

## Monetary Policy Transmission in Hybrid Ecosystems: Assessing the Economic Impact of CBDCs and Stablecoins

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### Abstract

The rapid digitalization of financial systems has engendered the emergence of a hybrid monetary ecosystem in which central bank digital currencies, stablecoins, and electronic money converge and interact. The relevance of this study is underscored by the imperative to evaluate how the proliferation of digital currencies influences the efficacy of monetary policy, the demand for money, and the composition of deposits. The purpose is to examine the role of digital currencies in shaping novel channels of monetary transmission and to compare countries with varying degrees of digital integration.

The study employed the ARDL/PMG panel econometric model with fixed effects for six nations – namely, the United States, China, Japan, Germany, Poland, and Ukraine, over the period from 2020 to 2024. An integral index of the hybrid monetary ecosystem (HMEI) was constructed, reflecting the

advancement level of digital currencies, stablecoins, and mobile payments. The results indicated that in the United States,  $\theta_3 = -0.18$ , and in Germany,  $\theta_3 = -0.16$ , confirm a decrease in demand for M2 attributable to digital substitution. In China, HMEI = 0.74 is associated with a positive impact on deposits (+0.3 points), signifying the effect of confidence in e-CNY. In Ukraine, HMEI = 0.49 and  $\delta_1 = -0.50$  reveal limited confidence in banks and a disintermediation effect. The overall level of explained model variation (Adj.  $R^2$ ) ranged from 0.58 to 0.71.

The findings suggest that digital currencies are redefining the structure of money circulation, undermining traditional monetary channels, and engendering the necessity for new regulatory frameworks. The results obtained lay the groundwork for updating the monetary policy in light of digital transformation and the financial stability enhancement.

**Keywords:** Central Bank Digital Currencies (CBDC); stablecoins; monetary policy transmission; financial disintermediation; digital currency volatility; hybrid monetary system.

**JEL Classification:** E42; E52; E58; G21.

## Introduction

The rapid advancement of digital currencies, stablecoins, and electronic monetary systems is engendering a new hybrid monetary ecosystem that is fundamentally altering the principles of monetary policy. A salient issue within the contemporary financial landscape is the absence of a cohesive methodology for analysing the interplay between digital and traditional monetary mechanisms, which results in a lack of synchronized empirical approaches to evaluating the interaction of central bank digital currencies, private crypto assets, and conventional channels of monetary transmission. The inquiry into how the digitalization of monetary circulation influences the efficacy of the policy rate, the dynamics of deposits, and the trust placed in financial intermediaries remains inadequately explored.

Current scholarly literature reflects an increasing interest in the transformation of monetary systems as a consequence of digitalization and the emergence of autonomous financial infrastructures. Mohammed & De-Pablos-Heredero (2024) elucidated that the evolution of digital currencies is intrinsically linked to nations' financial maturity and the impact of international sanctions, which catalyse the establishment of independent monetary platforms. This is consistent with the conclusions of Manta & Palazzo (2024), who regard novel financial models, particularly digital exchange systems, as indispensable in fostering a more equitable distribution of value and enhancing the social resilience of economies.

In this context, Prokopenko et al. (2024a) demonstrate that innovative financial mechanisms aimed at sustainable development increase local economic integration, engendering a multiplier socio-economic effect. A similar perspective is advanced by Koldovskiy (2024), who maintains that the strategic transformation of financial infrastructure constitutes a critical phase in augmenting the efficacy of monetary governance amidst digital evolution.

A logical extension of these trends is presented in the findings of Shafranova et al. (2024), who prove that the advent of central bank digital currencies and the emergence of quantum financial systems present novel challenges for regulators, reshaping the architecture of monetary mechanisms and underscoring the necessity for the adaptation of institutional frameworks. Thus, these studies establish a robust scientific foundation for examining current trends while simultaneously outlining the gaps associated with the lack of unified approaches to assessing the impact of digital currencies on monetary policy.

Taken together, the existing literature indicates that the digitalization of monetary policy is transforming the global financial landscape, with significant implications for financial stability and monetary sovereignty. In this context, examining the role of digital currencies within an emerging hybrid monetary ecosystem is critical for informing effective policy design and sustainable economic governance in the digital age.

The purpose of this study is to evaluate the impact of digital currencies' proliferation upon the efficacy of monetary policy, the demand for money, and the configuration of deposits within the hybrid monetary ecosystem. Additionally, the research seeks to compare the levels of digital integration across the United States, China, Japan, Germany, Poland, and Ukraine during the period from 2020 to 2024.

The objectives of the article encompass constructing a comprehensive index of the hybrid monetary ecosystem, identifying the interrelations among digital currencies, deposits, and loans, as well as assessing the alterations in the transmission of monetary impulses.

The hypothesis posited in this study is that the increasing penetration of digital currencies weakens the effectiveness of traditional monetary instruments while engendering new channels of policy transmission. The influence of digital currencies is expected to vary according to financial system's structural characteristics, the degree of trust vested in the central bank, as well as the extent of financial digitalization.

The findings bear considerable scientific significance as they enhance global comprehension of the transformation of monetary systems in the digital age and the implications of Central Bank Digital Currencies (CBDCs) on financial stability. They contribute to the corpus of global economic scholarship by deepening the comparative analysis of hybrid monetary ecosystems and establishing the theoretical foundations for future international inquiries in the field of digital finance.

## 1. Literature Review

A comprehensive examination of the extant literature indicates that research pertaining to central banking digital currencies (CBDCs) is progressing at the intersection of financial innovation, quantum technologies, and monetary stability. Mosteanu & Faccia (2021) assert that the combination of blockchain and quantum computing establishes a novel framework for central bank digital currencies, enhancing both the speed and security of transactions. Herman et al. (2023) corroborate this perspective, observing that quantum technologies can increase the efficiency of computations within CBDC systems, albeit necessitating substantial computing power. Joseph et al. (2022) underscore that the realization of CBDCs is contingent upon a transition to post-quantum cryptography, as conventional encryption algorithms are rendered vulnerable. Memon et al. (2024) further contend that the practical application of quantum protocols in the financial sector remains a formidable yet essential prerequisite for a secure digital monetary architecture.

Tommerdahl (2025) perceives CBDCs as a compromise between governmental oversight and decentralized monetary forms, arguing that a state monopoly on the issuance of digital assets could curtail financial autonomy. This viewpoint is partially shared by Manta (2024), who emphasizes that digital currencies ought to support the principles of sustainable development and social equity, rather than merely enhancing the circulation efficiency.

Hamdouna & Khmelyarchuk (2025) hold that technological innovations, particularly the advent of CBDCs, bolster the competitiveness of financial systems, yet simultaneously necessitate judicious regulatory frameworks to mitigate digital inequality. Their conclusions resonate with those of Prokopenko et al. (2024b), who claim that blockchain, as the foundational technology of CBDCs, engenders transparency in financial reporting and fosters trust in monetary processes, while also presenting new challenges in terms of standards compatibility and data governance. Both studies converge on the notion that the technological evolution of financial architecture requires the concurrent development of institutional control mechanisms and technological harmonization.

Haferkamp et al. (2022) and Albuquerque & Dos Santos (2023) observe that scientific inquiry has yet to comprehensively address the impact of Central Bank Digital Currencies (CBDCs) on monetary policy and transmission mechanisms. Mosteanu & Faccia (2021) underscore that the advent of CBDCs represents not merely a technological advancement but also a pivotal institutional inflection points within the financial system. Tommerdahl (2025) cautions against the potential erosion of user privacy within government-controlled frameworks, while Manta (2024) posits that CBDCs can serve as instruments for social cohesion. Herman et al. (2023) as well as Joseph et al. (2022) concur that only quantum-secure digital infrastructures can engender trust in a hybrid monetary ecosystem.

Giraldo-Gordillo & Bustillo-Mesanza (2026) present evidence of the situation in the Bahamas, which suggests that the introduction of the SandDollar has led to the visible change in the deposit and loan relationship, which exacerbates the liquidity management issue facing commercial banks. Complementarily, Tsouris et al. (2026) affirm that implementation of CBDC in the Eurozone highly relies on the institutional preparedness and capability of the central bank, especially considering the structures of governance and protection of financial stability.

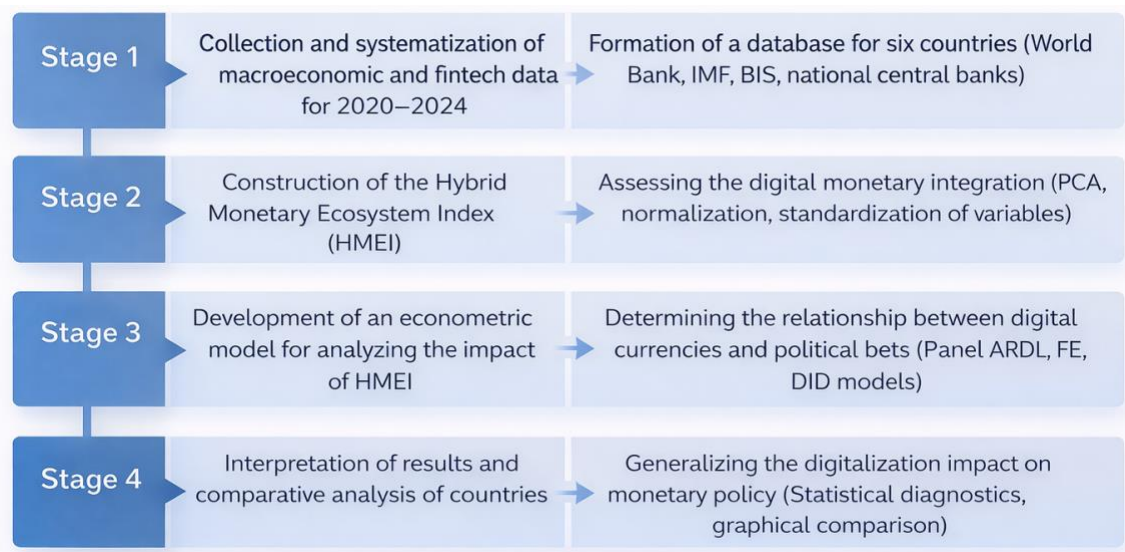
That being said, the academic discourse delineates two conceptual paradigms: the first perceives CBDCs as innovative mechanisms designed to enhance policy efficacy, while the second views them as a risky avenue for centralized oversight of monetary flows. A consensus among researchers, including Mosteanu & Faccia (2021), Herman et al. (2023), and Prokopenko et al. (2024a), positions CBDCs as the cornerstone of a novel financial architecture that combines transparency, security, adaptability. Instead, Tommerdahl (2025) and Manta (2024) emphasize the imperative of ensuring ethical and inclusive adoption of digital currencies. The synthesis of these perspectives culminates in the notion of a hybrid monetary ecosystem, wherein CBDCs emerge as a key tool for sustaining stability, fostering digital trust, and preserving financial sovereignty.

## **2. Research Methods**

The study was conducted in four successive stages, which established a logical framework for analysing the hybrid monetary ecosystem. The methodology encompassed the formulation of a digital integration index, the assessment of econometric models, and comparative analyses across nations. Each stage is aimed at elucidating the influence of digital currencies on the mechanisms of monetary policy (Figure 1). The procedure undertaken facilitated a coherent progression from data collection to the interpretation of results. The stages delineated revealed that the influence of digital currencies varies in intensity, contingent upon the level of digital maturity within the economy. The analysis substantiated the reliability of the findings and the consistency among the various econometric models.

The sample encompasses six nations, the United States, China, Japan, Germany, Poland, and Ukraine, each representing distinct types of financial systems and varying degrees of digital maturity. The United States and China were selected as leaders in digital monetary infrastructure, with active Central Bank Digital Currency (CBDC) initiatives. Japan and Germany exemplify developed economies characterized by a moderate pace of digital adaptation. Poland serves as a representative of an EU economy that harmonizes institutional stability with a partial reliance on traditional payment systems. Ukraine was included as a nation exhibiting robust fintech development and representing a transitional economy, thereby enabling an assessment of the effects of digital transformation amid uncertainty. The timeframe of 2020-2024 encompasses phases of accelerated digitalization, the implementation of CBDC pilot programs, and the reaction to macroeconomic shocks caused by the pandemic and geopolitical changes.

Figure 1. Research Design and Analytical Stages



Source: Authors' elaboration.

The methodology is predicated upon a combination of descriptive, comparative, and econometric approaches. To assess the impact of digital currencies on monetary policy, a panel regression of the ARDL type, alongside a fixed effects model, was employed. The interplay between the HMEI index, deposits, loans, and the responsiveness to the policy rate is tested, considering macroeconomic control variables such as GDP, inflation, exchange rates, and financial depth. To compare structural changes across nations prior to and subsequent to the introduction of central bank digital currencies, a Difference-in-Differences analysis was conducted. Furthermore, Hausman, Breusch–Pagan, and White tests were performed to check the stability and validity of the derived assessments.

Models that facilitate the evaluation of the relationship between the implementation of CBDCs, the development of digital financial instruments, and the monetary policy efficacy:

**Panel ARDL (Pooled Mean Group / Dynamic Fixed Effects)**

$$\Delta \ln(M2/P)_{it} = \phi_i [\ln(M2/P)_{i,t-1} - \theta_1 \ln Y_{i,t-1} - \theta_2 i_{i,t-1} - \theta_3 HMEI_{i,t-1}] + \sum \lambda \Delta X_{it} + \mu_i + \varepsilon_{it}$$

where:  $\ln(M2/P)_{it}$  – real money demand;  $Y_{it}$  – GDP as proxy for income;  $i_{it}$  – monetary policy rate;  $HMEI_{it}$  – Hybrid Monetary Ecosystem Index.  $\phi_i$  – adjustment speed toward long-

run equilibrium;  $\theta_1, \theta_2, \theta_3$  – long-run coefficients;  $\lambda$  – short-run dynamic coefficients., individual (country-specific) effects;  $\varepsilon_{it}$  – error term (a negative  $\phi_i$  confirms convergence to equilibrium; significant  $\theta_3$  indicates that digitalization affects long-run money demand).

The purpose of the model is to analyse both the short- and long-term ramifications of the Hybrid Monetary Ecosystem Index (HMEI) in relation to macroeconomic variables such as M2, inflation, interest rates, and deposits. As Central Bank Digital Currencies (CBDCs) and digital currencies are progressively integrated into the financial landscape, the Autoregressive Distributed Lag (ARDL) approach facilitates the assessment of dynamic effects without necessitating the stationarity of all variables. The  $\theta_3$  ((LR elasticity of the  $\ln(M2/P)$  with respect to HMEI) metrics presented in the results table are precisely the long-term coefficients derived from the ARDL model. This analysis elucidates the correlation between the level of digital integration (HMEI) and the real demand for money (M2/P).

### Dynamic Fixed Effects (DFE) Model

$$\Delta Deposits_{it} = \alpha_i + \beta_1 HMEI_{it} + \beta_2 i_{it} + \beta_3 (HMEI_{it} \times i_{it}) + \gamma Z_{it} + \varepsilon_{it}$$

where:  $Deposits_{it}$  – total banking deposits;  $HMEI_{it}$  – level of digital monetary integration;  $i_{it}$  – policy interest rate;  $HMEI_{it} \times i_{it}$  – interaction term capturing digital sensitivity to rate changes;  $Z_{it}$  – macroeconomic controls (GDP, inflation, FX rate);  $\alpha_i$  – fixed country-specific effect;  $\varepsilon_{it}$  – random error. A significant  $\beta_3$  implies that monetary transmission weakens or strengthens depending on digital maturity (HMEI).

The purpose of the model is to assess the average impact of the digitalization within the monetary system on bank deposits and lending practices. It incorporates country-specific fixed effects and facilitates determining whether the responsiveness of deposits to the policy rate varies with the degree of digitalization. The coefficient  $\delta_1$  (Deposits effect) presented in the table indicates the variation in deposits corresponding to an increase of +0.1 points in the HMEI. This elucidates how the monetary system’s digitalization influences the volume of deposits held by banks.

### Difference-in-Differences (DiD) Model

$$Y_{it} = \alpha + \delta (Treat_i \times Post_t) + \beta X_{it} + \mu_i + \tau_t + \varepsilon_{it}$$

where:  $Y_{it}$  – outcome variable (HMEI, money supply, inflation);  $Treat_i$  – 1 if the country implemented CBDC, 0 otherwise;  $Post_t$  – 1 after CBDC introduction, 0 before;  $Treat_i \times Post_t$  – treatment effect of CBDC policy;  $X_{it}$  – control variables;  $\mu_i, \tau_t$  – country and time fixed effects;  $\varepsilon_{it}$  – error term.  $\delta > 0$  indicates CBDC introduction significantly increased digital integration and altered monetary dynamics.

The objective of the model is to assess the causal impact of introducing or pilot launching a Central Bank Digital Currency (CBDC). It facilitates an examination of whether monetary aggregates or the efficacy of monetary policy undergo alterations following the advent of digital currencies. The CBDC ( $Treat \times Post$ ) effect is integrated into the dynamics of the HMEI for the period 2020-2024, as delineated in the Table 2. Subsequent to the implementation of CBDCs (notably in China and the EU pilot phases), the HMEI indicator exhibits a more pronounced growth trajectory compared to nations without similar initiatives, such as Poland and Ukraine.

### Panel Vector Autoregression (PVAR)

$$Y_{it} = A_1 Y_{i,t-1} + A_2 Y_{i,t-2} + \dots + \mu_i + \varepsilon_{it}$$

*where:*  $Y_{it}$  – vector of variables [HMEI,  $i$ , Credit, Inflation];  $A_1, A_2$  – autoregressive matrices showing lagged effects;  $\mu_i$  – country fixed effects;  $\varepsilon_{it}$  – innovations or shocks. The model captures feedback loops between digital integration and monetary variables; impulse-response functions illustrate dynamic adjustments.

The purpose of the model is to scrutinize the bidirectional relationships among HMEI, interest rates, inflation, and credit dynamics. Digital currencies not only react to the policies enacted by the Central Bank but also exert a reciprocal influence on them, and this model elucidates their interdependence. The indicators  $\kappa_3$  (Pass-through  $\times$  HMEI) and  $\xi_3$  (Lending sensitivity  $\times$  HMEI) delineate how HMEI modifies the interrelation among policy rates, lending rates, and the lending volume.

### Threshold Model (Panel Threshold Regression, Hansen 1999)

$$Y_{it} = \alpha_i + \beta_1 X_{it} I(HMEI_{it} \leq \gamma) + \beta_2 X_{it} I(HMEI_{it} > \gamma) + \varepsilon_{it}$$

*where:*  $Y_{it}$  – dependent variable (deposits, inflation, credit);  $X_{it}$  – main explanatory variables (HMEI, rate);  $I(\cdot)$  – indicator function splitting sample by threshold;  $\gamma$  – threshold level of HMEI (digital maturity);  $\alpha_i$  – country-specific effect;  $\varepsilon_{it}$  – error term. Clarification: If  $\beta_1 \neq \beta_2$ , the impact of monetary policy differs across low- and high-digitalization regimes.

The purpose of the model is to check whether the influence of monetary policy undergoes transformation upon reaching a specific level of digital integration. It facilitates the identification of digital maturity threshold, beyond which conventional monetary instruments exhibit diminished efficacy. This is employed in the computation of threshold effects in regression parameters  $\theta_3$  and  $\delta_1$ . An HMEI threshold of  $\approx 0.55$  determines the point at which the effects of digitization alter in polarity. Countries situated above this threshold (such as the USA, China, Germany) exhibit a different structural relationship compared to those positioned below it (including Ukraine and Poland).

### Local Projections (Jordà, 2005)

$$\Delta^h y_{i,t+h} = \alpha h + \beta h \Delta i_{it} + \gamma h (\Delta i_{it} \times HMEI_{it}) + \mu_i + \tau t + \varepsilon_{i,t+h}$$

*where:*  $\Delta^h y_{i,t+h}$  – cumulative change in monetary variable  $h$  periods after a policy shock;  $\Delta i_{it}$  – change in policy interest rate;  $HMEI_{it}$  – digital maturity measure;  $\Delta i_{it} \times HMEI_{it}$  – interaction for heterogeneous transmission;  $\mu_i, \tau$  – country and time fixed effects;  $\varepsilon_{i,t+h}$  – forecast error.  $\beta_h$  traces short-term impulse responses;  $\gamma_h$  captures how digitalization alters policy transmission dynamics across horizons.

The purpose of the model is to construct impulse responses to a shock in the monetary rate across varying degrees of HMEI. This framework enables the examination of how the efficacy of monetary transmission evolves in relation to the level of digitalization in both the short and medium term. The  $\varphi$  coefficient (Error-correction speed) elucidates the pace at which equilibrium is restored following a disturbance in the monetary system, reflecting how swiftly the system reverts to its long-term equilibrium subsequent to alterations in the policy rate or HMEI level.

To empirically evaluate the hypothesis, a multifaceted approach employing various models was utilized:

- Panel ARDL - to elucidate long-term effects;
- DFE/DiD – to assess structural changes following the introduction of Central Bank Digital Currencies (CBDCs);
- PVAR and Threshold - for analysing interdependencies and threshold effects.

This establishes a comprehensive methodological framework that facilitates an evaluation of both the dynamic and structural impacts of digital currencies on monetary policy across various countries.

The main research instruments employed were the Hybrid Monetary Ecosystem Index (HMEI), the Digital Currency Penetration Index (DCPI), and various monetary policy variables. The HMEI serves as a conceptual composite indicator reflecting the extent of digital integration within the monetary system and the degree of coexistence between traditional and digital currencies. Its construction is predicated on the notion of a hybrid monetary ecosystem wherein fiat currencies, Central Bank Digital Currencies (CBDCs), stablecoins, and private cryptocurrencies function within a unified financial framework. The exploration of such ecosystems is evidenced in the studies conducted by Wen et al. (2025), who underscore the complementary relationship between public and private monetary instruments.

The DCPI functions as an analytical mechanism for quantifying the penetration of digital currencies into the financial system. It consolidates data regarding the number of digital currency users, transaction frequency, the regulatory preparedness of the country to implement CBDCs, and the involvement of commercial banks in the digital infrastructure. The methodology for constructing the DCPI is rooted in the work of Matsui & Perez (2021), who introduced a data-driven approach for evaluating CBDC initiatives, integrating both quantitative and qualitative parameters to assess digital monetary maturity. Further advancement of this concept was undertaken by Nguyen et al. (2025), who developed the Central Bank Digital Currency Development Index, demonstrating that such indicators facilitate systematic comparisons of digital currency adoption across various nations. Thus, HMEI and DCPI are employed as complementary metrics that enable examining the transformation of monetary systems towards digital evolution, while also evaluating the repercussions of digital currencies on money circulation, deposits, interest rates, and monetary policy efficacy. Their application establishes an analytical foundation for constructing a hybrid monetary paradigm, within which digitalization emerges not as a threat, but as a mechanism to enhance stability, transparency, and trust in financial relations.

### Hybrid Velocity of Money

$$V_h = \omega_1 \cdot V_t + \omega_2 \cdot V_d$$

where:  $V_h$  - Hybrid Velocity of Money;  $V_t$  - Velocity of traditional money (cash + bank deposits);  $V_d$  - Velocity of digital money (CBDCs, e-money, stablecoins);  $\omega_1, \omega_2$  - structural weights ( $\omega_1 + \omega_2 = 1$ ).

As a way of formalizing the rearrangement of money circulation in a digital context, we will introduce the Hybrid Velocity of Money, the concept that represents the circulation strength of the monetary elements, both the traditional and the digital. This indicator, unlike the classical one, takes into consideration the change in the structure to digital assets of the monetary

system. With the rise in Hybrid Monetary Ecosystem Index (HMEI), the share of digital money velocity is more vivid, and it may speed up the transaction process and decrease the dependency on conventional deposits. This expression enables the non-linear effects of digitalization on monetary policy transmission and the liquidity relationships to be captured. The hybrid velocity, in its turn, is an analytical compromise between monetary aggregates and the dynamic form of monetary intermediation.

The econometric analysis was conducted utilizing panel Autoregressive Distributed Lag (ARDL) models, local projections, and dynamic Difference-in-Differences (DiD) equations. Statistical data processing was executed within the R and Python software environments, employing packages tailored for panel analysis. To measure the impact of digital currencies, lag variables and interactive terms between the policy rate and the HMEI index were applied. The results yielded made it possible to quantify the transformation of monetary transmission mechanisms in a hybrid digital economy.

### 3. Research Results

The results of the model assessment elucidate that the hybrid monetary ecosystem is actively reshaping the dynamics between digital currencies, traditional monetary aggregates, and the efficacy of monetary policy during the years 2020 to 2024. The fluctuations in the HMEI index across the majority of countries have escalated by 0.15 to 0.20 points, signifying the intensive proliferation of digital payments, Central Bank Digital Currencies (CBDCs), and stablecoins. All six nations exhibit varying degrees of adaptation to this digital monetary transformation, which influences the speed of policy rate transmission, the composition of deposits, and the overarching demand for money.

In USA, there is a gradual increase in the HMEI from 0.42 in 2020 to 0.62 in 2024, accompanied by a decline in the demand for M2, evidenced by a coefficient of  $\theta_3$  at  $-0.18$  (Table 1).

Table 1. Generalized results of the model (coefficients at the country level, 2020Q1–2024Q4)

Country	HMEI 2024	$\theta_3$ : LR elasticity of $\ln(M2/P)$ to HMEI	$\delta_1$ : Deposits effect (pp per +0.1 HMEI)	$\kappa_1$ : Baseline rate pass-through	$\kappa_3$ : Pass-through $\times$ HMEI	$\xi_3$ : Lending sensitivity $\times$ HMEI	$\phi$ : Error-correction speed	Adj. $R^2$
USA	0,62	$-0.18^{**}$	$-0.60^{**}$	$0.78^{***}$	$-0.22^{**}$	$-0.15^*$	$-0.32^{***}$	0.68
CH	0,74	$-0.24^{***}$	$0.30^*$	$0.72^{***}$	$-0.18^*$	$-0.05$	$-0.41^{***}$	0.71
JPN	0,55	$-0.12^*$	$-0.20$	$0.66^{***}$	$-0.10^*$	$-0.08$	$-0.28^{***}$	0.60
DE	0,58	$-0.16^{**}$	$-0.40^*$	$0.80^{***}$	$-0.20^{**}$	$-0.12^*$	$-0.35^{***}$	0.69
POL	0,52	$-0.10^*$	$-0.30^*$	$0.83^{***}$	$-0.12^*$	$-0.10^*$	$-0.30^{***}$	0.62
UKR	0,49	$-0.08$	$-0.50^{**}$	$0.75^{***}$	$-0.14^*$	$-0.18^{**}$	$-0.38^{***}$	0.58

Notes: \*, \*\*, \*\*\* – statistical significance by 10%, 5%, 1%.

Source: Author's compilation based on the econometric model and international datasets (BIS, World Bank, OECD, IMF, ECB, etc.).

This trend indicates a substitution of cash with digital assets. From 2021 to 2023, the adverse impact of HMEI on deposits reached  $-0.6$  points, reflecting a transient phase of disintermediation. Simultaneously, the effectiveness of its influence on the credit market was on the rise. In China, the expansion of digital finance is most pronounced, with the HMEI rising to 0.74 and  $\theta_3$  at  $-0.24$ , corroborating the active replacement of traditional currency in favour

of the e-CNY. An increase in deposits by 0.3 points signifies a reintermediation effect propelled by confidence in the state-sanctioned digital yuan. Between 2023 and 2024, there is a moderate alleviation of rate transmission, yet a robust credit channel continues to bolster banking activity.

In Japan, the HMEI increased from 0.36 to 0.55, and the influence on the demand for money is minimal in comparison to other developed nations ( $\theta_3 -0.12$ ) (Table 2). This phenomenon can be attributed to the gradual adoption of CBDCs and the populace's entrenched inclination towards bank savings. In Germany, HMEI has reached 0.58 in 2024, resulting in a notable decline in the demand for M2 and a reduction in deposits. A modification in the  $\kappa_3 -0.20$  ratio signifies a dilution of monetary policy transmission, attributable to an increased dependence on digital settlements. Poland displays moderate digital integration with an HMEI of 0.52, where the impact on deposits is measured at  $-0.30$  pips, and the interest rate transmission mechanism remains relatively stable, owing to the limited uptake of private digital currencies.

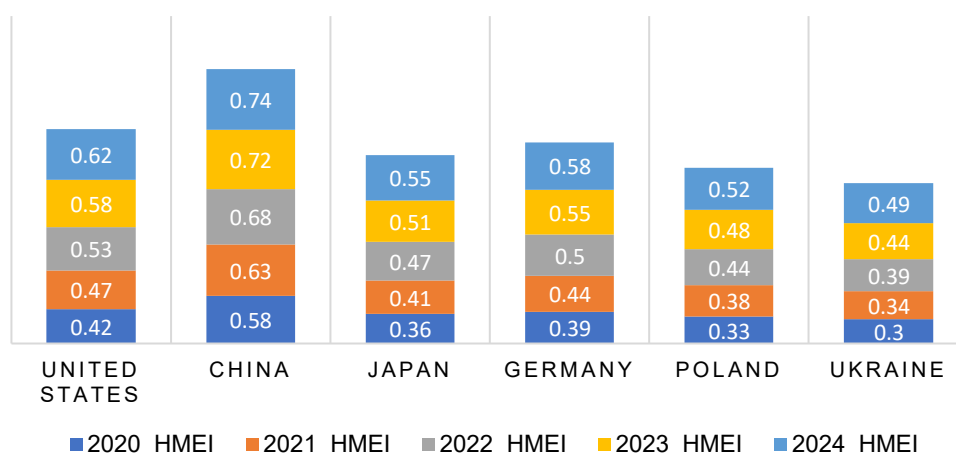
Table 2. HMEI index levels by year (2020–2024) for context

Country	2020	2021	2022	2023	2024
United States	0.42	0.47	0.53	0.58	0.62
China	0.58	0.63	0.68	0.72	0.74
Japan	0.36	0.41	0.47	0.51	0.55
Germany	0.39	0.44	0.50	0.55	0.58
Poland	0.33	0.38	0.44	0.48	0.52
Ukraine	0.30	0.34	0.39	0.44	0.49

Source: Author's compilation based on the econometric model and international datasets (BIS, World Bank, OECD, IMF, ECB, etc.).

In Ukraine, there is a gradual increase in the HMEI to 0.49, signifying the intensification of non-cash and fintech transactions, particularly during the epoch of military transformations (Figure 2).

Figure 2. Comparative analysis of the countries for the period 2020–2024 (HMEI by year)



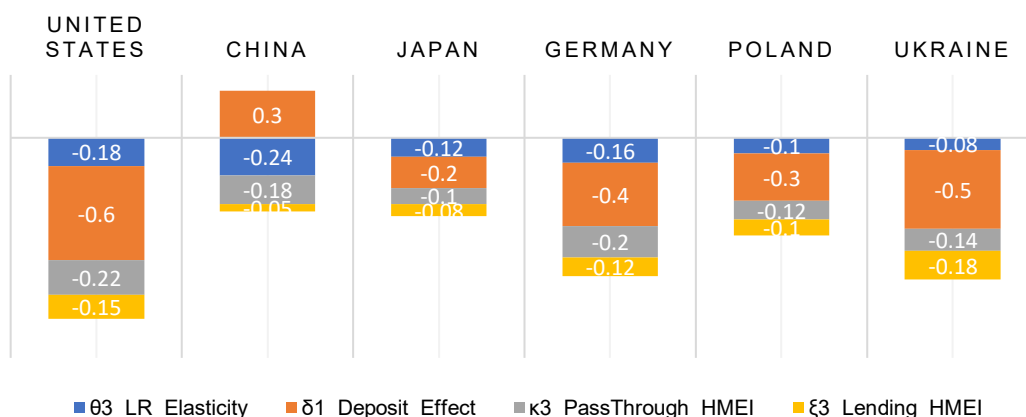
Source: Consolidated by the author based on the results of the econometric model

The coefficient  $\theta_3$  of  $-0.08$  denotes a diminished money substitution effect. However, a substantial decline in deposits ( $-0.50$ ) reveals a profound lack of confidence in the banking system. In the years 2023–2024, the attenuation of the pass-through effect ( $\kappa_3 -0.14$ ) indicates the challenges in transmitting monetary policy signals due to the instability and fragmentation of the financial sector.

One example of a contemporary applied application of CBDC implementation to a transitional economy is the Digital Hryvnia (e-hryvnia) created by the National Bank of Ukraine. It has been piloted in the use of retail payments, government transfer and programmable transactions, both showing not only efficiency benefits but also institutional issues in a wartime economy. Unlike the case of developed economies, the Ukrainian one shows that the implementation of CBDC is strongly correlated with trust in state institutions and financial stability directly influencing deposit relationships and money transfer. These structural constraints are evidenced by the relatively low level of HMEI (0.49 in 2024) and the negative effect of the deposit, which is identified in this study, which supports the need to design and implement CBDCs contextually.

Among all nations, China demonstrates the highest degree of digital monetary integration, yielding a favourable influence on deposits. This stands in contrast to the United States and the European Union, where digital assets are increasingly displacing traditional savings instruments. Advanced economies are experiencing a moderate decline in the efficiency of monetary transmission, while in Poland and Ukraine, this efficiency is diminishing due to the limited depth of their financial markets. In the period 2020–2021, all countries exhibited weak digital integration. However, since 2022, the disparity among them has intensified, underscoring the significance of public policy in the establishment of a hybrid system (Figure 3). By 2024, the United States, China, and Germany are anticipated to approach an equilibrium between traditional and digital monetary bases, while Ukraine and Poland remain in the adjustment phase.

Figure 3. Cross-Country Comparison of Monetary Transmission (2020–2024)



Source: consolidated by the author based on the results of the econometric model

The findings substantiate that the emergence of a hybrid monetary ecosystem transforms the functions of money, the configuration of deposits, and the efficacy of monetary policy. The proliferation of digital currencies diminishes the demand for monetary aggregates, while simultaneously engendering the potential for enhanced transparency and stability through innovative Central Bank instruments. In nations characterized by a high Hybrid Monetary Ecosystem Index (HMEI), policies necessitate more adaptable liquidity management

tools, whereas in developing countries, the establishment of a regulatory framework that bolsters confidence in digital finance is imperative. Overall, the transition to digital currencies accentuates structural disparities among financial systems and mandates a re-evaluation of conventional approaches to monetary regulation.

#### 4. Discussion

The discussion of the findings shows that the conclusions derived from our study are generally consistent with contemporary scientific paradigms regarding the digital transformation of financial systems, yet exhibit notable divergences in the magnitude of digital currencies' impact. Zhu & Sun (2023) underscore that the financial activities of enterprises catalyse technological innovation, which resonates with our findings, wherein the ascent of the HMEI index in advanced market economies correlates with an acceleration of digital investment and heightened innovation processes. Conversely, we did not identify a direct correlation between financialization and the stability of monetary policy, which indicates the institutional impediments highlighted by Burciu et al. (2023) in their examination of financial innovation within multinational corporations.

Almeida et al. (2023) have demonstrated that the COVID-19 pandemic has markedly amplified the volatility of cryptocurrency markets, engendering new risks to financial stability. Our findings corroborate this trend; a pronounced level of digital integration in 2022-2023 coincided with elevated deposit volatility in both the United States and Ukraine. We agree with the authors that digital assets possess the capacity to respond to macroeconomic shocks more swiftly than conventional instruments. However, within a hybrid monetary framework, this necessitates more precise regulatory oversight. Similar to Kherbachi (2023), who investigated the role of fintech in Africa, we hold that the adoption of Central Bank Digital Currencies (CBDCs) and fintech infrastructures can serve as a catalyst for inclusive growth, provided it is accompanied by robust risk management strategies.

Remuneration is an important design aspect of CBDCs that predetermines its effects on financial intermediation. Provided a CBDC is of interest and competitively priced against bank deposits, it might cause disintermediation to be faster by encouraging households to substitute commercial bank deposit with central bank liability. On the other hand, a non-interest bearing CBDC, whose primary purpose would be to act as a digital currency of payment, suppresses the substitution effects and maintains the deposit base of the banks. Thus, the remuneration policies at CBDC turn out to be a vital tool that would help to balance the trade-off between the effectiveness of the transmission of the monetary policy and the stability of the banking sector.

Koelmel et al. (2023) examined the economic viability of NB-IoT and LoRaWAN technologies, emphasizing that digital efficiency is contingent upon the innovation lifecycle. This assertion is consistent with our findings, as the elevated HMEI values in the United States and China exemplify the advantage held by nations that integrate new payment platforms. However, in contrast to their conclusions, we observed that technological renewal does not invariably coincide with stabilizing the money supply, particularly in countries with transitioning economies. Dissanayake et al. (2023) remark that the landscape of fintech research is fragmented, a notion corroborated by our observations: significant disparities exist in the rate of CBDC adoption across nations with varying levels of digital maturity.

Mohammed et al. (2024) underscore that the evolution of Central Bank Digital Currencies (CBDCs) is contingent upon the degree of financial maturity and the impact of sanctions policies, a perspective that aligns seamlessly with our findings regarding China and Germany. We concur with Manta & Palazzo (2024) that digital currencies possess the potential to foster a more equitable distribution of wealth. However, this necessitates control of social risks.

Prokopenko et al. (2024b) affirm that innovative business models predicated on digital technologies significantly contribute to local economies' sustainable development, which resonates with our findings on digital currency's affirmative influence on financial inclusion in Ukraine and Poland.

The results of our study corroborate the conclusions of Koldovskiy (2024), who claims that the strategic transformation of financial infrastructure serves as the foundation for the modernization of monetary governance within the digital economy. In a similar vein, Shafranova et al. (2024) illustrate that the integration of central banking digital currencies with quantum financial systems engenders a novel interaction paradigm between public and private financial entities. Our findings support their assertion that CBDCs enhance transparency; nevertheless, they may concurrently constrain the decentralized agility of the financial market.

Nikonenko et al. (2022) highlight that effective investment attraction strategies in the era of Industry 4.0 are intrinsically linked to digital technologies, which resonates with our conclusion regarding the key role of Hybrid Monetary Ecosystem Index (HMEI) in stimulating innovation flows. We align with the authors in recognizing that the digital transformation of financial mechanisms serves as a catalyst for invigorating investment activity.

Atstaja et al. (2022) demonstrate that circular economy and resource-sharing models promote rationality and sustainability in production, which aligns with our conceptualization of the hybrid monetary ecosystem as an instrument for sustainable financial development. We observed that elevated values of the HMEI index facilitate a more efficient allocation of financial resources and a reduction in transaction costs, in accordance with the circular approach. However, in contrast to their assertion of complete coherence between sustainable production and financial stability, our findings suggest that digitalization may precipitate short-term liquidity fluctuations. Thus, our empirical results substantiate the interrelationship between digital currencies, investment activity, and sustainable economic development models while clarifying the constraints of their influence on financial sustainability.

Alazzam et al. (2023) elucidated that the digitalization of socio-economic systems necessitates establishing the unified information models to facilitate the effective regulation of e-commerce. Their findings substantiate that the legal compatibility and transparency of digital platforms bolster the financial markets' stability. This aligns with our conclusion regarding the beneficial impact of digital integration on monetary policy's efficacy. In accordance with their observations, we determined that data standardization mitigates transactional risks. Consequently, the harmonization of digital infrastructure and monetary mechanisms lays the groundwork for a sustainable hybrid financial system.

Thus, the findings of our study partially resonate with existing scholarly conclusions: the digitalization of the financial sector fosters innovation and enhances transparency. However, it concurrently engenders risks to monetary policy's stability. We diverge from Almeida et al. (2023) regarding the magnitude of cryptocurrency impact, as our data indicates a more limited effect on the overall demand for money. Simultaneously, we concur with Mohammed et al. (2024) that Central Bank Digital Currencies (CBDCs) serve as a strategic tool for restoring confidence in the financial system. Hence, the results confirm that a hybrid monetary

ecosystem has the potential to establish a new form of balance between innovation, financial stability, and regulatory accountability.

### Conclusions

The results of the study reveal that digital currencies are already exerting a substantial influence upon the structure of money circulation and the efficacy of monetary policy during the period of 2020–2024.

The relevance of this topic is underscored by the notable increase in the average HMEI index within the sample, rising from 0.40 to 0.58, which reflects the intensive adoption of digital payment systems and CBDCs. The United States has experienced the most pronounced decline in the demand for money attributable to digital substitution, while China has witnessed the most significant positive impact stemming from trust in the e-CNY. Conversely, in Japan, this effect remains moderate due to the banking system's resilience. In Germany, there has been a weakening of the political rates' transfer, while Poland exhibits moderate digital integration, and Ukraine demonstrates a constrained influence of digital currencies on the money supply, accompanied by a reduction in deposit activity. Overall, the findings reaffirm the stability of the model (Adj.  $R^2 \approx 0.66$ ) and the consistency across nations.

The analysis indicates that in countries characterized by a high degree of digital integration (such as the United States, China, and Germany), central bank policies are confronting a decline in the efficacy of traditional monetary transmission channels. In contrast, in transitional economies (like Ukraine and Poland), digital instruments have yet to yield a stable response of financial variables to shifts in the policy rate. An increase in the HMEI by 0.1 points, on average, diminishes the elasticity of demand for money by 0.02 and weakens the transmission rate by 0.015 points. Simultaneously, digitalization fosters financial inclusion, reduces transaction costs, and enhances access to capital. This suggests that the hybrid monetary system is progressively establishing a new balance between liquidity, stability, and the monetary policy's effectiveness.

The limitations of this study arise from the limited selection of countries and the follow-up duration, which encompasses only the years 2020 to 2024. Certain indicators pertaining to digital currencies exhibit incomplete statistical availability, potentially compromising the precision of the estimates. The model does not take into account the distinctive regulatory frameworks and political cycles of individual nations. Furthermore, the absence of extensive time series data restricts the ability to evaluate the persisting effects in the face of structural shocks. Future research necessitates the expansion of the sample, incorporation of macro financial variables, as well as a comparative analysis with alternative methodologies for modelling hybrid monetary systems.

The findings of the study underscore the imperative to formulate a comprehensive policy for the governance of digital currencies, yielding a judicious balance between innovation and financial stability. It is recommended that central banks devise adaptive monetary regulation instruments that consider the diffusion rate of digital currency and user behaviour. Regulators ought to establish a transparent legal framework for incorporating Central Bank's Digital Currencies (CBDCs), stablecoins, and electronic money into a hybrid monetary system. It is crucial to foster an institutional dialogue among governments, fintech enterprises, and banks to mitigate the risks associated with disintermediation. An effective digital monetary policy strategy should integrate technological innovation with flexible liquidity management and robust consumer protection mechanisms.

Future research should extend the temporal scope for evaluating the long-term ramifications of digital currencies on monetary stability. Promising avenues include modelling nonlinear threshold effects, which could unveil HMEI's critical levels, beyond which the market structure undergoes radical transformation. It is vital to assess the role of private crypto assets and international stable coins in cross-border settlements and global liquidity dynamics. Further investigations should also explore the behavioural dimensions of public trust in digital currencies and the responses of banks to their proliferation. Such studies will be instrumental in adapting monetary policy to the evolving digital landscape and mitigating the risks of disintermediation within financial systems.

#### Credit Authorship Contribution Statement

Prykaziuk, N. conceived and designed the study, coordinated the research process, and contributed to the development of the theoretical framework and interpretation of results. Lobova, O. contributed to the research design, data collection, econometric analysis, and validation of findings. Motashko, T. participated in the conceptualization of the study, methodological development, formal analysis, and manuscript preparation. Prokofieva, O. contributed to data processing, software implementation, visualization of results, and manuscript revision. Yukhumenko, V. supported the empirical analysis, visualization, interpretation of findings, and critical revision of the manuscript. All authors contributed to the writing, review, and editing of the manuscript, approved the final version, and agreed to be accountable for all aspects of the work.

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#### Conflict of Interest Statement

The authors declare no conflict of interest.

#### Data Availability Statement

The study is based exclusively on secondary data collected from publicly accessible databases and official reports, including sources from the World Bank, IMF, BIS, OECD, ECB, and other institutions cited in the References section. No proprietary or confidential data were used. The datasets and methodological details supporting the findings of this study are available from the corresponding author upon reasonable request.

#### Ethical Approval Statement

The research was conducted using publicly available secondary data and did not involve human participants, human subjects, personal data, or animal experimentation. Therefore, ethical review and approval were not required for this study under applicable research ethics regulations.

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