

THE RELATIONSHIP BETWEEN MACROECONOMIC INDICATORS AND THE DEVELOPMENT OF CENTRAL BANK DIGITAL CURRENCIES

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ABSTRACT

The rise of Central Bank Digital Currencies (CBDCs) offers transformative potential for financial systems, yet their adoption and development hinge on macroeconomic conditions remain underexplored in existing literature. While prior studies emphasize CBDC's benefits, such as financial inclusion and reduced transaction costs, and risks like banking disintermediation, they overlook how economic factors shape its trajectory. Using a panel dataset of 947 country-year observations from 165 countries (2010-2021), sourced from the CBDC Tracker and World Bank, we assess how GDP per capita growth, inflation, and population growth are related to CBDC development. Results show all three factors significantly boost CBDC development. In addition, while the development of retail CBDC ties strongly to all three macroeconomic indicators, wholesale CBDC development shows weaker links to GDP growth and inflation and no association with population growth. The findings suggest that policymakers should tailor CBDC strategies to macroeconomic conditions, prioritizing retail CBDCs in developing economies and wholesale CBDCs in developed ones, with flexible frameworks to address evolving challenges and risks. This research, therefore, is critical for aligning CBDC designs with diverse national contexts, enabling central banks to optimize digital currencies for stability and growth, particularly in developing economies where economic priorities differ from mature markets.

Keywords: Central Bank Digital Currency; GDP growth; Inflation; Population growth.

TÓM TẮT

Sự gia tăng của Tiền Kỹ thuật số Ngân hàng Trung ương (CBDC) mang lại tiềm năng thay đổi lớn cho các hệ thống tài chính, nhưng việc áp dụng và phát triển CBDC phụ thuộc vào các điều kiện kinh tế vĩ mô, một khía cạnh chưa được khám phá đầy đủ trong các tài liệu hiện có. Trong khi các nghiên cứu trước đây nhấn mạnh lợi ích của CBDC như tăng cường hòa nhập tài chính và giảm chi phí giao dịch, cùng với các rủi ro như loại bỏ trung gian ngân hàng, đa phần lại bỏ qua cách các yếu tố kinh tế ảnh hưởng tới sự phát triển của CBDC. Phân tích dữ liệu gồm 947 quan sát từ 165 quốc gia trong giai đoạn 2010-2021, chúng tôi đánh giá mối liên hệ giữa tăng trưởng GDP bình quân đầu người, lạm phát, tăng trưởng dân số và sự phát triển của CBDC. Kết quả cho thấy cả ba yếu tố này đều thúc đẩy đáng kể sự phát triển của CBDC. Ngoài ra, trong khi sự phát triển của CBDC bán lẻ liên kết mạnh mẽ với cả ba chỉ số kinh tế vĩ mô, CBDC bán buôn chỉ cho thấy mối liên hệ yếu hơn với tăng trưởng GDP và lạm phát, và không có liên hệ với tăng trưởng dân số. Các phát hiện này gợi ý rằng các nhà hoạch định chính sách nên điều chỉnh chiến lược CBDC theo điều kiện kinh tế vĩ mô, ưu tiên CBDC bán lẻ ở các nền kinh tế đang phát triển và CBDC bán buôn ở các nền kinh tế phát triển, với các khung linh hoạt để giải quyết các thách thức và rủi ro đang thay đổi.

Từ khóa: Tiền Kỹ thuật số Ngân hàng Trung ương; Tăng trưởng GDP; Lạm phát; Tăng trưởng dân số.

1. Introduction

The entry of digital currencies, particularly Central Bank Digital Currencies (CBDC), has been of great interest among policymakers and experts in recent years. This type of currency is highly potent in reconfiguring financial systems, highlighting aspects such as enhanced financial inclusion (Infante et al., 2024), smoothing of the business cycle (Barrdear and Kumhof, 2021), and making safer asset usage more productive (Williamson, 2022; Niepelt, 2024). The entry of CBDC, however, is not trouble-free. It may potentially cause some issues, including banking disintermediation, diminishment of banking credits, negative financial stability outcomes (Infante et al., 2024), or declined net interest income growth of commercial banks (Dinh and Dinh, 2022). To address such risk factors and deliver hassle-free integration of CBDC in the financial system, careful considerations of risk and benefit of CBDC in each economy's unique context is a matter of high necessity.

Previous studies have extensively studied the implications of CBDC, for instance, in potentially improving welfare through competition against private payment systems (Williamson, 2022), improving gross domestic product (GDP) through lower transaction costs (Barrdear and Kumhof, 2021), and minimizing financial frictions (Infante et al., 2024). At the same time, more recent studies examine the determinants of CBDC adoption, for instance, technology infrastructure, institution digitalization, and public inclusion (Lee et al., 2021; Auer et al., 2023). However, the role of macroeconomic factors in determining the development and

adoption of CBDC has not received adequate examination. Whatever the end goal, the uptake of CBDC must necessarily rely on correspondence between designs and the varied economic conditions of different nations (Auer et al., 2023; Huynh, 2022). For instance, the CBDC adoption pattern can be much different between emerging economies and more mature ones. The insights on such connections and mechanisms have so far been systematically examined in none of these studies. In the absence of this nexus, policy authorities have nothing on which evidence can be based for customizing designs of a CBDC for macroeconomic environments.

A more critical literature gap is that most of the current studies only focus on examining real adoption or pilot of CBDC (e.g., Bijlsma et al, 2024; Luu et al., 2023). In other words, extant studies mostly ignored how factors can affect the development of CBDC to different extents. Filling this gap is important because it allows central banks to make informed decisions on different stages of CBDC development. The ability to identify what factors have the greatest influence on CBDC development outcomes enables decision-makers to allocate resources more efficiently.

In addressing these gaps, this study poses a question: How do macroeconomic metrics such as inflation, GDP per capita growth, and population growth affect the adoption and development of a CBDC? To address this question, we make an effort to fill the gap between macroeconomic thoughts and policies on digital currencies so that national digital currency programs have a foundation in economic conditions.

This study supplements the discussion on CBDC by linking macroeconomic factors with the CBDC integration process, as well as accounting for how factors can affect the

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different levels of CBDC development. At the same time, it addresses the question regarding whether economic growth induces or hinders CBDC adoption and development. In a more functional sense, this research allows policymakers to make more informed decisions by providing information on how macroeconomic indicators affect the development level of CBDC. In mapping out macroeconomic variables with CBDC development, our work prepares central banks to counter risks such as disintermediation while making digital currencies calibrated instruments for national economic aims.

The remainder of this paper is laid out as follows. Section 2 outlines the literature review and hypothesis development. Section 3 presents the data and research methodology. Section 4 discusses the empirical results. Finally, Section 5 summarizes major insights and research implications.

2. Literature review and hypothesis development

2.1. Central Bank Digital Currency

Central Bank Digital Currency (CBDC) is a digital form of a country's national currency, issued and regulated by its central bank. It marks a new chapter in the evolution of money, offering a stable unit of account, an efficient medium of exchange, and a secure store of value (Hoang et al., 2023; Sethaput and Innet, 2023). CBDCs come in two forms: retail CBDC, which facilitates interactions between commercial banks and end-users via token-based accounts, and wholesale CBDC, which operates between the central bank and commercial banks (Kumar, 2021).

The adoption of CBDC presents transformative opportunities for economic and financial systems. At its core, CBDC can drive macroeconomic benefits, such as sustained GDP growth by lowering transaction costs,

reducing distortive taxes, and enhancing monetary efficiency (Barrdear and Kumhof, 2021; Infante et al., 2024). These gains are bolstered by improved monetary policy tools, as CBDC equips central banks with adjustable mechanisms like interest rates or supply controls to stabilize business cycles and respond to economic shocks (Barrdear and Kumhof, 2021; Sethaput and Innet, 2023). Beyond macroeconomic advantages, CBDC can enhance financial stability by reducing reliance on short-term debt and fostering competition in deposit markets, thereby weakening banks' market dominance and benefiting consumers with higher deposit rates (Williamson, 2022). Socially, CBDC addresses key challenges: it promotes financial inclusion by providing accessible digital money to unbanked populations, counters the decline of physical cash, and mitigates risks to monetary sovereignty posed by private digital currencies (Lee et al., 2021; Sethaput and Innet, 2023). Importantly, the traceability of CBDC transactions strengthens efforts to combat illicit activities like money laundering and tax evasion, balancing transparency with anonymity (Lee et al., 2021; Sethaput and Innet, 2023; Williamson, 2022).

Despite its advantages, CBDC carries significant risks requiring careful mitigation. A primary concern is the potential disintermediation of banks, as households and firms might shift deposits to CBDC during crises, destabilizing banks and restricting credit access, especially without alternative funding sources (Infante et al., 2024; Dinh and Dinh, 2022). Operational vulnerabilities, such as cybersecurity threats in distributed ledger systems or identity breaches in account-based models, could undermine system integrity and public trust (Sethaput and Innet, 2023; Lee et al., 2021). Privacy trade-offs also arise: while transaction traceability aids anti-money laundering efforts, it erodes the anonymity of

cash (Sethaput and Innet, 2023). Legal and regulatory uncertainties further complicate deployment, with gaps in oversight and challenges in addressing digital counterfeiting (Lee et al., 2021). Poorly designed CBDC can disrupt monetary policy transmission, complicate interest rate adjustments, and weaken central banks' control over economic outcomes (Barrdear and Kumhof, 2021; Sethaput and Innet, 2023). Internationally, cross-border CBDC flows could heighten exchange rate volatility and erode monetary autonomy in economies reliant on foreign digital currencies (Barrdear and Kumhof, 2021). Rapid financial innovation, such as unregulated CBDC derivatives, might fuel shadow markets while excluding vulnerable populations due to the barriers of digital literacy gaps and inadequate infrastructure (Lee et al., 2021). These risks underscore the need for meticulous design, robust safeguards, and adaptive regulations to balance innovation with financial stability and equity.

Currently, central banks are exploring CBDC for both retail and wholesale purposes (Claessens et al., 2024). Public sentiment toward CBDC shows growing global positivity (Ngo et al., 2023). The Bahamas has fully implemented a CBDC, while China and Uruguay have completed pilot tests (Náñez Alonso et al., 2021), serving as benchmarks for others. Nigeria and Venezuela have also adopted CBDC amid the inflation-driven devaluation of their traditional currencies (Adewale, 2025; Fast, 2021).

2.2. Hypothesis development

The Mundell-Fleming model (Mundell, 1961; Fleming, 1962) posits that an economy cannot simultaneously maintain (1) free capital mobility, (2) a fixed exchange rate, and (3) an independent monetary policy. Developing economies often prioritize monetary policy independence to manage

inflation. However, the introduction and adoption of Central Bank Digital Currency (CBDC) may not only fail to enhance monetary independence but could also foster policy interdependence among nations. Specifically, CBDC is seen as a tool to improve the efficiency and reduce the costs of cross-border payments and transfers (Barrdear and Kumhof, 2021). While beneficial for trade and individuals, a widespread use of CBDC in international transactions could more tightly link monetary conditions across participating countries. Consequently, developing economies might hesitate to adopt and develop CBDC, as it could undermine monetary policy autonomy, particularly if CBDC facilitates capital flows or pressures exchange rates toward greater stability.

Meanwhile, other evidence suggests an opposite direction. Empirical studies have indicated bi-directional causation between growth in economies and technological advancement in the long term (Pradhan et al., 2017), driving the uptake of CBDC (Lee et al., 2021). For example, when income levels and populations increase, there is a corresponding increase in demand for a more advanced and convenient payment systems, which prompts central banks to create CBDC in an effort to facilitate easier processing of transactions.

This disparity in perspectives indicates that little of this literature includes macroeconomic factors in analyzing CBDC development. Extremely few studies have taken a detailed look at how macroeconomic factors, such as growth in GDP per capita, inflation rate, and population growth, intersect with governments and policy agendas in informing policy for CBDC. In not taking this process into account, the existing literature is not able to conclude whether macroeconomic circumstances drive, inhibit, or overlap with CBDC uptake. This is a

question this study seeks to address using an empirical test.

2.2.1. Impact of Per Capita GDP Growth Rate on the Development Level of CBDC

Empirical evidence underscores the critical role of technological infrastructure development in driving long-term economic growth in OECD countries, with Nair et al. (2020) highlighting the intricate interdependence between these variables. Complementing this, Pradhan et al. (2017) identify a bidirectional causal link between economic growth and technological progress, suggesting that economic expansion not only fosters but is also reinforced by advancements in technological infrastructure. Integrating these theoretical foundations with Lee et al.'s argument that robust technological infrastructure serves as a foundational enabler for the successful adoption and development of Central Bank Digital Currency (CBDC) (2021), it is evident that sustained economic growth, reflected in per capita GDP dynamics, can enhance institutional and technological capacities, thereby creating favorable conditions for CBDC implementation. Based on this interplay, we propose the following hypothesis:

H1: GDP per capita growth is positively associated with the development level of CBDC.

2.2.2. Impact of Inflation Rate on the Development Level of CBDC

It is widely recognized that inflation can signal rapid economic growth, potentially fostering technological infrastructure development and, ultimately, the advancement of Central Bank Digital Currency (CBDC) (Pradhan et al., 2017; Nair et al., 2020). While inflation and economic growth exhibit a positive correlation at low levels, this relationship turns negative when

inflation exceeds a certain threshold (Ghossoub, 2023). Although high inflation may hinder economic growth, some central banks have introduced CBDC during inflationary periods to retain control over monetary systems, as it can stabilize business cycles and enhance resilience to economic shocks (Barrdear and Kumhof, 2021; Sethaput and Innet, 2023). For instance, the Central Bank of Nigeria cited inflation and currency instability as key drivers for the eNaira, aiming to reduce USD dependency and stabilize transactions (Adewale, 2025). Similarly, Venezuela's hyperinflation directly spurred the adoption of a digital currency to replace devalued physical cash (Fast, 2021). Based on these insights, we propose the following hypothesis:

H2: The inflation rate is positively associated with the development level of CBDC.

2.2.3. Impact of Population Growth Rate on the Development Level of CBDC

According to Solow's economic growth model (1956), an increase in the population growth rate boosts the growth rate of real output (i.e., a proxy for economic growth). As previously noted, economic growth can enhance institutional and technological capacities (Pradhan et al., 2017; Nair et al., 2020), thereby facilitating the adoption and development of CBDC (Lee et al., 2021). At the same time, as population sizes grow, the need for more advanced and convenient payment solutions increases, encouraging central banks to develop CBDC, particularly retail CBDC, to streamline transaction processes and enhance financial inclusion (Lee et al., 2021). Accordingly, we propose the following hypothesis:

H3: The population growth rate is positively associated with the development level of CBDC.

3. Methodology and data

3.1. Measurement of CBDC adoption

Our data on CBDC development come from a new, all-encompassing database called the CBDC Tracker (<https://cbdctracker.org/>), which is developed by the Boston Consulting Group. The tracker tracks and reports on the progress and take-up of CBDC in all regions of the world and classifies them into five categories: i) Research (countries that have conducted first explanatory studies on CBDC); ii) Proof of Concept (Countries that are in an advanced research stage and have published a CBDC proof of concept); iii) Pilot (Countries that have developed a CBDC

that is tested in a real environment either with a limited number of parties or on a wide scale); (iv) Launched (Countries that officially fully launched a CBDC); and (v) Cancelled (Countries that cancelled or decommissioned a CBDC). In December 2021, there were a total of 84 territories and states that have been researching and adopting a CBDC in some shape or form, of which 56 were in research, 12 in proof of concept, and 11 in developing and piloting a CBDC in a live environment. Only two states (Bahamas and Jamaica) have a full rollout of a CBDC, and there were three states that have cancelled a CBDC project (Finland, Ecuador, and Denmark).

Table 1. Variable definition

Variable	Definition
<i>CBDC</i>	Time-varying CBDC adoption index for each country from 2010 to 2021. The index ranges from 0 to 4, representing different stages of CBDC adoption: 0 - not involved, 1 - research, 2 - proof of concept announcement, 3 - pilot testing, and 4 - fully launched CBDC.
<i>GDP_per_capita_Growth</i>	GDP per capita growth rate
<i>Population_Growth</i>	Population growth rate
<i>Inflation_Rate</i>	Inflation rate

We constructed a panel dataset of the levels of CBDC development (*CBDC*) based on these phases for all of these countries between 2010 and 2021: a reading of 0 indicates a country is in none of CBDC adoption phases; a reading of 1 indicates a country that is researching a CBDC; a reading of 2 is given for an announcement of a proof of concept; a reading of 3 indicates a country is pilot-launching a CBDC in a live environment; and a reading of 4 indicates a country is live in full on its CBDC. The value for the levels of CBDC development for each country is maintained until the year when there is an official announcement on the upgrade/downgrade of its CBDC development process. Since our measure shows a progressive development of CBDC,

we do not include countries that have cancelled a CBDC project in our sample. To verify this dataset, we also cross-reference primary input from the CBDC Tracker against data published by national authorities responsible for building CBDC.

For macroeconomics variables, we employ panel data on (1) the growth of GDP per capita (*GDP_per_capita_Growth*), (2) the growth of population (*Population_Growth*), and (3) the inflation rate (*Inflation_Rate*). These data are sourced from the World Development Indicators database provided by World Bank (<https://databank.worldbank.org/source/world-development-indicators>).

Macroeconomics data are merged with CBDC data, resulting in our final sample

comprising 947 country-year observations from 165 countries. Table 1 summarizes the definitions of all variables in our regression model.

Table 2. Summary statistics

Variable	N	Mean	SD	p5	p50	p95	Min	Max
<i>CBDC</i>	947	0,145	0,420	0,000	0,000	1,000	0,000	3,000
<i>GDP_per_capita_Growth</i>	947	2,071	3,241	-3,698	1,860	6,646	-8,342	10,513
<i>Population_Growth</i>	947	0,720	0,490	-0,050	0,725	1,709	-0,549	1,986
<i>Inflation_Rate</i>	947	2,742	2,940	0,119	2,000	8,855	-1,139	16,332

Table 2 presents the summary statistics of all variables. Accordingly, the relatively low mean value of *CBDC* (0,145 on a 0-4 scale) indicates that, on average, countries in the sample exhibit limited progress in adopting and developing CBDC. This mean value is significantly lower than the observed maximum (3,000), highlighting substantial heterogeneity among countries, with CBDC development predominantly at low levels.

The average annual per capita GDP growth rate (*GDP_per_capita_Growth*) of 2,071% reflects moderate economic expansion across the sample. However, a high standard deviation (SD = 3,264) underscores significant variability, with some countries in recession (minimum = -8,342%) and others experiencing rapid growth (maximum = 10,513%). The mean slightly exceeds the median (1,860%), suggesting a slight right skew in the distribution, indicating that a few high-growth economies pull the average upward.

The average population growth rate (*Population_Growth*) of 0,720% indicates a slow but positive demographic expansion. The narrow range between the 5th percentile (-0,050%) and 95th percentile (1,709%) suggests most countries have stable population growth, with limited extremes. The proximity of the mean to the median (0,725%) implies a nearly symmetrical distribution.

The average inflation rate (*Inflation_Rate*) of 2,742% aligns with typical central bank price stability targets (e.g., 2%). However, a wide standard deviation (SD = 2,940) and range (min = -1,139%, max = 16,332%) reveal significant disparities across countries, with some facing deflationary pressures and others suffering from high inflation. The median (2,000%) being lower than the mean indicates a right-skewed distribution, suggesting the presence of a few economies with elevated inflation rates.

3.2. Model specification

We test for macroeconomic determinants of CBDC take-up and growth using the following econometric model:

$$CBDC_{it} = \delta_0 + \delta_1 GDP\ per\ capita\ growth_{it} + \delta_2 Population\ growth_{it} + \delta_3 Inflation\ rate_{it} + \rho_t + \epsilon_{ijt}$$

Where *i* denotes the country, and *t* denotes the year. We also include country fixed effects and year fixed effects (ρ_t) to alleviate the potential problem of omitted variables. All variables are winsorized at 1% and 99%. The model is estimated using ordinary least squares (OLS) and robust standard errors in an attempt to address potential heteroskedasticity issues. Four different specifications test for (1) the growth of GDP per capita, (2) the growth of population, (3) the inflation rate, and (4) all three macro indicators are employed. This

multi-specification test allows the examination of individual and combined influences of the three macro indicators on the development of CBDC.

4. Results

4.1. Baseline regression results

Table 3 presents macroeconomic determinant baseline regression results. Columns 1-3 report the results examining the association of each macroeconomic factor with CBDC development. In all three regressions, the coefficients of the macroeconomics factors are positive and statistically significant at the one percent level. This indicates that each of these determinants is positively related to CBDC

development. Column 4 reports the results of a regression model combining all three factors in a joint model. The coefficients of all macroeconomic factors remain positive and significant, confirming that all of these are jointly significant in explaining CBDC development. In terms of economic significance, an increase of 1% in each of these macroeconomic determinants (*GDP_per_capita_Growth*, *Population_Growth*, *Inflation_Rate*) translates into an increase in the CBDC Index of 0,038, 0,189, and 0,044 units, respectively. These are equivalent to a 26%, 130%, and 30% increase from the mean value of *CBDC* (i.e., 0,145 - see Table 2), respectively.

Table 3. Baseline regressions - the relationship between macroeconomic indicators and CBDC development

Regression	(1)	(2)	(3)	(4)
	<i>GDP per Capita Growth</i>	<i>Population Growth</i>	<i>Inflation Rate</i>	<i>All variables</i>
<i>GDP_per_capita_Growth</i>	0,038*** (0,012)			0,047*** (0,011)
<i>Population_Growth</i>		0,189*** (0,048)		0,346*** (0,059)
<i>Inflation_Rate</i>			0,044*** (0,014)	0,056*** (0,011)
<i>Constant</i>	-0,183*** (0,035)	-0,268*** (0,047)	-0,187*** (0,040)	-0,668*** (0,083)
Observations	947	947	947	947
R-squared	0,251	0,240	0,252	0,298
Robust	YES	YES	YES	YES
Year & Country FEs	YES	YES	YES	YES

This table reports regression results testing the relationship between macroeconomic indicators and CBDC development. Variable definitions are summarized in Table 1. ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively.

Although population growth seems to exert the largest impact on CBDC development, this variable has less variation than the other two variables, with the standard deviation of *Population_Growth* being

0,490% compared to the standard deviations of *GDP_per_capita_Growth* and *Inflation_Rate* (3,241% and 2,940%, respectively). Overall, these results provide support for all three hypotheses.

4.2. Robustness test

Table 4. Robustness tests

	(1) <i>Include</i> <i>Lagged CBDC</i>	(2) <i>Cluster by</i> <i>Country</i>	(3) <i>Exclude</i> <i>COVID Period</i>	(4) <i>GMM</i>	(5) <i>Additional</i> <i>macro var.</i>
Regression					
<i>L.CBDC</i>	-0,250*** (0,077)				
<i>GDP_per_capita_Growth</i>	0,046*** (0,014)	0,047* (0,025)	0,049*** (0,012)	0,162*** (0,027)	0,019* (0,010)
<i>Population_Growth</i>	0,348*** (0,074)	0,346*** (0,108)	0,474*** (0,056)	1,660*** (0,289)	0,257*** (0,081)
<i>Inflation_Rate</i>	0,055*** (0,010)	0,056* (0,028)	0,048*** (0,010)	0,024** (0,011)	0,026*** (0,008)
<i>FMD</i>					0,008*** (0,002)
<i>Human_Capital</i>					0,666* (0,357)
<i>Digitalization</i>					-0,000 (0,000)
Observations	773	947	816	947	647
R-squared	0,350	0,298	0,302	-	0,362
Robust	YES	NO	YES	YES	YES
Year & Country FEs	YES	YES	YES	YES	YES
Cluster	NO	YES	NO	NO	NO

This table reports the robustness checks to confirm the relationship between macroeconomic indicators and CBDC development. Variable definitions are summarized in Table 1. ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively.

To assess the validity of the baseline findings, we use three robustness checks. In Column 1, we use a dynamic panel model incorporating a one-period lag of the CBDC Index to confirm that results are not driven by serial correlation, with the coefficients of all macroeconomic indicators remaining significant. In the second column, we utilize a regression model in which standard errors are clustered at the country level to account for within-country correlation. The results remain consistent with our baseline results, although the coefficients for *GDP_per_capita_Growth* and *Inflation_Rate* are only significant at the

ten percent level. In Column 3, we exclude the COVID-19 period (i.e., 2020-2021) from our sampling period to mitigate the concern that pandemic-driven economic shocks disproportionately influenced results. In Column 4, to mitigate the endogeneity concern, we employ the Generalized Method of Moments (GMM) model to rerun our regression. Finally, in Column 5, we add to the model three institutional factors as control variables, including (1) Financial market development (*FMD* - Stock market capitalization to GDP), (2) Human Capital Index (*Human_Capital*), and (3)

Digitalization (Secure Internet servers per 1 million people). All data are sourced from the World Bank's database. While the results for our three main variables remain qualitatively consistent, we also find that countries with more financial market development and Human Capital Index tend to have a higher level of CBDC development. These findings are reasonable since advanced financial systems ensure robust infrastructure and trust, while a skilled, educated workforce drives innovation and efficient implementation,

fostering the development of CBDCs. Interestingly, our results show no significant relationship between CBDC index and the level of digitalization. Overall, across all specifications, whether adjusting for dynamics, heteroskedasticity, exogenous shocks, or endogeneity issues, the core relationship between macroeconomic factors and CBDC development persists, underscoring the robustness of our conclusions.

4.3. Further analyses

Table 5. Further analyses - the relationship between macroeconomic indicators and Retail/Wholesale CBDC development

	(1)	(2)
Regression	<i>Retail</i>	<i>Wholesale</i>
<i>GDP_per_capita_Growth</i>	0,037*** (0,011)	0,016** (0,007)
<i>Population_Growth</i>	0,378*** (0,055)	-0,013 (0,036)
<i>Inflation_Rate</i>	0,040*** (0,007)	0,017** (0,007)
Observations	947	947
R-squared	0,383	0,079
Robust	YES	YES
Year & Country FEs	YES	YES

This table reports regression results testing the relationship between macroeconomic indicators and Retail/Wholesale CBDC development. Variable definitions are summarized in Table 1. ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively.

Table 5 summarizes the outcomes of a regression analyzing the relationship between macroeconomic indicators and the development of retail and wholesale CBDCs. We utilize the same econometric model but replace the dependent variable with *Retail* and *Wholesale*, indicating the level of development of retail and wholesale CBDC, respectively. In Column 1, the results show that all three macroeconomic indicators have a positive and highly significant coefficient of

1%, indicating a positive association of each factor with the development of retail CBDC. For wholesale CBDC (Column 2), only *GDP_per_capita_Growth* and *Inflation_Rate* have positive and statistically significant coefficients, whereas the coefficient for *Population_Growth* turns insignificant. The magnitudes of the coefficients in Column 2 are also lower than those in Column 1. Collectively, these results conclude that macroeconomics indicators have a stronger

and more consistent association with the development of retail CBDC relative to the growth of wholesale CBDC.

5. Discussion

Our empirical results show that macroeconomic measures, including GDP per capita growth, inflation rate, and population growth, are directly related to the development of CBDC, validating classical and contemporary economics theories. Both classical and contemporary economic theories affirm that technological advancements, as well as aggregate factor productivity, are drivers of long-term economic growth (Solow, 1956; Park and Choi, 2019; Zhou et al., 2020). Empirical observations also suggest that innovation, as well as growth, has bidirectional causality (Pradhan et al., 2017), meaning that CBDCs are both a consequence and a driver of increased productivity in the future, which is also in line with our observations. In addition, the contrasting roles in retail versus wholesale CBDC also reflect the Keynesian monetary theory (Keynes, 1937). We document that retail CBDC development is linked with population growth and, thus, transactional demands (e.g., daily payments), reflecting transaction motive for money. In contrast, wholesale CBDC development is less dependent on macroeconomic fluctuations, reflecting the speculative motives of institutions maximizing liquidity as well as settlement efficiency.

5.1. Theoretical contributions

Theoretically, this study has settled the debate over whether economic expansion promotes or inhibits the adoption and development of CBDCs. Specifically, we establish that macroeconomics, including GDP growth, inflation rate, and population growth, are crucial in determining CBDC trajectories. These findings add to the

literature that emphasizes the role of digital infrastructure or digitalization in the development of CBDC (Lee et al., 2021; Auer et al., 2023). We also discovered how macroeconomic indicators influence the development level of different types of CBDC. By showing that retail take-up in CBDC is driven by structural demand (for instance, growth in a country's population), while CBDC adoption in a central bank-wholesale context is a question of institutional efficiency, we offer an approach that brings Keynesian monetary theory into digital innovation.

5.2. Practical contributions

For policymakers, our work highlights the importance of targeted CBDC strategies attuned to macroeconomic circumstances. Central banks in developing economies can lead with retail CBDC with attributes such as minimal transaction costs to meet pressing stability and inclusion requirements, as these systems address transactional demand directly. In more developed economies, on the other hand, wholesale CBDC development can be prioritized with a focus on interoperability and risk mitigation, tapping into their insulation from macrocycles. Notably, our outcomes also sound a warning about inflexible technical architecture: as Auer et al. (2023) suggest, central banks will have to have elastic frameworks that respond dynamically to shifting economic circumstances, whether in terms of adjustable interest rates on retail CBDC in volatile regimes or modularity in settlement layers in wholesale systems. In mapping macro drivers into design priorities, for example, coupling inflation-prone economies with digital monetary instruments, policymakers can counteract disintermediation risks while unleashing CBDC as a driver of growth. Such a strategy turns CBDC from experimental

ventures into calibrated instruments attuned to national economic imperatives.

5.3. Conclusion

To conclude, our research reveals that macroeconomic conditions form the building blocks of CBDC development paths, giving central banks evidence-based advice as they steer through this revolutionary financial technology. For developed economies, policies should prioritize wholesale CBDCs, focusing on system interoperability and risk mitigation, leveraging high GDP, robust

financial infrastructure, and strong human capital development. Less developed economies should advance retail CBDCs with minimal transaction costs to enhance financial inclusion and stability, addressing high population growth and inflationary pressures. As central banks align the design of CBDCs with economic realities, they will be in a better position to leverage digital currency as a tool to enhance financial stability, inclusivity, and long-term economic development.

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