment or application software, such as radios, TVs, mobile phones, computers, network hardware and software, satellite systems, etc. ICT is the foundation and core of digital technology. This study uses ICT patent applications (PCT) to measure digital technology innovation. Specifically, it refers to patents that have been filed in at least two IP offices worldwide, one of which among the Five IP offices (namely the European Patent Office, the Japan Patent Office, the Korean Intellectual Property Office, the US Patent and Trademark Office and the State Intellectual Property Office of the People Republic of China).

3.2.2 Measuring Population Size

Considering the differences in acceptance and use of digital technology and the digital economy across age groups, this study uses population size by age group to measure population size, specifically the population aged 20-44, 45-64, and 65 and above.

3.2.3 Measuring Market Size

This study uses direct ICT users to measure market size, mainly including fixed telephone subscriptions, mobile cellular subscriptions, and internet users. Fixed telephone subscriptions refers to the sum of active number of analogue fixed telephone lines, voice-over-IP (VoIP) subscriptions, fixed wireless local loop (WLL) subscriptions, ISDN voice-channel equivalents and fixed public payphones. Mobile cellular telephone subscriptions are subscriptions to a public mobile telephone service that provide access to the PSTN using cellular technology. Internet users are individuals who have used the Internet (from any location) in the last 3 months.

3.2.4 Control Variables

Based on previous research methods and theoretical analysis, this study mainly selects R&D investment, R&D personnel, and economic development level as control variables. R&D investment includes R&D expenditure as a percentage of GDP. R&D personnel refer to the number of R&D researchers per million people. Economic development is measured by GDP per capita.

3.3 Descriptive Statistics

The descriptive statistics of each variable are shown in Table 1.

Table1: Descriptive statistics

Variables	Mean	Std Dev	Min	Max
Patent applications in ICT (number)	1496.03	4239.39	0	28127
Population aged 20-44 (1000 persons)	3702.79	10467	10.20	56539.38
Population aged 45-64 (1000 persons)	1309.56	3186.56	5.02	25885.14
Population aged 65 years over (1000 persons)	917.24	2079.75	3.06	17777.41
Fixed telephone subscriptions (1000 persons)	21254048	44281954	107032	367786000
Cellular subscriptions (1000 persons)	61243215	180074889	28500	1746238000
Internet users (1000 persons)	3110.35	8575.58	0.99	98851.45
R&D expenditure as % of GDP (%)	1.63	0.98	0.13	5.71
R&D researchers per million people (persons)	3076.01	1940.92	57.96	8614.63
GDP per capita (USD)	35980.73	19567.49	2218.82	120647.80

4.0 Empirical Results

4.1 Model Selection

This study establishes a panel model to test the impact of population size and market size on digital technology innovation, as shown in equation 1:

$$ICT_{it} = \alpha_0 + \alpha_1 POP_{it} + \alpha_2 MKT_{it} + \delta X_{it} + \mu_{it} + \lambda_{it} + \varepsilon_{it} \quad (1)$$

Where ICT represents digital technology innovation, POP represents population size factors, MKT represents market size factors, X_{it} represents control variables, α_0 is the intercept term, α_1 is the regression coefficient for population size, α_2 is the regression coefficient for market size. μ_{it} is the intercept term for country i , representing individual fixed effects; λ_{it} is the intercept term for time t , representing time fixed effects; ε_{it} is the random disturbance term.

4.2 Main Results

Table 2 shows the baseline regression results for the impact of population size and market size on digital technology innovation. In model 1, population size factors and control variables are included in the regression analysis. The results show that population size has a significant positive effect on digital technology innovation. The coefficient for the population aged 20-44 is positive and significant at the 5% level. In model 2, market size factors and control variables are included in the regression analysis. The results indicate that the expansion of market size promotes digital technology innovation. The coefficients for fixed telephone subscriptions and internet users are positive and significant at the 1% level. Model 3 includes population size, market size, and control variables. The results show that population size and market size factors remain significant, with the market size coefficient being positive. Among the population size factors, the coefficient for the population aged 20-44 is positive, while the coefficient for the population aged 45-64 is negative, indicating that different age groups have different impacts on technological innovation. Hypotheses 1 and 2 are validated.

4.1 Robustness Checks

4.3.1 Lagged Dependent Variable Regression

The dependent variable is lagged by one period and regressed again, as shown in model 1 of Table 3. The results indicate that the sign and significance of the core explanatory variables' regression coefficients remain unchanged, and the coefficients of control variables also show no significant changes, indicating the robustness of the model results.

4.3.2 Alternative the Dependent Variable

This study uses ternary ICT patent applications to replace the dependent variable. The volume of ternary ICT patent applications refers to a set of patents taken at the European Patent Office (EPO), the Japan Patent Office (JPO) and the US Patent and Trademark Office (USPTO) that

protect a same invention. Regression is performed again, as shown in model 2 of Table 3. The results show that the sign and significance of the core variables' regression coefficients remain unchanged, and the coefficients of the control variables also show no significant changes, indicating the robustness of the model results. Further, the total patent applications in various fields are used to replace the dependent variable, and regression is performed again, as shown in model 3 of Table 3. The results show that population size factors are not significant, indicating that population factors only play a role in the field of digital technology innovation, and the model results are reliable.

Table 2: Baseline regression results

	Model 1	Model 2	Model 3
Population aged 20-44	0.733** (2.40)		0.696** (2.53)
Population aged 45-64	0.053 (0.25)		-1.256*** (-6.06)
Population aged 65 years over	0.061 (0.37)		0.204 (1.20)
Fixed telephone subscriptions		0.311*** (5.30)	0.301*** (4.44)
Cellular subscriptions		0.044 (1.03)	0.138*** (2.99)
Internet users		0.188*** (4.61)	0.216*** (4.72)
R&D expenditure as % of GDP	0.512*** (4.95)	0.404*** (4.32)	0.384*** (4.07)
R&D researchers	0.047 (0.64)	0.091 (1.41)	0.145** (2.21)
GDP per capita	2.885*** (21.91)	1.941*** (14.01)	1.902*** (13.65)
Constant	-31.197*** (-16.95)	-23.161*** (-12.52)	-22.908*** (-9.33)
R-squared	0.620	0.671	0.697
Number of id	43	43	43
ID FE	YES	YES	YES

Notes: Standard errors are shown in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

4.3.3 Excluding Samples with Small Population Size

Countries with a population of less than 2 million (Estonia, Iceland, Luxembourg, Latvia) are excluded, and regression is performed again, as shown in model 4 of Table 3. The results indicate that the sign and significance of the core variables' regression coefficients remain

unchanged, and the coefficients of the control variables also show no significant changes, indicating the robustness of the model results.

4.3.4 Winsorization

To avoid the potential impact of outliers on the regression results, this study performs 1% winsorization on the data to remove the influence of extreme values. The model is re-estimated, and the results are shown in model 5 of Table 3. The results indicate that the sign of the regression coefficients for the core explanatory variables and control variables remains unchanged, further validating the robustness of the regression results.

Table 3: Robustness checks

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
	ICT patent applications	ternary ICT patent applications	Total patent applications	ICT patent applications	ICT patent applications
Population aged 20-44	0.752*** (2.73)	1.601*** (3.571)	-0.263 (-1.590)	1.327*** (9.87)	0.808*** (3.03)
Population aged 45-64	-1.235*** (-5.86)	-1.965*** (-5.959)	0.049 (0.383)	-1.058*** (-7.96)	-1.348*** (-6.46)
Population aged 65 years over	0.313* (1.82)	-0.716*** (-2.630)	-0.085 (-0.782)	-0.090 (-1.44)	0.190 (1.14)
Fixed telephone subscriptions	0.200*** (2.95)	0.501*** (4.634)	0.201*** (4.651)	0.389*** (6.86)	0.285*** (4.21)
Cellular subscriptions	0.081 (1.61)	0.020 (0.267)	-0.041 (-1.511)	0.153*** (3.27)	0.119*** (2.63)
Internet users	0.338*** (6.76)	0.277*** (3.724)	0.181*** (6.553)	0.163*** (3.65)	0.242*** (5.44)
Constant	-22.466*** (-8.98)	1.601*** (3.571)	-12.403*** (-8.062)	-30.082*** (-17.09)	-22.367*** (-9.29)
R-squared	0.725	0.312	0.731	0.706	0.703
Number of id	43	43	43	39	43
CONTROL	YES	YES	YES	YES	YES
ID FE	YES	YES	YES	YES	YES

Notes: Standard errors are shown in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

4.4 Heterogeneity Analysis

To explore the impact of population size and market size on digital technology innovation at different levels of economic development, this study divides high-income and low-income economies for heterogeneity testing. According to the World Bank's latest classification standard, low-income economies are defined as those with a 2022 per capita gross national

income (GNI) of \$4,465 or less; upper-middle-income economies are those with a GNI per capita between \$4,466 and \$13,845; high-income economies are those with a GNI per capita of \$13,846 or more. This study defines economies with a GNI per capita of \$13,846 or more as high-income countries and those below \$13,846 as low-income countries.

Table 4: Heterogeneity Analysis

	Low-income countries	high-income countries
Population aged 20-44	6.689*** (2.88)	-0.264 (-0.81)
Population aged 45-64	-3.347*** (-3.21)	-0.924*** (-3.36)
Population aged 65 years over	0.346 (0.63)	0.156 (0.74)
Fixed telephone subscriptions	0.070 (0.32)	0.336*** (3.30)
Cellular subscriptions	-0.171 (-1.64)	0.173*** (2.61)
Internet users	0.470*** (4.21)	0.168*** (2.71)
Constant	-55.137*** (-3.33)	-16.712*** (-4.77)
R-squared	0.858	0.579
Number of id	9	34
CONTROL	YES	YES
ID FE	YES	YES

Notes: Standard errors are shown in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

The results show that the impact of population size and market size on digital technology innovation varies significantly across countries with different levels of economic development. The population aged 20-44 promotes digital technology innovation in low-income countries, while market size factors promote digital technology innovation in high-income countries.

5.0 Conclusion and Discussion

In the era of digital technology and the digital economy, the role of population size differs from previous times, requiring a reevaluation of its importance. In the future, with the advent of the AI era, the demand and consumption role of the population as the main body of the economic and social system may become more crucial. Based on panel data from 38 OECD member countries and 5 BRICS countries from 1996 to 2020, this study uses a fixed effects model to empirically test the impact of population size and market size on digital technology innovation. It also analyzes the differences in the impact of these factors on digital technology innovation

across countries with different levels of economic development. The main conclusions of this study are as follows:

First, both population size and market size significantly impact digital technology innovation. Different age groups have varying impacts on technological innovation: the population aged 20-44 promotes technological innovation, while the population over 45 inhibits it. This indicates that the population size and the scale of Internet communication users, representing market size, are key carriers of digital technology incubation. Their systemic innovation advantages, such as providing rich application scenarios on the demand side, amplifying innovation returns, and demand-induced innovation, combined with the supply side's abundant human capital and massive data accumulation, accelerate digital technology innovation.

Second, the impact of population size and market size on digital technology innovation varies significantly across countries with different levels of economic development. The population aged 20-44 promotes digital technology innovation in low-income countries, while market size promotes digital technology innovation in high-income countries. This study confirms the positive effect of population size on digital technology innovation in low-income countries, while market size has no effect on technological innovation in low-income countries, possibly due to low income and consumption capacity. Therefore, low-income countries benefit from population size effects but need to increase population purchasing power and market size advantages. Conversely, market size has a positive effect on digital technology innovation in high-income countries, while population size has no effect on technological innovation in high-income countries, possibly because high-income countries' income and consumption capacity surpass the mere size of the population. Therefore, high-income countries should maintain market size while increasing birth rates.

Additionally, this study has some limitations that need further improvement. Firstly, the study does not consider the borderless market characteristics of digital technology. Future research should consider both local and foreign markets. Secondly, different stages of digital technology innovation or different stages of innovation need to be specifically considered. Future research is recommended to classify ICT patents in detail.

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