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MCM/ICM

Summary Sheet

A new way forward for currency system — Central Bank Digital Currency

Summary

'As long as I can control the issuance of a country's currency, I don't care who makes the law.' This quote from the *Currency Wars* may be too radical, but it does reveal the significance of monetary sovereignty, which is also the key thought of our model.

In recent years, the vigorous development of digital currency has triggered extensive debate on the monetary system. Some reckon that the traditional currency system may become obsolete. Some government, however, believe the decentralized digital currency does more harm than good primarily due to the lack of regulation around these currencies and the risky feature of cryptocurrency for its anonymity.

Towards this problem, we propose a **Central Bank Digital Currency** system based on advanced algorithms while guaranteeing national monetary sovereignty, which integrates the efficiency of digital currency and the importance of national monetary sovereignty. We firmly believe that the complete decentralized digital currency is not a way forward for the current monetary system mainly for two reasons. First, because it is impossible to make most countries abandon their monetary policy sovereignty. Besides, in a strict sense, non-statutory digital currency represented by Bitcoin is only a commodity asset instead of a form of currency.

First, we start our model by making the definition of currency clear. We believe that the essence of money is the social consensus and the primary function of currency is to decrease costs occurred in transactions, management, etc.

Second, we construct a model to determine the *return value* and *consensus value* of both banknotes and digital currency based on the rationale of **Cobb-Douglas Function**, through which we derive the maximal proportion of currency issuance of digital currency is around 0.76.

Third, to construct a model that adequately represents this type of financial system, we use the **Analytic Hierarchy Process (AHP)** to determine the different needs and willingness of countries to work with this new financial marketplace.

In addition, to make the result more elegant, we use **BP Neural Network Algorithm** to build an **AI model**. According to the characteristics of the model, we apply **Kalman filter** to the recursive model of neural networks to make further modifications.

Next, as for the supervision of central bank digital currency, we improve the **'Regulation Sandbox'** promoted by England, which will effectively reduce the risks of statutory digital currency to the traditional market.

Finally, we conduct the sensitivity analysis on our models above and extend your analysis to consider the long-term effects of such a system on the current banking industry, the economy, and international relations between countries.

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A New Way Forward for Currency System: Central Bank Digital Currency

1 Introduction

1.1 Problem Background

Throughout the history of monetary development, the form of currency has always evolved with the development of technological progress and economic activities. From barter exchange to the emergence of token money, to the rapid development of credit, electronic money, and digital money, we can see that it is an inevitable trend to witness currency changing from the physical possession to the virtual form. Currency is a symbol and it does not need to be valuable in itself. Its value may come from the law or consensus.

Since the birth of digital currency(e.g. Bitcoin), whether it can be regarded as legal tender has been widely debated. Some experts reckon that a universal, decentralized, digital currency with internal security like Bitcoin can promote the efficiency of the market by eliminating barriers to the flow of money and it will save costs incurred by merchants. Some governments, however, believe the decentralized digital currency does more harm than good primarily due to the lack of regulation around these currencies and the risky feature of cryptocurrency for its anonymity.

Towards this problem, as a policy modeling team of the International Currency Marketing Alliance, we are supposed to build a model validly supporting a brand new global digital financial market. We also identify key factors which would either limit or facilitate its growth, access, security, and stability at both the individual, national, and global levels. The working model also takes the different needs and degree of willingness of different countries into consideration.

1.2 Our Work

We believe that the limitations of the current the monetary system lead to discussions about digital money. From the perspective of monetary attribute, although the present decentralized digital currency is not a complete monetary form, it has the potential to become a kind of currency. As far as the development trend is concerned, the transformation from paper money to digital money is bound to occur.

However, we firmly believe that the decentralized digital currency is not a way forward for the current monetary system mainly for two reasons. First, because it is impossible to make most countries abandon their monetary policy sovereignty. Second, in a strict sense, non-statutory digital currency represented by Bitcoin is only a commodity asset instead of a form of currency.

The utopian idea that everyone can issue money has actually been experienced in history. For more than 20 years after the end of the Civil War, the United States had no central bank, and there was no law regulated who could issue a unified currency. So almost all commercial banks in the United States were able to issue money at that time. According to historical records, every businessman in the U.S. had to carry a thick account book with numerous information. Not only the form of money is confusing, but the transaction costs were extremely high. This is the era known as the "wild cat" of banking. Never can we exhaust examples to prove the decentralized digital currency system is impossible.

There is a famous theorem in a modern financial theory called **Impossible trinity** proposed by Robert Mundell. It says it is impossible for a country to realize **the freedom of capital flow**, **the effectiveness of monetary policy** and **the stability of the exchange rate at the same time**. That is to say, a country can only own two of them at most. So the key point is that which factor is significant for different countries based on the different economic condition. It is safe to say that most countries lay great emphasis on the effective monetary policy, which not only assures the smooth development of the economy but also represents the national sovereignty to some extent.[2]

Let’s turn our attention to the decentralized digital currency. Besides the discussion above, the reasons why it can’t be viewed as a kind of currency is that, in a strict sense, non-statutory digital currency represented by Bitcoin is only a commodity asset. Because it does not conform to the so-called consensus rule.

So we believe that the universal digital currency system is possible, as long as we abandon the form of ‘complete decentralization’, which means we are constructing a model called the Central Bank Digital Currency, that recommend central bank to issue digital money. And the form remains unchanged — from the central bank to commercial banking, then to individuals.

Under such circumstance, we first determine that the essence of money is the social consensus and the primary function of a currency is to decrease transaction cost.

Second, we construct a model to determine the *return value* and *consensus value* of both banknotes and digital currency based on the rationale of **Cobb-Douglas Function**, through which we derive the maximal proportion of currency issuance of digital currency is around 0.76.

Third, to construct a model that adequately represents this type of financial system, we use the **Analytic Hierarchy Process** (**AHP**) to determine the different needs and willingness to work with this new financial marketplace.

Fourth, to make the result more elegant, we use **BP Neural Network Algorithm** to build an **AI model**. According to the characteristics of the model, we apply **Kalman filter** to the recursive model of neural networks to make the further modification.

Fifth, for the supervision of central bank digital currency, we improve the **'Regulation Sandbox'** promoted by England, which will effectively reduce the risks of statutory digital currency to the traditional market.

Then, we conduct the sensitivity analysis on our models above and extend your analysis to consider the long-term effects of such a system on the current banking industry, the economy, and international relations between countries.

2 Core Nomenclature & General Assumptions

2.1 Core Nomenclature

- **Legal Tender** - A medium of payment recognized by a legal system to be valid for meeting a financial obligation.
- **World Currency** - Money that plays the role of generic equivalents in international commodity circulation is called world currency. When commodity exchange goes beyond national boundaries, commodities generally develop their own value in the world. [1]
- **Nation-based currencies** - A system of money issued by a central bank and in common use within a particular nation or group of nations.
- **Electronic Money** - Money which exists in banking computer systems and is available for transactions through electronic systems. Its value is backed by fiat currency and it can be exchanged into physical form however its uses are often more convenient electronically.[3]
- **Digital Currency** - A type of currency available in digital form (in contrast to physical, such as banknotes and coins). It exhibits properties similar to physical currencies but can allow for instantaneous transactions and borderless transfer-of-ownership. It can either be centralized, where there is a central point of control over the money supply, or decentralized, where the control over the money supply can come from various sources. Digital currency can be denominated to a sovereign currency and issued by the issuer responsible to redeem digital money for cash.[4]

- **Cryptocurrency** - A digital or virtual currency that uses cryptography (protecting information through the use of codes) for security. Bitcoin is a typical example of cryptocurrency.
- **Central Bank Digital Currency** - The central bank digital currency is issued by the Central Bank based on an encryption algorithm while maintaining physical cash issuance, which assures the monetary sovereignty of the National Government.

2.2 General Assumptions

- Considering the rapid development of digital money, we assume that there are no technical barriers, the technical conditions for developing digital currency are adequate in the near future.
- In our policy model, we would not require countries to abandon their own nation-based currencies. But they must use digital currency conducting business internationally.
- Based on the great efficiency and security of digital currency, we assume that it can be perfectly used as the world currency, in other words, It will become the currency that plays the role of generic equivalents in international commodity circulation.
- To be as viable as possible, we assume the most important issuer of world currency remains unchanged, in other words, we recommend that the United States embark on the development of digital money and issue dollars and the central bank digital currency at the same time.
- The United States can determine the issuance of digital currency in the early stage, but the transformation from dollars (banknotes) to digital currency will not change the total volume of legal tender.

3 Utility Model based on Consensus and Saving Value

3.1 Assumptions

- We assume that there brand new currencies will not appear for a relatively long time to come.
- It is allowable for countries to choose their original currency conducting domestic transactions.
- The degree of contribution of different kinds of currency can be measured by their ‘return value’ and ‘consensus value’.
- Old people and extreme-poor-people will have trouble using digital currency.

3.2 Notations

Notations	Definitions	Notations	Definitions
U	Total utility of the U.S.	**DOC_B**	Degree of contribution of banknotes
C_D	Consensus value of digital currency	**ω_D**	Weight of digital currency
C_B	Consensus value of banknotes	**ω_B**	Weight of banknotes
π	Total cost spent on mintage	**W**	Percent of population over 65 years
S_D	Saving value of using digital currency	**w_i**	Percent of population over 65 years in country i
S_B	Saving value of using banknotes	**pi**	Population of country i
$cost_D$	Cost of using digital currency	**P**	World's total population
$cost_B$	Cost of using banknotes	**V**	Percent of extreme poverty
DOC_D	Degree of contribution of digital currency	**L**	Amount of countries considered

3.3 Process

3.3.1 Consensus Value

We define 'consensus value' as the degree of recognition on a certain currency. The currency has higher 'consensus value' if it is highly guaranteed.[5] Depending on the influence of the U.S. dollar and the guarantee the U.S. provides, the dollar is widely used in the world-trade-market. So we consider the banknotes(dollar) have a high level of consensus value. And it will not change for a long time.

As for the digital currency, we employ the **Logistic Equation** to describe the consensus. Logistic Equation is a method to describe the social demand of a new product coming to the market. We define $x(t)$ as the consensus at time t, a as the ceiling of consensus value of the digital currency. According to the equation[6]:

$$\frac{dx}{dt} = kx(a - x)$$

The logistic line is:

$$x(t) = \frac{a}{1 + e^{-ac}e^{-akt}}, \ a = 1, c = -3.6, k = 0.012$$

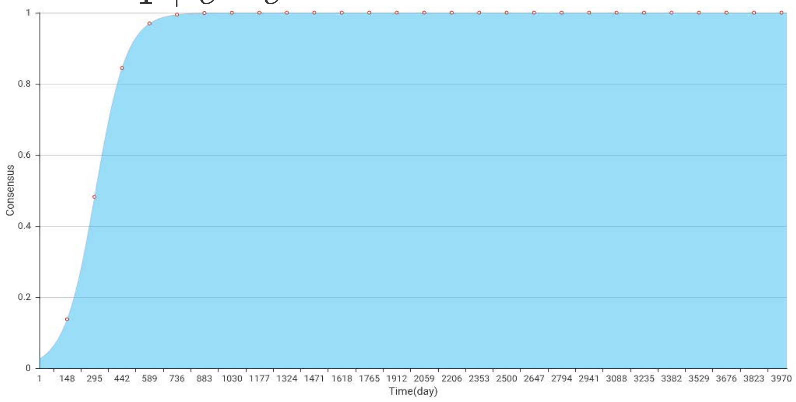


figure1.Logistic Line

We set the variable a equals 1, which means that after about 3 years, digital currency will reach the ceiling of consensus value. At that time, the consensus value of the digital currency is almost identical to the consensus of banknotes. Also, we believe this circumstance will last for a long time.

3.3.2 Saving Value

The cost of banknotes mainly refers to the cost of transportation and management.

The cost of digital currency mainly refers to the huge cost of research and development, which can be amortized in the long run. So compared with various kind of expenses of cash, Its cost is much smaller.

$$S_D = \pi - cost_D$$
$$S_B = \pi - cost_B$$

3.3.3 Degree of Contribution Model based on the Cobb-Douglas Function

Cobb-Douglas Function describes the relation between Y (the output value) and *labor* and *capital*. We use the principle to value DOC. We assume the aging population above 65 and the people in extreme poverty will have trouble using smart-phones. They have the need of bank notes[7] [8] [9]. Taking those into consideration, we get to the following equations:

$$DOC_D = S_D^{\alpha} C_D^{\beta} \mu$$
$$DOC_B = S_B^{\alpha} C_B^{\beta} \mu$$
$$U = \omega_D DOC_D + \omega_B DOC_B$$
$$W = \sum_{i=1}^{L} \omega_i \frac{p_i}{P}$$
$$p_{max} = 1 - W - V + WV$$

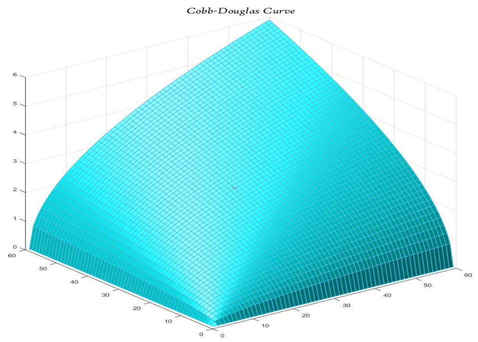


figure2.Cobb-Douglas Curve

The result is $W = 0.0784, V = 0.1714, p_{max} = 0.7636$. So the upper bound of ω_D is 0.7636. We suggest that the Federal Reserve changing no more than 76.36% of banknotes into digital currency. If the ratio becomes larger, the utility will decrease.

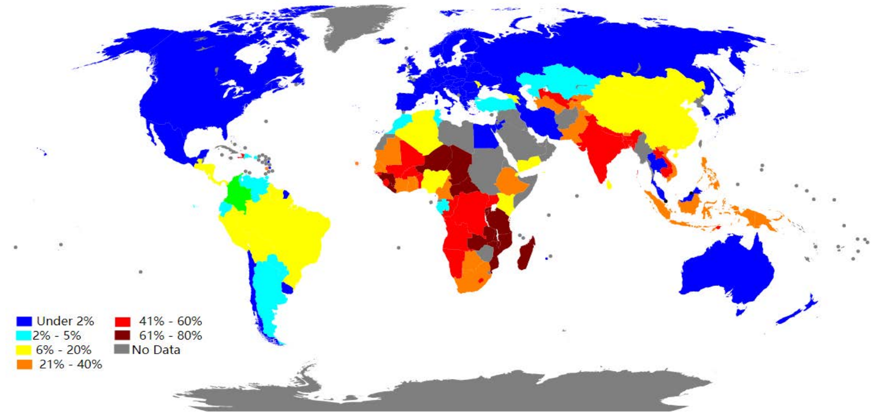


figure3.Percents of Population Living in Extreme Poor ©Source:Wikimedia

4 Demand Analysis model based on AHP

4.1 Assumptions

- Taking the effectiveness of monetary policy into consideration, we assume that most countries are not willing to hold too much digital currency.
- We assume that the factors that determine the different need of digital currencies among different countries are: (1)International trade,(2)economy,(3)knowledge,(4)diplomacy,(5)government credit.
- We don't force countries to abandon their own currency for the internal transactions, but they must use the central bank digital currency in international trade.

4.2 Notations

Notations	Definitions
λ	The maximum eigenvalue
A	Corresponding eigenvector

4.3 Demand Analysis over Different Countries

We have already determined the maximal level of digital currency issued at the early stage. But we need to determine the differing need of different countries. Given the role of digital currency, we reckon the most important factors are — (1)International trade, (2)economy,(3)knowledge,(4)diplomacy,(5)government credit. Every factor includes several measurable parameters. For instance, we can use GDP to measure economic and the imports and exports to measure the vitality of international trade.

Aiming at determining the weight of these factors, we preliminary employ **Analytical Hierarchy Process (AHP)**, which helps transform our subjective preferences to an accurate criterion to value the significance of those factors above.

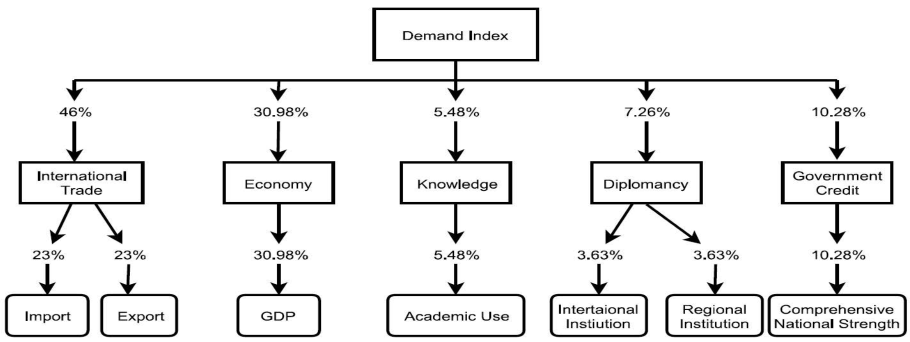
First, we construct a 5*5 comparison matrix, which shows the different extent of preference between factor i and j ($1 \leq i \leq 5$, $1 \leq j \leq 5$). We show a special preference for the economy and international trade for its importance contribution for the development of trade. So we come to the following comparison matrix.

$$A = \begin{pmatrix} 1 & 2 & 6 & 6 & 5 \\ 1/2 & 1 & 5 & 5 & 4 \\ 1/6 & 1/5 & 1 & 1/2 & 1/2 \\ 1/6 & 1/5 & 2 & 1 & 1/2 \\ 1/5 & 1/4 & 2 & 2 & 1 \end{pmatrix}$$

Then we calculate the maximum eigenvalue λ and the corresponding eigenvector A.

$$A\omega = \lambda\omega$$

So we derive the weights of each factor, and the result is shown below.



In order to test the consistency of the comparison matrix, we need to calculate the $Consistency\ Ratio(CR)$, which can be defined as the ratio of $Consistency\ Index(CI)$ to $Average\ Random\ Consistency\ Index(RI)$.

n	1	2	3	4	5	6	7	8
RI	0	0	0. 58	0. 90	1. 12	1. 24	1. 32	1. 41

$$n = 5, RI = 1.12$$

$$CI = \frac{\lambda - n}{n - 1} = 0.0658$$

$$CR = \frac{CI}{RI} = 0.0588$$

Since CR is smaller than 0.1, the consistency of the matrix is confirmed.

From the discussion above, we find that the most important factors are the economy and international trade. So we view both of them as the main criterion to identify the different need of countries.

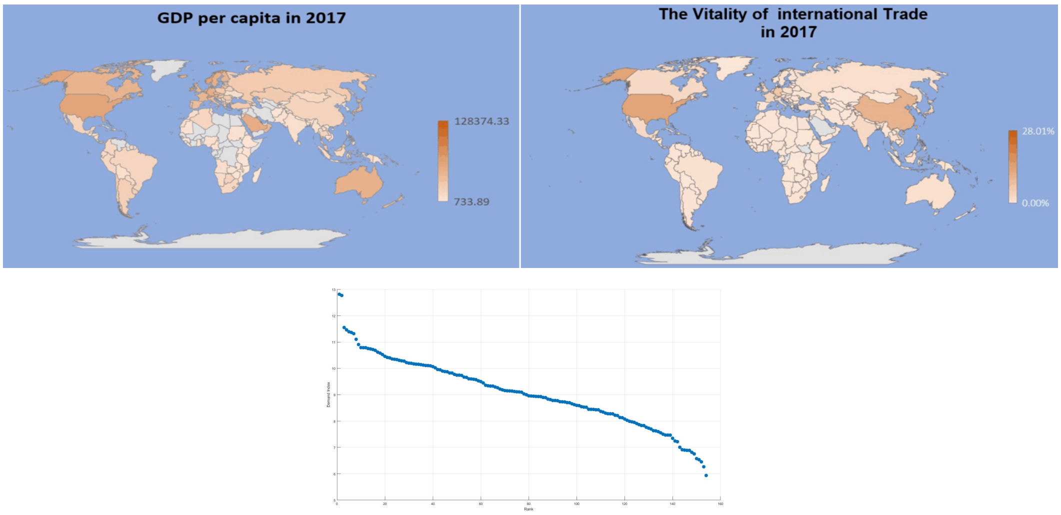


figure4.Demand of Different Countries Based on Economy and International Trade

4.4 Special cases

the United States

Obviously, as the issuer, its need of digital currency is under no consideration. We have already come into the conclusion that the weight recommended is about 76 percent, and it may grow in the future because of the development of society.

China

As the biggest developing country, China can be viewed as the most active one of them. It has been a while for PBOC(People's Bank of China) studying on the Central Bank Digital Currency, and last year it set up a research institute called the Digital Currency Research Laboratory. Yao Qian, Director of Digital Money Research Institute of the People's Bank of China, has made a series of valuable research on this issue.

Switzerland

Although Switzerland is the most block-chain-friendly country in Europe, it doubts the usefulness of CBDC. Andra M. Maechler, a member of the Swiss Central Bank (SNB) regulatory committee, rejected calls for the central bank to issue digital currency. We believe it may be due to the special feature of SBC.

5 Artificial Intelligence Model of Money Issuance

We already arrived at the conclusion of the maximum weight of digital currency, and different need of different countries. Taking the influence of the speed of issuance into consideration, we will focus on the total issuance of digital currency at a specific period. To describe it precisely, we have developed an Artificial Intelligence model for currency issuance based on the foreign exchange expansion.

5.1 Key Factors

Our Central Bank Digital Currency system obtains the following key factors, which will have an effect on individuals, countries and global levels:

(1)**Higher efficiency in foreign trade(HEFT)**. Digital currency transactions take a point-to-point network, without the need for third-party clearing institutions, so they have cost and time advantages in cross-border payment.

(2)**Lower cost(LC)**. At present, the management costs of banknotes include printing, replacing, escorting, cash management costs for enterprises and businesses, etc. If the digital currency is adopted, the central bank will only build the management platform of central bank digital currency once and for all, and then the cost of issuing digital currency will decrease gradually.

(3)**Safety(ST)**. Legal digital currency has a stronger ability of hacker attack defense and anti-sanction. Even if local nodes temporarily fail, the transaction data recorded in each node of the whole network will not be lost. The issuance of statutory digital currency and the control of core technology by the monetary authorities can also avoid the negative effect of illegal statutory digital currency on the financial system.

(4)**Higher financial containment(HFC)**. Digital money networks do not need to be tied to bank accounts, thus helping people in remote areas to enjoy modern financial services.

(5)**Transparent information transmission(TIT)**. The information on legal digital currency transactions is transparent, which is helpful to the efficiency of the financial market and regulate illegal business.

(6)**National credit support(NCS)**.Different from private digital currency(bitcoin), the issuance of the central bank digital currency is guaranteed by the national credit.

Besides, there are other specific factors for each level. For example, for individuals, the digital currency increases the efficiency of small transactions greatly. Besides, it help countries eliminate and strike the illegal behavior called money laundering. In the view of the global level, it effectively increases the vitality of international trade.

5.2 Demand Forecast Model based on the State Space Model and BP Neural Network

5.2.1 Notations

Notations	Definitions
ECO	The economic condition of a country
ITR	A country's vitality to international trade
KNO	A country's scientific and technological level
DIP	A country's vitality to diplomacy
NC	National credit of a country

5.2.2 Process

The first task is to describe the observable economic system. We use the key factors above, namely, economy (ECO), international trade (ITR), knowledge (KNO), diplomacy (DIP), national credit (NC), etc to construct the Vector Autoregression Model (VAR)[10]. (Here we consider country m first)

The general form of the VAR model is:

$$y_t = c + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \ldots + \phi_p y_{t-p} + \epsilon_t \qquad (1)$$

$$\epsilon : n \times 1 \; white\ noise\ vector, \; c : n \times 1 \; constant\ vector$$
$$\phi : n \times n \; matrix\ of\ autoregressive\ coefficients$$

$$E(\epsilon_t) = 0$$
$$E(\epsilon_t \epsilon_\tau) = \begin{cases} \xi^2 & t = \tau \\ 0 & t \neq \tau \end{cases}$$
$$\xi^2 \; n \times n \; Symmetric\ positive\ definite\ matrix$$

The second task is to describe the unobservable economic system, in which investment efficiency (HEFT), management cost (LC), security (ST), financial inclusiveness (HFC), financial market information transmission (TIT), national credit support (NCS) are unobservable variables. Therefore, we can only use state space model to 'work backward' to get information about unobservable variables from observable economic variables.

The State Space Model can be expressed in (2) and (3):

$$u_t = f(x_t, y_t, \sigma_{1t}) \qquad (2)$$

$$x_t = h(x_{t-1}, u_t, \sigma_{2t}) \tag{3}$$

Formula (3) is the observation equation, u_t is the observable output variable, x_t is the unobservable state variable, y_t is the observable input variable, and e_{1t} is the observation error. Formula (4) is an unobservable equation of state, and e_{2t} is a state error.

It is noteworthy that VAR is a state space model as well, because (1) is equivalent to space state model of equation(4) and (5).

The observed equation:

$$y_t = (1, 0, \ldots, 0) \begin{Bmatrix} y_t \\ y_{t-1} \\ \ldots \\ y_{t-p} \end{Bmatrix} \tag{4}$$

The state equation:

$$\begin{Bmatrix} y_t \\ y_{t-1} \\ \cdots \\ y_{t-p+1} \\ y_{t-p} \end{Bmatrix} = \begin{Bmatrix} \phi_1 & \phi_2 & \cdots & \phi_{p1} & \phi_p \\ 1 & 0 & \cdots & 0 & 0 \\ 0 & 1 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 1 & 0 \end{Bmatrix} \begin{Bmatrix} y_{t-1} \\ y_{t-2} \\ \cdots \\ y_{t-p} \\ y_{t-p-1} \end{Bmatrix} + \begin{Bmatrix} \epsilon_t \\ 0 \\ \cdots \\ 0 \\ 0 \end{Bmatrix} \tag{5}$$

Under this digital currency system, the demand for digital money in various countries is to be described. We consider five variables, namely, economy (ECO_m), international trade (ITR_m), knowledge (KNO_m), diplomacy (DIP_m) and national credit (NC_m), which are all unobservable variables. So as long as we select the five-variable P-order lag VAR, we can replace the observable variable y_t separately. The model is as follows:

$$\begin{Bmatrix} ECO_{m,t} \\ ITP_{m,t} \\ KNO_{m,t} \\ DIP_{m,t} \\ NC_{m,t} \end{Bmatrix} = a_{m,0} + \sum_{i=1}^{p} A_{m,i} \begin{Bmatrix} ECO_{m,t-i} \\ ITP_{m,t-i} \\ KNO_{m,t-i} \\ DIP_{m,t-i} \\ NC_{m,t-i} \end{Bmatrix} + \begin{Bmatrix} \epsilon_{m,1t} \\ \epsilon_{m,2t} \\ \epsilon_{m,3t} \\ \epsilon_{m,4t} \\ \epsilon_{m,5t} \end{Bmatrix} \tag{6}$$

Among them, $a_{m,0}$ is the constant term matrix and $A_{m,i}$ is the coefficient matrix.

We use the `varsoc` command in STATA to calculate the lag order P. Thus, we can build the model with two estimation objectives: one is a coefficient matrix, the other is the covariance matrix of the error term. Because the result obtained by using `var inflation Unrate ffr, lags (1/P) dfk small` in STATA contains too many coefficients, which are not intuitive enough, the reward we adopt is **impulse response** — give a standard deviation fluctuation to a variable to see how it affects the variables of the whole system.

On the basis of the establishment of **P-order VAR model** with five variables of ECO_m, ITR_m, KNO_m, DIP_m and NC_m, we can deduce the investment efficiency ($HEFT_m$), management cost (LC_m), security (ST_m), financial inclusiveness (HFC_m) and financial market information transmission (TIT_m) in the economic system of digital currency issuance. The impact of the six non-observable variables of National Credit Support (NCS_m) on the whole digital currency issuing system. It shows that no matter the economic system is observable or not, it can always be described by the state space model. So combined with the econometric idea of state space model and the modeling idea of neural network, we use the state space model recursive neural network to establish the AI model of currency issuance.

The model based on BP neural network is shown as below:

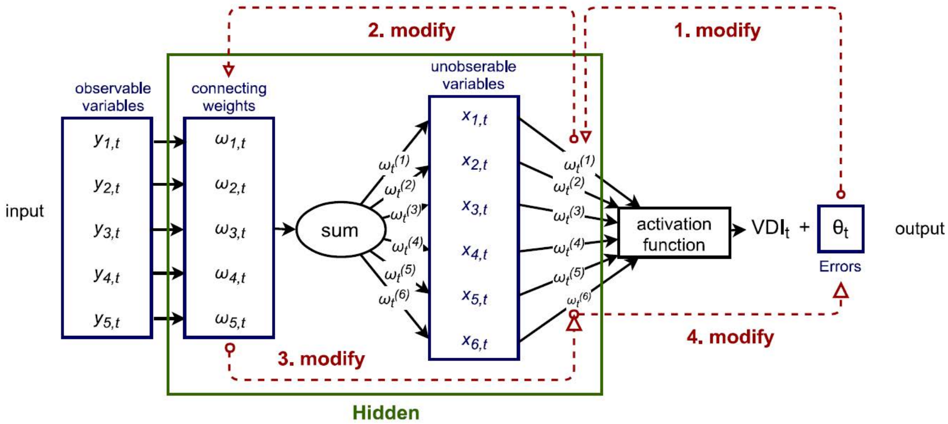


figure5.Schema of BP Neural Network

Among them, Y_t is the vector of observable variables $y_{1,t}$, $y_{2,t}$, $y_{3,t}$, $y_{4,t}$, $y_{5,t}$. X_t is the vector of unobservable variables $x_{1,t}$, $x_{2,t}$, $x_{3,t}$, $x_{4,t}$, $x_{5,t}$, $x_{6,t}$. VDI_t is the output signal, the predictive value of the optimal circulation of digital currency in a country, θ_t is the error term. Step1 to 4 are the correction process of the error θ_t and the connection weights $\omega_{1,t}$,$\omega_{2,t}$,$\omega_{3,t}$,$\omega_{4,t}$,$\omega_{5,t}$.

Specifically, we observe five variables: economy (ECO), international trade (ITR), knowledge (KNO), diplomacy (DIP), and national credit (NC) and import these five variables into the neural network model shown in figure i as input signals.

On the basis of pre-given connection weights $\omega_{1,t}$,$\omega_{2,t}$,$\omega_{3,t}$,$\omega_{4,t}$,$\omega_{5,t}$, the system will give the output of VDI_t and an error term θ_t after being processed by hidden layer. The error term θ_t will return to the hidden layer as an unobservable variable to modify the connection weight of the unobservable variable (step 1), After the modification of connection weights of unobservable variables, the weights of observable ones will be modified(step 2), and the weights of unobservable variables will be modified again later(step 3). Thus, passing through the activation function, we can get the modified output signal VDI_t^* and the modified error term θ_t^*(step 4). After repeating the above process for several times, the influence caused by the error term can be neglected, so we can forecast the output signal VDI_t accurately, which is, the volume of digital currency issued during period t.

5.3 Modification Algorithm: *Kalman Filter*

5.3.1 Notations

Notations	Definitions
VID_t	The output signal at period t
A_1	The state transition matrix
Y_t	The input signal at period t
B	the input gain matrix
W_t	The process noise which obeys the Gaussian normal distribution and its mean equals 0
Z_t	The measured value at t
H_1	The measurement matrix
V_t	The measurement noise which obeys the Gaussian normal distribution and its mean equals 0
The Prediction Process	
VID^*_t	The optimal estimated value at period t
$P_{t\|t-1}$	The prediction error covariance matrix at period t
P^*_{t-1}	Kalman Estimation Error Covariance Matrix at period t-1
A^T_1	The transpose matrix of A_1
Q	The covariance of the system process
The Modification Process	
K_t	The Kalman Gain
R	The covariance of the measurement process

5.3.2 Process

Kalman filter is an optimal recursive data processing algorithm, which also can be viewed as a modified algorithm for predictive variables. We now apply it to the recursive model of neural networks above to obtain the most precise output value VID_t, the optimal amount of currency in circulation[11].

In fact, the Kalman filter consists of two processes: prediction and correction. In the prediction phase, it uses the estimated value of the previous state to make a prediction of the current state. In the modification phase, it utilizes the observation data at the current stage to modify the estimated value obtained at the prediction stage.

We use the Kalman filter algorithm to further modify the output value VID_t of the previous neural network recursive model system. By eliminating the influence of noise on the forecast value, the accuracy of the whole digital currency issuance model is further improved.

First, to make it easy to understand, we divide the process of noise reduction into two parts and use a flow chart to describe the operation process of the algorithm. The first process is to calculate the state estimator, second is the calculation of covariance P^*_t.

The flow charts of both processes:

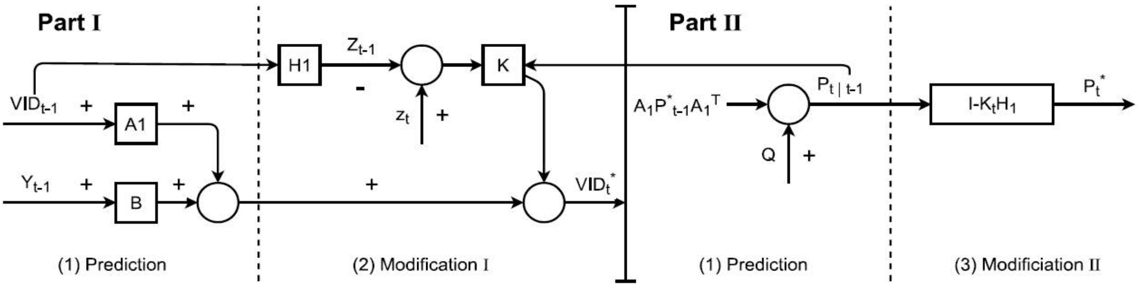


figure6.the Flow Charts of Kalman Filter Algorithm

To describe the application of the Kalman filter in AI model of digital currency issuance more accurately, we give the corresponding mathematical expression. Combining fig1 with fig2, it can be seen intuitively that Kalman filtering algorithm is well integrated with the recurrent model system of the neural network in this AI model.

Prediction and Observational equation of system state:

$$VID_t = A_1 VID_{t-1} + BY_t + W_t \tag{7}$$

$$Z_t = H_1 VID_t + V_t \tag{8}$$

In the equations, VID_t is the output signal at period t, A_1 is the state transition matrix, Y_t is the input signal, B is the input gain matrix, W_t is the process noise which obeys the Gaussian normal distribution and its mean equals 0. Z_t is the measured value at t, H_1 is measurement matrix, V_t is the measurement noise which obeys the Gaussian normal distribution and its mean equals 0.

The prediction process:

$$VID_{t|t-1} = A_1 VID^*_{t-1} + BY_t \tag{9}$$

$$P_{t|t-1} = A_1 P^*_{t-1} A_1^T + Q \tag{10}$$

In the equation, VID^*_{t-1} is the optimal estimated value, $P_{t|t-1}$ is the corresponding covariance matrix, Q is the covariance of the system process. Formulas (9) and (10) are the predictive formulas of the Kalman filter for the system.

The modification process:

$$VID_t^* = VID_{t|t-1} + K_t(Z_t - H_1 VID_{t|t-1})$$

$$K_t = \frac{P_{t|t-1} H_1^T}{H_1 P_{t|t-1} H_1^T + R} \tag{12}$$

So far, we have obtained the optimal predicted value VID_t under t-period. But in order to keep Kalman filter running until the end of the system process, we also need to update the covariance matrix of VID_t^*.

Updating covariance estimation:

$$P_t^* = P_{t|t-1} - K_t H_1 P_{t|t-1} \tag{13}$$

At this point, we get a new covariance matrix, and after repeating the process after entering period $t+1$, the Kalman filtering algorithm can be operated on autoregressively.

Here, we define $TVID_t$ as the best total amount of digital currency issued in the t period. After predicting, correcting and de-noising VID_t of each country, We can get $TVID_t$ by simple summation:

$$TVID_t = \sum_{i=m}^{All\ countries} VID_{m,t} \tag{14}$$

6 Digital Currency Supervision System

6.1Regulatory Sandbox

Fintech could make financial service more efficient with a lower barrier but it also adds risk to the market.

We divided the risk as follows:

- **Technical risk**: the risk of data leakage and technical failure. The development of Fintech will inevitably be threatened by a network attack, which may lead to data leakage, capital loss , and other problems.
- **Long-tail-risk**: some investors without enough financial knowledge are at risk of fraud. Fintech has a minimal marginal cost when providing financial service. It allows more people to join the market, which is called “long tail effect”. Fintech serves a large number of people who are not covered by traditional financial service. As a vulnerable group in the financial market, these people may suffer a loss easily.

- **Systemic risk:** fintech is pervasive and explosive in the market, allowing risk to span multiple regions. When risk erupts, it will lead to larger damage.[12]

  In 2015, the UK raise the idea of "regulatory sandbox". [13]The government provides a place called "sandbox" for innovative models, where we can test new theory without bringing bad effects outside.

6.2 Application of Regulatory Sandbox in Digital Currency

We take the world's two largest economic entities, the United States and country m(who are not the issuer) as examples.

- **the U.S.**: since we assume the U.S. is the issuer of digital currency, the U.S. can issue digital currency in some particular cities. After some time they can get enough data to reflect the market condition. And then decide when to allow digital currency circulate around the whole country and the world.
- **country m**: At the beginning, those countries may not accept it widely, however, taking the advantages of digital currency into consideration, they can make the capital circulate more effectively. They can use the sandbox in regulatory and accept the currency step by step.

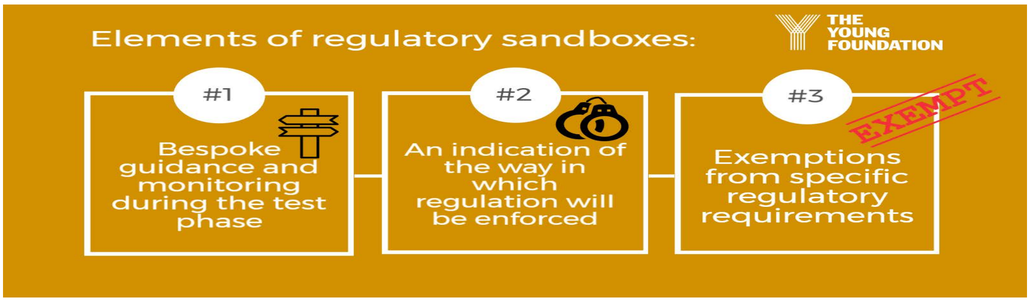


figure7.Regulatory Sandbox ⊙Source:The Young Foundation

6.3 Advantage of Regulatory Sandbox

- **Regulatory in time**: regulatory usually lag behind the fast developing fin-tech. Due to the purpose of safety, traditional regulatory usually set too much limit to fin-tech market, which is harmful to the financing process. It can be reduced signally with the regulatory sandbox.
- **Encourage financial innovation**: sandbox allows fin-tech run more freely, which can reduce the time cost and the capital cost. Also, sandbox allow the company to adopt market faster. the company can improve their product with the experience in the sandbox.
- **Protect customer**: sandbox provides effective protection to the customer. The only customer who is informed of the potential risk and compensation can join the sandbox test.

7 Sensitivity Analysis

We will do a sensitivity analysis on our Degree of Contribution Model. It shows that the fluctuation of different variables has a different effect on the result. Ignore the random jamming ($\mu = 1$). We assume that S_x and C_x expand t times at the same time:

$$\begin{aligned} DOC_x{}' &= (tS_x)^{\alpha}(tC_x)^{\beta}\mu \\ &= t^{(\alpha+\beta)}DOC_x \\ x = D \text{ } or \text{ } B \quad &, \quad \mu = 1 \end{aligned}$$

When $\alpha + \beta = 1$, the function display constant returns to scale.

When $\alpha + \beta < 1$, returns to scale are decreasing.

When $\alpha + \beta = 1$, returns to scale are increasing.

Moreover, we assume the percent of the population over 65 has a changing percent ΔW.

$$p' = 1 - (W + \Delta W) - V - (W + \Delta W)V$$
$$\Delta p = (V - 1)\Delta W$$

Similarly, when the percent of the extreme-poor population has a changing percent ΔV.

$$\Delta p = (W - 1)\Delta V$$

From the data in 2018, ΔW has a more remarkable effect on the result. But with the popularizing of technology, the elder generations will be more familiar with new technology. The poverty is the problem we should consider more.

8 Long-term Effect

8.1 Effect on the Current Banking Industry

First, the issuance of legal digital currency will improve the efficiency of currency issuance. The process of issuing, circulating and returning money will be upgraded from the physical level to the electronic level. It will bring remarkable efficiency improvement to the bank payment system. It will bring about the following effects: First, the demand for bank physical outlets will decline. Second, it will influence the structure of talents. Demand for cashiers, clerks and other cash-related personnel will decline, while demand for technological and financial innovators and financial big data analysts will increase.

Second, under the new digital monetary system, the original ‘central bank-commercial bank’ dual system remains unchanged. It effectively protects the enthusiasm of commercial banks and promotes their functional transformation in the era of comprehensive digitalization.

8.2 Effect on the International Relations between Countries

First, we have already said one of the significant advantages our model has is the efficiency improvement in the international trade. Based on that, we believe it will greatly promote international economic exchanges. Second, our model provides a new idea for those district with the free market economy like Hong Kong.

9 Further Work

- The international relationship is often affected by politics. In our model, we don't consider much about the politic factors. The strict policy may limit the circulation of digital currency.
- Technology plays an important role in the digital market. The break of technology may cause unprecedented disaster, which must be avoided technically. We don't consider the technological risk in our model.
- Financial product with digital currency will differ from the original financial system. We don't discuss the variation of the financial product and the influence of this change.

10 Strength and Weakness

Strength

- We conduct a thorough analysis of different need of different countries from their standpoints.
- Our policy model breaks people's inherent understanding of digital money. With the support of national credit, the digital currency gets its widely-accepted consensus value.
- Our recommendation points out that countries don’t need to abandon their current national-based currencies, protecting their monetary sovereignty at utmost.

Weakness

- Because of the lack of data, the consensus value of currencies can only be evaluated.
- Since our model is fundamentally protecting the monetary policy sovereignty, the Triffin Dilemma still exists to some extent.

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Policy Recommendation

Dear national leaders,

With the rapid development of digital currency in recent years, whether it can replace paper money and become a new form of legal tender has been debated widely.

We have to admit that the current monetary system has its limitations, but it is of vital importance to recognize the complete decentralized currency (e.g., Bitcoin) is not a way forward for the current monetary system. There are mainly two reasons. First, it is virtually impossible for most counties to abandon the monetary policy sovereignty, which not only assures the smooth development of the economy but also represents the national sovereignty. Second, in a strict sense, the private digital currency (again, Bitcoin) is only a commodity asset instead of a form of currency. The reason is that it doesn't conform to the essence of currency — it does not conform to the social consensus rule.

So our policy model points out that the universal digital currency system is possible, as long as we abandon the form of 'complete decentralization', which means we are constructing a model that recommend central bank to issue digital money (CBCD). In our model, we don't require countries to abandon their own nation-based currencies.

1 The essence of currency

To develop a new currency system, we determine the essence of currency first and divide it into two parts:

Saving Value is the cost that a kind of specific currency can save (transaction cost, management cost, etc.) **Consensus Value** is the degree of recognition on a certain currency. And we employ the logistic equation to describe it, which fits reality well.

Then we construct a model to determine them based on the principle of the **Cobb-Douglas Function.** And we derive the maximal proportion of digital currency issuance should reach around **0.76.**

2 The viability of our model

Our model is rather practical due to the different methods applied to describe the optimal issuance project. In this process, we utilize **AHP**, which helps transform our subjective preferences to accurate criterion to value the significance of factors that would affect the demand of different countries, and they are: (1) International trade, (2) economy, (3) knowledge, (4) diplomacy, (5) government credit. As a result, the significant impact factors are the economy and international trade. Then we conduct the **Demand Forecast Model based on VAR and BP neural network.** Because the key factors of vital importance are actually unobservable, we need to utilize the state space model and BP neutral to 'work backward' to get the information about the unobservable variables. We use **Kalman filter algorithm** to further modify the output value VDIt (the optimal amount of digital currency issuance for a certain country at period t) of the previous neural network recursive model system by eliminating the influence of noise on the forecast value.

3 The effect of our model

Positive effect on supervision the risk brought by the digital currency can be limited at a certain district by conducting earlier tests.

Influence on individuals, banking industry countries and global level

Individuals: the advantages provided by the CBDC currency system on an individual level include lower transaction cost, improvement in security, higher financial containment and higher efficiency on small transactions.

Banking system: As for the banking industry, the biggest improvement is the higher efficiency of the payment system. Besides, this change also influences the structure of talents.

Countries: The system promotes efficiency in foreign trade and decreases the management cost at the same time. The information is also more transparent, useful for striking illegal behavior like Money Laundering.

Global level: As said before, because of the advantages of foreign trade, it helps increase the vitality of international trade remarkably.

Sincerely, Team # 1915842