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A study on anti-money laundering regulation in e-CNY cross-border payments

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ABSTRACT

The rapid rise of digital currencies has encouraged central banks to design their own central bank digital currencies (CBDCs). Among these, China's digital currency (e-CNY) is a leading example, especially in the field of cross-border payments. However, the expansion of e-CNY raises serious concerns about money laundering risks. This study examines the regulation of e-CNY in cross-border payments and explores solutions to anti-money laundering (AML) challenges. The analysis applies cost-benefit theory and cooperative game theory. From a single-country perspective, the optimal level of AML regulation should balance costs and benefits, thereby maximizing net social gains. If AML regulation can significantly improve payment system efficiency, the optimal regulatory intensity should increase; if the efficiency gains are limited, a reduction is recommended. From a multi-country perspective, AML regulation involves both competition and cooperation. Game theory is applied to study cooperative and competitive strategies among monetary authorities. Using the Shapley value approach, this research shows that cooperative models provide greater benefits than independent regulation. Cooperation ensures stability, fair benefit distribution, and long-term effectiveness. Based on these findings, three recommendations are proposed: strengthen cross-border AML cooperation, draw lessons from private digital currencies, and integrate advanced technologies into AML regulation.

1. Introduction

The digitization of currencies offers substantial opportunities to enhance the efficiency and functionality of payment systems. Nevertheless, it also poses new challenges and potential risks for anti-money laundering (AML) efforts in different countries (monetary authorities) (Soana and de Arruda, 2024). To ensure payment system stability while promoting sustainable innovation and controlling risks in the payments industry, regulatory agencies should prioritize AML regulation of cross-border payments involving central bank digital currencies. The selection of AML regulation of cross-border payments in e-CNY as the research objective has significant theoretical and practical value, given China's earlier research and efforts on central bank digital currencies (CBDCs) (Cheng, 2023).

The implementation of AML regulations for cross-border payments involving digital currencies poses significant challenges. Currently, most international rules for digital currencies are still being researched and developed, with the primary implementation stage being the Financial Action Task Force's (FATF) regulatory recommendations for mitigating money laundering and terrorist financing risks associated with cryptocurrencies. Due to the absence of issuers for crypto-assets, third-party service providers, such as crypto-asset exchanges, have become a regulatory priority. However, many developing countries have yet to establish regulations for these service providers to implement the FATF's recommendations effectively (Yeh, 2022).

More generally, the landscape for payments is rapidly shifting at both the retail and wholesale levels. Along with the rise of new technologies such as DLT, new crypto-assets are emerging – including stablecoins – and new actors, such as Big Tech companies, are entering the market for payments and financial services or amplifying the role they already play. Two trends could raise three types of

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challenges from the perspective of central banks. First, they could lead to a loss of sovereignty in the payments field if foreign players become dominant in those markets. Secondly, Anti-money laundering (AML) regulations for cross-border payments involving digital currencies require coordination among agencies, sectors, and jurisdictions to ensure a consistent, global response to the associated risks (Brunnermeier and Oehmke, 2013). These challenges require central banks and policymakers to adopt a holistic approach with three types of response. The first one is regulatory, to ensure that new actors do not benefit from regulatory arbitrage. The last response suggests that central banks should become innovators themselves and conduct their experiments. The rapid development of digital currency technology demonstrates that national regulations solely focused on anti-money laundering are insufficient to address cross-border use. This highlights the urgent demand for a comprehensive global regulatory framework that addresses the issue of anti-money laundering in cross-border payments involving digital currencies.

2. Literature review

The emergence of CBDCs has introduced new complexities to anti-money laundering (AML) regulation, particularly in cross-border contexts. Recent scholarship has identified several critical challenges and proposed innovative solutions for integrating CBDCs into global AML frameworks.

The administrative authority for AML. The AML Law grants the PBOC the authority to conduct China's AML regulation and oversee the implementation of AML responsibilities by all parties. The proposed revisions to the PBOC Law, which are currently open for comment, provide further clarification that "the CNY encompasses both physical and digital forms" (Sunstein, 2018). The e-CNY is issued through a two-tier operational system, with the central bank responsible for issuing digital fiat currency to authorized operators who facilitate the exchange and circulation of e-CNY. It has been integrated into the Anti-Money Laundering (AML) regulatory framework. As e-CNY is China's fiat currency, existing international standards and Chinese laws on AML/CFT apply. The PBOC, as the competent administrative authority for AML, conducts AML regulation by urging all parties concerned to fulfill their AML obligations and supervising compliance accordingly.

Significant impact on financial oversight and crime prevention. This is primarily due to the e-CNY's design, which enables the People's Bank of China (PBoC, 2021) to maintain a comprehensive record of all transactions, providing the PBoC with the ability to monitor, trace, block, and reverse transactions. This capability has the potential to significantly enhance efforts to prevent and prosecute financial crimes, including illicit transactions, tax evasion, and money laundering (PBoC, 2021). Scorer (2017) identified eight technology requirements for designing a CBDC. One of these requirements is "Confidentiality," which ensures that CBDC users can transact privately, with transaction details visible only to their counterparts. However, this does not imply complete anonymity, as central banks should be able to identify and associate these transactions with real-world identities to prevent money laundering or terrorism financing activities (Scorer, 2017). Additionally, the People's Bank of China (PBoC, 2021) engages in both multilateral and bilateral exchanges and cooperation and has responded to initiatives like the G20 to enhance cross-border payments by assessing the suitability of the central bank's digital currency in the cross-border domain. The PBOC adheres to the principles of "non-disruptive, compliant, and interoperable" in this regard. The People's Bank of China acknowledges the importance of maintaining a balance between safeguarding privacy and complying with regulations. It emphasizes that absolute anonymity for all transactions is not feasible (Sunstein, 2018).

Auer et al. (2021) emphasized the importance of interoperable AML/KYC frameworks in multi-CBDC systems. They proposed cryptographic "travel rule" mechanisms to address gaps in current FATF compliance within pilot projects. As outlined in Sethaput and Innet (2023), the Project Dunbar prototype explores a multi-CBDC shared platform for cross-border payments, including the application of AML/CFT measures across participating jurisdictions. Combined with AML-specific discussions in the literature (see AML Implications of CBDCs, Springer), the work highlights substantial technical and governance obstacles to implementing uniform AML data-sharing in decentralized multi-CBDC networks.

At the same time, a central issue in CBDC design is the trade-off between privacy and regulatory oversight. Schueffel (2025) modeled these trade-offs and recommended a tiered identity verification framework in which low-risk, small-value transactions remain more private, while higher-risk transactions trigger stronger identity checks. Cunha et al. (2021), reporting on the European Central Bank's proof-of-concept, examined the "managed anonymity" model, which proposes real-time AML checks at the settlement layer through mechanisms such as anonymity vouchers to balance privacy and oversight. In contrast, Soana and de Arruda (2024) warned that CBDCs could enable excessive regulatory surveillance through real-time monitoring, and argued for applying proportionality principles to AML data requests to protect individual privacy.

Cross-border coordination further complicates these challenges. Chin and Zhao (2022) identified conflicts between legal frameworks, especially between EU GDPR privacy protections and FATF's data-sharing requirements. They argued for treaty-based protocols for information exchange to reduce risks of legal fragmentation in global CBDC implementation. Using network analysis

substantially improves AML detection performance in transaction data, and benefits increase when analysis spans multiple institutions/jurisdictions (Ouyang et al., 2024).

Finally, Gaisina and Finger (2025) provided comparative evidence on the effectiveness of CBDCs. Their study compared cryptocurrency (including DeFi and CeFi) activity and CBDC adoption, showing that while CBDCs can reduce anonymity-based laundering risks, this improvement relies on robust AML frameworks and suggests a need for strong cross-border supervisory cooperation. So, the hypotheses in this research are as follows:

Hypothesis 1: If the implementation of E-CNY cross-border payment leads to increased payment system efficiency, then potential to significantly improve payment system efficiency, so should the intensity of AML regulations for a country (monetary authority).
Hypothesis 2: If a country (monetary authority) prioritizes payment industry stability over payment system efficiency, it is recommended to increase the intensity of anti-money laundering regulations.
Hypothesis 3: If a country (monetary authority) prioritizes payment system efficiency over payment industry stability, and AML regulations have the potential to improve payment industry efficiency significantly, it is recommended to increase the intensity of anti-money laundering regulations.
Hypothesis 4: If a country (monetary authority) prioritizes payment system efficiency over payment industry stability, and AML regulations have limited potential to improve payment industry efficiency, it is recommended to decrease the intensity of anti-money laundering regulations.
Hypothesis 5: If there are benefits to be obtained from cooperation in anti-money-laundering regulation among multiple countries (monetary authorities), any one country (monetary authority) will gain more than if it were to regulate independently.

3. Research methodology

Based on the research objectives, establishing a fundamental target utility function of AML regulation is crucial for analyzing the comprehensive process of achieving long-term equilibrium within AML regulation agencies. From an economic perspective, the optimal intensity of anti-money laundering (AML) regulation should strike a balance between the total benefits and costs of AML regulations. This approach maximizes the "net" benefits of AML regulations, making cost-benefit analysis the most appropriate method.

Game theory typically focuses on non-cooperative games, which prioritize individual rationality during the game process. In contrast, cooperative games highlight collective power and reflect collective rationality. Compared to non-cooperative games, cooperative games are no longer solely concerned with maximizing individual profits. Cooperative games can effectively guide various cooperative relationships by revealing the inevitability of cooperation, the methods of cooperation, and the distribution of cooperative benefits. British statistician Edgeworth first introduced the concept of cooperative games in his 1881 book "Mathematical Psychology." Cooperative games have been extensively utilized in studying corporate collaboration, regional economies, and intercountry cooperation. Considering the perspectives of group interests, social benefits, national interests, peace, and the beauty of humanity, cooperative games have greater significance than non-cooperative games. To examine how monetary authorities in different countries regulate anti-money laundering for e-CNY cross-border payments, game theory serves as an effective research method.

Firstly, with reference to Posner and Weyl (2013), which analyzes the regulatory agency through cost-benefit and equilibrium analysis. In this model, the regulatory agency seeks to strike a balance between the stability of the payment system, the efficiency of the payment industry, and the costs of regulation. We assume that the innovative technologies employed in e-CNY, such as blockchain and smart contracts, have a positive impact. Using e-CNY for cross-border payments improves the anti-money laundering measures for the regulatory agency. With the same level of regulation, the benefits of regulation increase while the costs decrease. Our analysis proceeds in two steps: first, we assess the regulatory agency's cost-benefit analysis, and then we perform an equilibrium analysis to determine the optimal level of regulation.

Secondly, we employed cooperative game theory to analyze anti-money laundering (AML) regulation across multiple countries' monetary authorities. We used an illustrative example to demonstrate the disparity in gains obtained from the regulatory coalition compared to independent regulation.

3.1. Cost-benefit analysis

3.1.1. Basic assumptions

We assume that the regulatory agency benefits primarily by promoting stability and efficiency in the payment system, while the implementation of anti-money laundering regulations imposes various costs. Therefore, the long-term net benefit function Pr of anti-money laundering regulation's cost is the difference between the increased stability and efficiency of the payment system and the regulation's cost.

$$Pr = k_1 S(x) + k_2 E(x) - C_r(x)$$

where, x represents the degree of regulation, $S(x)$ denotes payment system stability, $E(x)$denotes payment industry efficiency, and $C_r(x)$ represents the cost of anti-money laundering regulation. k_1 is the weight assigned to payment system stability, $k_2$is the weight assigned to payment industry efficiency,

and both k_1 and k_2 are greater than 0. The innovative technologies applied in e-CNY affect payment industry efficiency $E(x)$ and the cost of regulation $C_r(x)$.

3.1.2. Model construction

In the net benefit function of anti-money laundering (AML) regulation, the function of payment system stability increases with an increase in AML regulation intensity. However, the rate of increase gradually decreases, as demonstrated in S(x) in Fig. 1, the efficiency of the payment industry diminishes gradually to zero once it reaches its optimal state with increasing anti-money laundering regulatory intensity, as demonstrated in Fig. 1. It can be assumed that the payment industry efficiency reaches its highest possible value when x = a/2. Guoguang (2000) posited that increasing levels of financial regulation intensity correspond to a rise in marginal costs of financial regulation, according to their assumptions regarding financial regulation and cost function. In the traditional regulatory model, as the intensity of financial regulation increases, direct cost expenditures also increase correspondingly. Additionally, an increase in various indirect costs may be more pronounced. Consequently, the financial regulatory cost function is assumed to increase alongside the intensity of financial regulation, with an upward trend in the rate of increase, illustrated by C(x) in Fig. 1. However, when regulators adopt new regulation technology (RegTech) due to the use of e-CNY, our hypothesis differs. The AML regulatory cost function increases with AML regulatory intensity; the rate of increase will remain constant in the long run, as shown by $C_r(x)$ in Fig. 1, the use of e-CNY-based regulatory instruments and tools increases direct regulatory costs.

In addition, transparent regulatory information and standardized procedures and tools decrease indirect costs, specifically transaction costs associated with communication between regulators and obligated institutions. This results in a more effective anti-money laundering governance. In the long term, we can assume that these increases and decreases have no net effect on marginal costs.

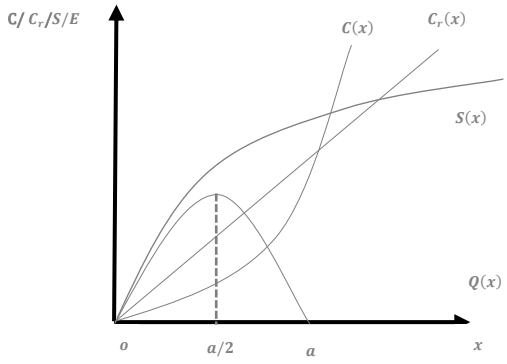

Fig. 1: Cost and benefit functions of AML regulatory agencies

3.2. Cooperative game analysis

3.2.1. Basic assumptions

In a game event involving n countries (monetary authorities), the set $N = \{1,2,\dots,n\}$ is defined as the player set. Any subset S of N, including the empty set, is called a coalition, and the set N is referred to as the grand coalition. The game involving n countries (monetary authorities) allows for a maximum of 2^N possible coalitions.

In a specific game event involving n countries (monetary authorities), if S is a coalition, the real-valued function $v(S)$ can be interpreted as the maximum benefit or cost savings that the players of coalition S can achieve when they cooperate. Typically, we consider the game (N, v) with the characteristic function v. The characteristic functions of a cooperative game involving a set of N players are designated as G^N.

The characteristic function v satisfies the property of superadditivity: for any coalitions S_1 and S_2, if $S_1 \cap S_2 = \Phi$, then $v(S_1 \cup S_2) \geq v(S_1) + v(S_2)$, which represents the notion of synergy in cooperative games.

3.2.2. Two-player cooperative game

The two-player bargaining problem is a fundamental issue in the theory of two-player cooperative games that game theorists investigated during the early years of the field's development. This problem involves price negotiation between two transaction parties, strategy selection between a regulator and the regulated, as well as the profit sharing of cooperators, and diverse two-person allocation problems concerning specific interests.

3.2.3. N-player cooperative games

n-player cooperative games involve more than two players. Let n be the number of participants in the game and let $N = \{1,2,3,\dots,n\}$ represent the set of all participants. In this type of game, a coalitional agreement is crucial for success. It is a binding agreement that can be reached among the members in a subset S of N (where $S \in N$). Participants can establish coalitions based on their interests. Once a coalition agreement is reached, it becomes binding and ensures uniform action toward a larger payoff. The structure will have a logical progression with causal connections between statements. A coalition may not always consist of all direct participants, as small groups and individuals can also join. Therefore, any $S \in N$, where S represents a coalition of N, $S = N$ is known as a grand coalition.

In an n-player cooperative game, participants can negotiate or collaborate to form coalitions. The unified entity maximizes the economic benefits for the group. Technical terms will be explained upon first use. If $|N| = n$, the number of coalitions in N is $C_n^1 + C_n^2 + \cdots + C_n^n = 2^n$. For instance, let us examine

how regions A, B, and C cooperate when voting on a resolution. There are eight possible coalitions: the $\emptyset, \{A\}, \{B\}, \{C\}, \{AB\}, \{AC\}, \{BC\}$, and $\{ABC\}$.

4. Results of data analysis

4.1. Cost-benefit analysis results

For the regulator, this model is based on the previous version, with a net benefit function of $Pr = k_1 S(x) + k_2 E(x) - C_r(x)$. The terms can be described as follows:

$$S(x),\ \frac{\partial S}{\partial x} > 0,\ \frac{\partial S^2}{\partial^2 x} < 0 \quad (1)$$

$$E(x),\ 0 \le x \le \frac{a}{2}\text{时},\ \frac{\partial E}{\partial x} > 0; \frac{a}{2} < x \le a\text{时},\ \frac{\partial E}{\partial x} < 0\ ;\ \frac{\partial E^2}{\partial^2 x} < 0 \quad (2)$$

$$C_r(x),\ \frac{\partial C_r}{\partial x} > 0,\ \frac{\partial C_r^2}{\partial^2 x} = 0 \quad (3)$$

Since $k_1 > 0$ and $k_2 > 0$, we can conclude that the second derivative of the net benefit function $\frac{\partial P_r^2}{\partial^2 x} = k_1 \frac{\partial S^2}{\partial^2 x} + k_2 \frac{\partial E^2}{\partial^2 x} - \frac{\partial C_r^2}{\partial^2 x} < 0$, indicating that the net benefit function attains a maximum value. This maximum value implies the existence of an optimal solution for Pr presented as (x^*). To obtain this optimal solution x^*, we first need to find the first derivative of the function.

$$P'_r(x^*) = k_1 S'(x^*) + k_2 E'(x^*) - C_r'(x^*) = 0 \quad (4)$$

$S(x)$ follows the function characteristic of $x^{\frac{1}{2}}$, $-x^2 + ax$ follows the function characteristic of $E(x)$, and x follows the function characteristic of $C_r(x)$. Thus, we obtain the following characteristic net benefit function for regulation:

$$P_r(x) = k_1 x^{\frac{1}{2}} + k_2(-x^2 + ax) - x. \quad (5)$$

The corresponding first derivative condition is:

$$P'_r(x) = \frac{1}{2} k_1 x^{-\frac{1}{2}} - 2k_2 x + ak_2 - 1 \quad (6)$$

The equation for determining the optimal regulatory level, x^*, is as follows:

$$\frac{1}{2} k_1 x^{-\frac{1}{2}} = 2k_2 x + (1 - \mathrm{ak}_2). \quad (7)$$

Let

$$g(x) = \frac{1}{2} k_1 x^{-\frac{1}{2}},\ f(x) = 2k_2 x + (1 - \mathrm{ak}_2). \quad (8)$$

We can observe how changing a, k_1 and k_2 affects the optimal regulatory level x^* through a coordinate plane graph. In this graph, k_1 and k_2 indicate the weights assigned to payment system stability and payment industry efficiency, respectively, in the net benefit of regulation. The value of a represents the critical point at which the efficiency function of the payment industry transitions from increasing to decreasing.

First, we examine how changes in the parameter a impact the optimal regulatory level x^*. According to Eq. 8, as k_2>0 and a>0, an increase in a while maintaining constant other conditions results in the function $f(x)$ shifting towards the bottom-right direction, progressing from $f_1(x) \to f_2(x) \to f_3(x)$. As a result, the optimal regulatory level x^* progressively increases from $x_1 \to x_2 \to x_3 \to$..... as shown in Fig. 2.

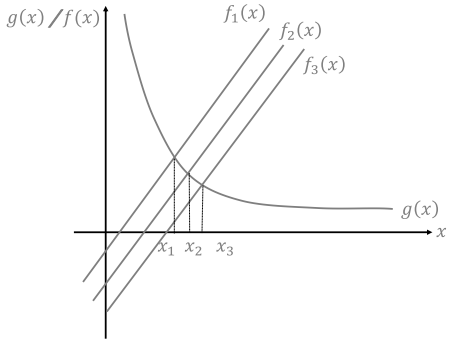

Fig. 2: Influence of parameters on the optimal regulatory level

Next, we examine how varying k_1 impacts the optimal regulatory level x^*. According to Eq. 8, as k_1 > 0, an increase in k_1 while other factors remain constant, the function $g(x)$ increases -- moving from $g_1(x) \to g_2(x) \to g_3(x) \to$ causing x^* to continuously rise from $x_1 \to x_2 \to x_3 \to$, as shown in Fig. 3.

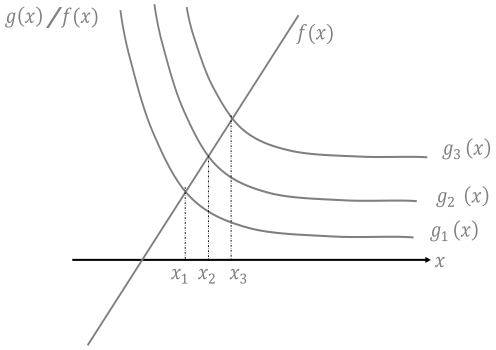

Fig. 3: Influence of parameter k_1 on the optimal regulatory level

Lastly, we examine changes in k_2 and their impact on the optimal regulatory level x^*. As k_2 > 0 and affects both the slope and intercept of the function $f(x)$. Two distinct scenarios arise regarding the effect of k2 on $f(x)$. In some instances, when k_2 continuously increases while other conditions remain constant, the change in the function $f(x)$'s intercept has a significantly greater effect than the change in its slope. This results in the function $f(x)$ shifting from $f_1(x) \to f_2(x)$, and the optimal regulatory level x^* increasing from $x_1 \to x_2$. When k_2 steadily increases while other conditions remain constant, the function $f(x)$ moves from $f_1(x) \to f_3(x)$ due to the significant change in the slope of the function compared to the minor change in the intercept.

As a result, the optimal regulatory level x^* decreases from $x_1 \to x_3$, as shown in Fig. 4.

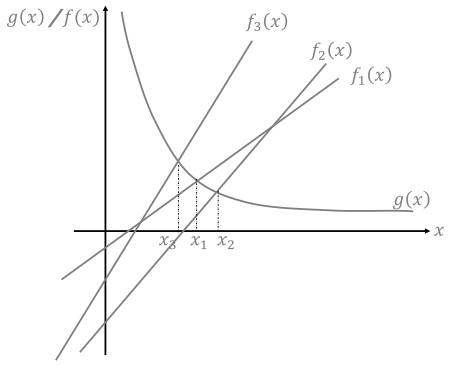

Fig.4: Influence of parameter k_2 on the optimal regulatory level

Based on the cost-benefit analysis above, we can draw the following conclusions. If a country's (monetary authority) has a greater capacity to enhance payment industry efficiency (greater value of a), it is advisable to increase the optimal intensity of anti-money laundering regulation (x^*). Therefore, hypothesis 1 is confirmed. If a nation's monetary authority prioritizes the stability of the payment system over efficiency in the two regulatory objectives (represented by a larger value of k_1), then the optimal level of anti-money laundering regulation (x^*) should be increased. Therefore, hypothesis 2 is confirmed. If a monetary authority prioritizes the efficiency of the payment industry over the stability of the payment system among the two regulatory objectives (larger value of k_2), then the optimal intensity of anti-money laundering regulation (x^*) is affected by the efficiency function $E(x)$. If anti-money laundering regulation has significant potential for improving the efficiency of the payment industry (larger value of a), then the optimal regulatory intensity (x^*) must be increased. Therefore, hypothesis 3 is confirmed. However, if the potential for improving payment industry efficiency through anti-money laundering regulation is limited (i.e., a smaller value of 'a'), decreasing the optimal regulatory intensity (x^*) is necessary. Therefore, hypothesis 4 is confirmed.

4.2. Cooperative game analysis results

In the cooperative game model, countries (or monetary authorities) are the participants who agree, and the game follows a dynamic strategy with complete information. Thus, the sequence of the game is prearranged, as indicated in Fig. 5.

4.2.1. Two-player cooperative game analysis results

Suppose there is a 2-country (monetary authorities) cooperation game of the form shown in Table 1.

Table 1: Two-player cooperative games example

	Player 2: strategy a	Player 2: strategy b
Player 1: strategy a	-1, 2	6, 6
Player 1: strategy b	0, 12	0, 12

Let the empty set be denoted by ∅. The coalition that includes only country (monetary authority) 1 is written as {1}, while {2} represents the coalition that includes only country (monetary authority) 2. The set {1,2} shows the coalition formed when both countries (monetary authorities) join together. The characteristic function V gives the total benefit for each of these four possible coalitions. It is generally assumed that countries (monetary authorities) outside a coalition will act in ways that reduce the total benefit of that coalition.

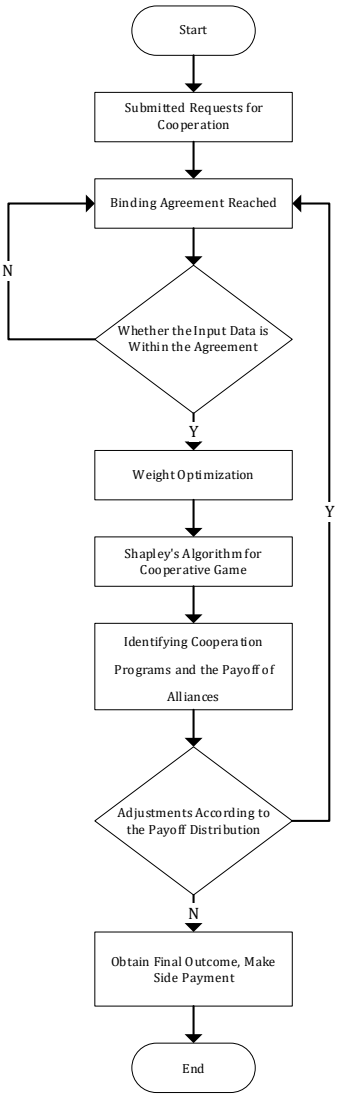

Fig. 5: Flow chart of cooperative game

First, $v(\emptyset)=0$ since a coalition with no country (monetary authority) in it will yield nothing. Second, $v(1)=0$. In this scenario, the worst outcome for country (monetary authority) 1 that country (monetary authority) 2 can impose is to utilize a strategy S_1, which will force the country (monetary authority) 1 to choose between 0 and -1.

Third, $v(2)=6$. In this scenario, the worst outcome for country (monetary authority) 2 is that country (monetary authority) 1 can impose a utilization strategy S_1, which will force country (monetary authority) 2 to choose between 2 and 6.

Lastly, $v(1,2) = 12$, meaning there are no countries (monetary authorities) outside of the

coalition. The maximum combined payoff attainable by countries (monetary authorities) 1 and 2 is 12.

The example demonstrates how cooperation between two countries (monetary authorities) can lead to mutually beneficial results. When gains are comparable, and side payoffs or transfers are feasible, the benefits of cooperation can be measured in a singular value, such as monetary units. If quantification is not feasible, the optimal outcome exists as an abstract Pareto optimal set.

4.2.2. N-player cooperative games analysis results

If three countries (monetary authorities), C, U, and E, are involved in regulating AML, it may be beneficial for them to collaborate due to the globalization of financial transactions. Table 2 outlines potential partnerships among the countries (monetary authorities).

Table 2: AML regulatory cooperation coalition and payoff

No.	Coalition structure
1	{C, U, E} (grand coalition)
2	{C, U} + {E}
3	{C, E} + {U}
4	{U, E} + {C}
5	{C} + {U} + {E} (separate)

Each row in Table 2 portrays a realistic coalition framework. The top row illustrates a grand coalition comprising three countries (monetary authorities), whereas the bottom row represents a coalition of a single country (monetary authority). The benefits of a single-country (monetary authority) coalition can be interpreted as the opportunity cost to each country (monetary authority) if it engages in any other coalition from a cooperative standpoint.

An illustrated example analysis follows. Three countries' monetary authorities formed a coalition to regulate anti-money laundering (AML). Each country (monetary authority) will contribute resources to the coalition, namely e_1=0.4, e_2=0.3, and e_3=.05. For computational convenience, $a = b = 1$. The coalition game characteristics of the function were calculated as shown in Table 3.

Table 3: The payoff for the coalition

Coalition / country	Payoff value
C	0.56
U	0.39
E	0.75
C + U	1.19
U + E	1.44
C + E	1.71
C + U + E (grand)	2.64

By applying Eq. 9:

$$y_i = \sum_{S \subset N} \frac{|S|!(n-|S|-1)!}{n!}[v(S \cup \{i\}) - v(S)] \quad (9)$$

We calculate the Shapley values for the three countries (monetary authorities).

$$y_C = \frac{0.56}{1\times3} + \frac{(1.19-0.39)+(1.71-0.75)}{2\times3} + \frac{(2.64-1.44)}{1\times3}$$

$$y_C = 0.88$$

$$y_U = \frac{0.39}{1\times3} + \frac{(1.19-0.56)+(1.44-0.75)}{2\times3} + \frac{(2.64-1.71)}{1\times3}$$

$$y_U = 0.66$$

$$y_E = \frac{0.75}{1\times3} + \frac{(1.71-0.56)+(1.44-0.39)}{2\times3} + \frac{(2.64-1.19)}{1\times3}$$

$$y_E = 1.10$$

$$\sum_{i=1}^{3} y_i = y_C + y_U + y_E = 2.64$$

$$\sum_{i=1}^{3} v_i = 0.56 + 0.39 + 0.75 = 1.7$$

$$\sum y_i > \sum v_i$$

Since the Coalition of the three countries (monetary authorities) generates synergy, the total utility is 2.64. C, U, and E, each country (monetary authority) receives a utility of 0.88, 0.66, and 1.10, respectively. This outweighs the advantages of the three countries' (monetary authorities) not collaborating and performing independent anti-money laundering oversight.

Thus, the optimal solution is the Grand Coalition, which yields a total payoff of 2.64 units, outperforming all other alternatives. The {CUE} coalition structure functions as the foundation of the game, dictating the type of coalition that guarantees coalition stability by preventing participants from abandoning it and forming a new coalition. Therefore, hypothesis 5 is confirmed.

4.3. Case study

The PBOC has partnered with the BIS Innovation Hub and other national central banks in the multi-CBDC Bridge project—an experimental CBDC arrangement leveraging DLT to facilitate cross-border payments. Compliance checks for cross-border financial transactions are complex and resource-consuming because regulatory requirements for AML/CFT checks, data protection, and sanction screening vary across jurisdictions. Both service providers and end-users may need to spend time and effort on documentation, information verification, and validations to fulfil these requirements. These issues not only raise costs but also make the validation procedure prone to errors.

5. Conclusion

Research Objectives are to address challenges related to cross-border payments involving digital currencies, develop a comprehensive global AML regulations framework, and collaborate with relevant stakeholders. The analysis is conducted from two perspectives:

- Use cost-benefit theory to analyze whether regulators choose to intensify their regulatory efforts under the different preferences of payment industry efficiency and payment system stability. This study aims to provide a basis for regulatory agencies to select strategies.
- Using the cooperative game theory to analyze whether countries (monetary authorities) pursuing the maximization of their interests

choose whether to participate in cooperation, with whom to cooperate, and whether to maintain long-term and stable cooperation to support the AML regulatory cooperation of e-CNY cross-border payments, with a reasonable theory of benefit distribution.

We use illustrative examples for empirical analysis. The cost-benefit analysis confirms the hypotheses 1-4 proposed in this study, namely:

H1: If the implementation of E-CNY cross-border payment leads to increased payment system efficiency, then the potential to significantly improve payment system efficiency, so should the intensity of AML regulations for a country (monetary authority).
H2: If a country (monetary authority) prioritizes payment industry stability over payment system efficiency, it is recommended to increase the intensity of anti-money laundering regulations.
H3: If a country (monetary authority) prioritizes payment system efficiency over payment industry stability, and AML regulations have the potential to improve payment industry efficiency significantly, it is recommended to increase the intensity of anti-money laundering regulations.
H4: If a country (monetary authority) prioritizes payment system efficiency over payment industry stability, and AML regulations have limited potential to improve payment industry efficiency, it is recommended to decrease the intensity of anti-money laundering regulations.

The illustrated example results of the two-player and n-player (n=3) cooperative games demonstrate that in the AML regulatory cooperation of e-CNY cross-border payments, the cooperation mechanism and mode can enhance the interests of the cooperating countries (monetary authorities) and thus ensure the overall interests are sustained. This analysis provides theoretical support for AML regulatory cooperation among countries (monetary authorities) and confirms the hypotheses 5proposed in this study, namely:

H5: If there are benefits to be obtained from cooperation in anti-money-laundering regulation among multiple countries (monetary authorities), any one country (monetary authority) will gain more than if it were to regulate independently.

So far, all 5 hypotheses of this study have been supported.

6. Discussion

Emerging technologies help e-CNY cross-border payment to enhance anti-money laundering efficiency. The choice of anti-money laundering regulatory intensity must consider the efficiency of the payment industry and the stability of the payment system. The final strategy is then selected based on a cost-benefit analysis.

For instance, the utilization of digital identification technology can enable us to bridge the gap between the digital and physical spheres, thereby improving the effectiveness of CDD. This technology can record digital currency transactions between users, leveraging smart contracts while also ensuring transactions comply with the principle of limited anonymity. These measures will not only enhance regulator efficiency but also assist AML-compliant entities in meeting their fundamental duties regarding customer due diligence (CDD), significant transactions, and reporting suspicious activities. This, in turn, will aid in the more effective combating of money laundering.

However, compared to cash, CBDCs may pose greater risks of money laundering and terrorist financing. Since CBDCs are backed by central banks within their respective jurisdictions, they have the potential to achieve widespread acceptance and usage. The combination of anonymity, portability, and broad accessibility makes them particularly attractive to criminals and terrorists seeking to launder money or finance illicit activities. Additionally, regarding anti-money laundering (AML) compliance for cross-border CBDC payments, attention must be paid to adherence to the "Travel Rule." This rule requires virtual asset service providers (VASPs) to transmit key identifying information between institutions to ensure transparency and compliance with AML obligations.

7. Recommendations

7.1. Anti-money laundering regulatory cooperation between states (monetary authorities)

Only through cooperation can we effectively enhance anti-money laundering regulation for digital cross-border CNY payments and curb money laundering crimes. To achieve this, countries (monetary authorities) must form a long-term coalition and maintain regulatory cooperation to ensure financial security and social stability. Such cooperation will provide countries (monetary authorities) with the necessary incentives to remain committed to anti-money laundering efforts. Maintaining stability in the e-CNY cross-border payment market and enhancing the efficiency of the cross-border payment system are necessary to balance anti-money laundering regulations.

Speed up the construction of an anti-money laundering regulatory cooperation mechanism for e-CNY cross-border payments. Currently, the core of the global cross-border payment system remains SWIFT (Society for Worldwide Interbank Financial Telecommunication) and CHIPS (New York Clearing House Interbank Payment System), both of which are primarily dominated by the United States. The flow of e-CNY around the world in digital form will inevitably pose more challenges to the current anti-money laundering regulation, especially when it involves the problems of multilateral countries

(monetary authorities). China has not yet established multilateral supervisory principles on digital currency with other countries, nor has it consulted on the rights and obligations of countries in the use and circulation of digital currency, nor has it achieved effective linkage in combating cross-border money laundering crimes, unless it establishes relevant cooperation agreements and cooperation arrangements with other countries. At the same time, there is no effective linkage in the cross-border fight against money laundering crimes. Therefore, if China does not establish corresponding cooperation agreements and coordination mechanisms with other countries, it will seriously affect the recognition of e-CNY and its large-scale cross-border application. Therefore, speeding up the construction of an anti-money laundering regulatory cooperation mechanism for cross-border payments of e-CNY should be one of the important issues in the financial regulation of e-CNY.

7.2. Learn from the AML regulatory experience of private digital currencies

The AML regulation of e-CNY cross-border payments must absorb and apply mature digital technology and combine it with the current regulatory frameworks of third-party payment platforms and international private digital currencies, use the digital currency user identification mechanism to support the maintenance of digital currency information and payment security, and use the digital currency AML regulatory framework to combat digital currency crimes. Although private digital currencies are only defined as property in China, this does not prevent us from exploring ways to address the money laundering risks associated with the legal tender within the existing regulatory model for private digital currencies. For example, financial institutions that provide exchange, storage, transfer, or custody of digital currencies should be subject to the same level of regulation and prudence as companies that provide similar services to existing digital currencies. Furthermore, the regulatory sandbox model, which has been widely cited in the regulatory testing of private digital currencies, focuses on providing FinTech with a space for "legitimate trial and error." Therefore, it is necessary to develop further the regulation of e-CNY in cross-border issuance, storage, circulation, payment, and settlement through the "regulatory sandbox" model to achieve a win-win model of financial security and technological innovation without harming the legitimate rights and interests of the existing financial system and financial consumers. In summary, the existing regulatory framework for digital currencies should be fully considered when conducting financial regulatory activities. The same level of regulation should be applied to the same crimes, and the same level of liability should be imposed to reduce the scope for arbitrage created by regulatory differentiation. At present, the risks and financial stability implications of private digital currencies are also unavoidable in the operation of e-CNY.

7.3. Strengthening the integration of emerging technologies and anti-money laundering regulation

The utilization of new technologies has revitalized and innovated traditional methods of anti-money laundering regulation. It has now become a widespread practice to enhance the efficacy of anti-money laundering regulation through scientific and technological advancements. To bolster risk monitoring of the e-CNY in anti-money laundering efforts, it is essential to employ advanced scientific and technological measures to enhance the effectiveness of money laundering risk monitoring, prevention, and control. In the future, e-CNY anti-money laundering regulations can benefit from the strengthened application of regulatory technology and the active utilization of big data, artificial intelligence, cloud computing, and other technologies to enhance the means of financial regulation. This will improve the screening, prevention, and resolution of cross-border, cross-market, and cross-industry money laundering risks. The principles mentioned can be applied to key aspects, including customer due diligence, monitoring suspicious and unusual transactions, and regulatory reporting, to heighten the prevention and disposal capacity of e-CNY cross-border payments against money laundering risks.

The creditworthiness of the e-CNY as a fiat currency will also depend on the reliability and anti-counterfeiting of the e-CNY in terms of currency technology. Maintaining information security and protecting the privacy of user data are crucial components of developing a digital currency regulatory system in the future. Strong information security technology is a powerful weapon for regulators to maintain the security of the transaction system and prevent the property and personal interests of e-CNY users from being violated. In addition, criminals can carry out illegal activities, such as digital currency counterfeiting or money laundering, by attacking the authentication system of the central bank's digital currency or using quantum technology to break the encryption loop of a node. At the same time, it is also necessary to use reliable cryptographic technology to effectively curb the illegal activities that may occur in the medium of circulation of legal digital currencies. Therefore, the support of regulatory technology is the foundation for the construction and good operation of the regulatory mechanism. As a new type of currency, e-CNY needs to constantly update its algorithms to ensure the operational safety of e-CNY. For example, the development of a new payment and clearing system with innovations in traceability, query, and verification is indispensable technical support for maintaining the transaction security of e-CNY. Only with the support of strong technology and a sound

system can the stability and security of the e-CNY cross-border payment system be effectively maintained.

List of abbreviations

AML	Anti-money laundering
BIS	Bank for International Settlements
CBDC / CBDCs	Central bank digital currency / Central bank digital currencies
CDD	Customer due diligence
CeFi	Centralized finance
CFT	Counter financing of terrorism
CHIPS	Clearing House Interbank Payments System
DeFi	Decentralized finance
DLT	Distributed ledger technology
e-CNY	Electronic Chinese yuan (China's central bank digital currency)
FATF	Financial Action Task Force
G20	Group of Twenty (an international forum of major economies)
PBOC / PBoC	People's Bank of China
RegTech	Regulatory technology
SWIFT	Society for Worldwide Interbank Financial Telecommunication
VASP / VASPs	Virtual asset service provider / Virtual asset service providers

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Compliance with ethical standards

Conflict of interest

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