Emergence of Key Currency by Interaction among International and Domestic Markets

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Abstract

In this research, we tackle the problem of the emergence of the key currency. A market model is proposed with the currency credibility as the standard of selection for the payment method. Artificial markets are constructed based on the X-Economy, which is a project aiming at offering a common platform for an artificial economy and artificial market research. The results of simulations show that the currency of a country without extensive economic power can become the key currency.

Introduction

Recently, the function of currency has been a focus of attention for researchers in not only the social sciences but also in multiagent system research related to modeling social interactions among traders. In this paper, the key currency is taken up as an important currency issue because the key currency has an strong influence on trade and the economy of each country in the world.

Generally speaking, the key currency is defined as the most widely used or centrally positioned currency in international transactions. The key currency country must maintain extensive economic power. Specifically, the following conditions have been mentioned: i) the currency value is stable, ii) the key currency country holds the largest share of world exports and imports, and iii) the international financial markets of that country are developed. Furthermore, in addition to the economic factor, the key currency country is also required to hold extensive political and military power.

In the micro-behaviors of the key currency, two persons pay in the currency of their own countries or that of a third country. These persons negotiate with each other over which currency they will use. As a result of accumulating these micro-behaviors, does a specific currency finally become the key currency as a macro-behavior of the overall international trade system? How is the key currency selected?

In this research, we propose a market model with the currency credibility as the standard of selection for the payment method. We use the X-Economy (3; 4; 5) to construct artificial markets. The X-Economy is a project aiming at offering a common platform (a standard problem, a server, an agent library, and communication protocol) for an artificial economy and artificial market research. In the proposed model, we observe the process of the selection of one currency and consider the factors related to the emergence of the key currency. Analysis of the properties of the key currency throughout agent-based simulation is indispensable for clarifying the guiding principle in planning trade policy and designing the means to regulate stability in the international trade system.

Background

In this research, we adopt an agent-based simulation that creates a macro phenomenon by accumulating the interactions among individuals because our purpose is to observe the process of selecting the key currency from among the currencies that the various agents use for dealings. A market constructed through simulation using agents is called an artificial market, and research is performed from various viewpoints, such as nonlinear dynamics, diversity, adaptive and learning systems, and gaming. Many researchers have used artificial markets that perform adaptive learning by using a genetic algorithm. As examples of artificial market research, projects have investigated the emergence and collapse of money (9), the bubble and crash in an artificial stock market (1), and the exchange rate dynamics in artificial foreign exchange markets (2).

Model of International Trade

We build an international trade model without financial systems as simple as possible. This model can be considered as a medieval times or a manorial economic system. Several countries exist in the system, and each country has its own currency. Agents in each country produce one of two kinds of goods, i.e., currency and consumer goods called food. Producing currency means that an agent can mine a rare metal, e.g., gold, silver, or a precious stone, e.g., diamonds. There are two kinds of agents belonging to a country. One is a production agent (6; 7; 8), and the other is a trade agent. Let $C = \{1, .., k, .., l\}$ be a country set, a production agent set and trade agent set in country k are represented as $P_k = \{1, .., i, .., m\}$ and $T_k = \{1, .., j, .., n\}$. There is one kind of agents belonging to no country, which is a foreign exchange agent. Let $F = \{1, .., h, .., r\}$ be a foreign exchange agent set.

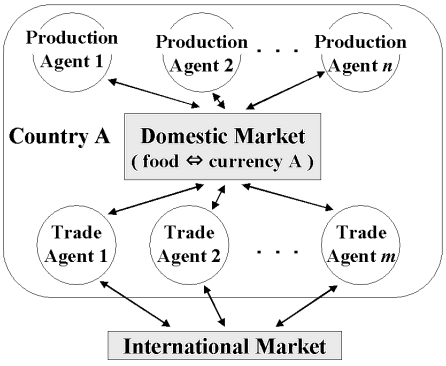

Figure 1: Domestic market

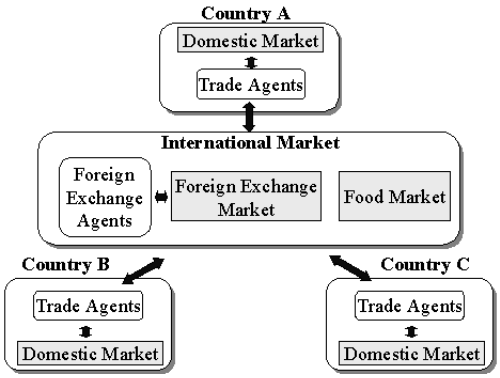

Figure 2: International market and domestic markets

Furthermore, there are two kinds of markets. One is the domestic markets in each country, where food is traded by domestic production agents and trade agents. The other is an international market, where trade agents from several countries trade both goods and currency and foreign exchange agents trade only currency.

The outline of the model is shown in Figures 1 and 2. A production agent produces the food or currency of its own country and consumes food. In its domestic market, the production agent trades food in the currency of its own country in order to keep the amount of possessed food constant. A trade agent produces neither food nor currency. The trade agent trades food between the domestic and the international markets in arbitration trade, that is, buys and sells food simultaneously in two different markets and takes a profit based on the difference in price. A foreign exchange agent produces neither food nor currency. The foreign exchange agent trades currencies in the international market, that is, buys a currency at a low exchange rate and then sell it at a higher exchange rate and takes a profit based on the difference in the exchange rate.

In the domestic market of a country, the sell/buy orders from production agents and trade agents are gathered, and matched orders are immediately processed. The contracted price is informed to all agents in this country as market information. In the international market, trade agents in different countries trade not only food but also currencies. The trade agent buying food can pay in any currency that the trading partner accepts. Foreign exchange agents trade only currencies. In the international market, the sell/buy orders from trade agents and foreign exchange agents are gathered, and matched orders are immediately processed. The contracted price is informed to all trade agents and foreign exchange agents as the exchange rate.

Currency Credibility

In international trade, there is the problem of determining in which currency trade agents should pay. We introduce the currency credibility as a selection standard of the payment method (9). The word day is defined as an indivisible time period. Each type of agents trades in the international or domestic market once a day. Trade agents in the same country have a different credibility for each currency, and it is updated every day. More precisely, currency credibility $C^{k_2}_{k_1,j}(t)$ of trade agent j in country k_1 for the currency of country k_2 at day t is calculated by the following equation (1).

$$C^{k_2}_{k_1,j}(t) = C^{k_2}_{k_1,j}(t-1) + amount_{k_1,j}/\alpha, \qquad (1)$$

where $amount_{k_1,j}$ is the quantity of food that a food seller offers, and α is a positive constant. The currency credibilties of a trade agent j are normalized in order to keep the amount of currency credibility of each country constant. In this model, the key currency is defined as the currency whose currency credibilties of all trade agents in all countries reach 100%.

If a trade agent is a seller of food, it requires the currency with the highest credibility of all currencies. If a trade agent is a buyer of food, it raises the credibility of the required currency. If the credibility of a certain currency is below a $minimum\ tolerance\ ratio$, trade agents refuse to receive the currency. Consequently, the currency with high credibility is used in the international market.

The initial credibility of a domestic currency is set to 100%. If the credibility of the domestic currency becomes 0%, it will become impossible to buy food on the domestic market. The ideal ratio of each currency inventory for a trade agent is the same ratio as the currency credibility of its own. The trade agent must hold the domestic currency above a $minimum\ holding\ ratio$.

Behavior of Agents

Production Agent

Each production agent is capable of producing food and domestic currency based on the skill levels of food and domestic currency, which are the quantities that a production agent can produce per day. The skill level of food of a production agent i in country k is denoted as $skill^f_{k,i}$ and that of domestic currency as $skill^c_{k,i}$. Production agent i produces domestic currency in day t when the value of currency is higher than food, i.e., when the following condition (2) is satisfied.

$$skill^c_{k,i} > P(t-1) \cdot skill^f_{k,i}, \qquad (2)$$

where $P(t-1)$ is the food price of day $t-1$. A parameter $reserve\ level$ of food is defined equally for all production agents, which means the quantity of food inventory that a production agent would like to maintain. When the quantity of food inventory is above/below a $reserve\ level$, the production agent sells/buys food. The quantity of food that a production agent sells/buys a day is the difference of the $reserve\ level$ and the quantity of food inventory. The order price $Bid_{k,i}(t)$ of production agent i in country k at day t is represented as the following equation (3).

$$Bid_{k,i}(t) = B(f,c) \cdot P(t-1), \tag{3}$$

where

$$\begin{aligned} &B(f,c) = (B(0,c))^{(1-f)}, \\ &f = food_{k,i}/r, \\ &c = currency_{k,i}/(P(t-1)\cdot r), \\ &B(0,c) = b_{0\infty} - (b_{0\infty} - b_{00})e^{-\phi c}, \\ &B(0,0) = b_{00}, B(0,1) = b_{01}, B(0,\infty) = b_{0\infty}, \\ &\phi = ln(\tfrac{b_{0\infty}-b_{00}}{b_{0\infty}-b_{01}}). \end{aligned} \tag{4}$$

Under conditions (4), $food_{k,i}$ is the quantity of food inventory and $currency_{k,i}$ is the quantity of currency that production agent i in country k holds at day t, and r is $reserve\ level$.

Trade Agent

Trade agents make two kinds of trades, i.e., food trade and currency exchange. Trade agent j in country k places an order to buy food on the domestic market and to sell it on the international market, if the following conditions (5) are satisfied.

$$\begin{aligned} &P_{max}(t-1) - P(t-1) > P(t-1) - P_{min}(t-1) \\ &margin_j > P_{max}(t-1)/P(t-1) - 1, \end{aligned} \tag{5}$$

where P_{max} and P_{min} are the highest and lowest food prices in all domestic markets, and $margin$ is a positive constant. Trade agent j in country k buys and sells at price $P(t-1)\cdot(1+margin_j)$. Otherwise, trade agent j in country k places an order to buy on the international market and to sell on the domestic market, if the following conditions (6) are satisfied.

$$\begin{aligned} &P_{max}(t-1) - P(t-1) < P(t-1) - P_{min}(t-1) \\ &margin_j > 1 - P_{min}(t-1)/P(t-1). \end{aligned} \tag{6}$$

Trade agent j in country k buys and sells at price $P(t-1)\cdot(1-margin_j)$. Trade agents offer their entire inventory of food for sale when they sell and try to buy as much as they can afford when they buy.

In currency exchange, a trade agent estimates a higher rate when the amount of currency exceeds the ideal quantity and estimates a lower rate when it is in short. The order rate $Bid\_rate_{k,j}(t)$ of trade agent j in country k is represented as the following equation (7).

$$\begin{aligned} &Bid\_rate_{k,j}(t) = exp(log\ \beta \cdot (1-M)) \cdot rate(t-1) \\ &M = money_{k,j}/q_{k,j}, \end{aligned} \tag{7}$$

where $rate(t-1)$ is the exchange rate of day $t-1$, $money_{k,j}$ is the quantity of currency, $q_{k,j}$ is the ideal quantity of the currency of trade agent j in country k, and β is a positive constant.

Foreign Exchange Agent

Foreign exchange agents always place orders to buy all currencies on the international market. A foreign exchange agent decides an order rate by using the forecast exchange rate based on the last exchange rate. The forecast method is common to all foreign exchange agents. The forecast exchange rate $F_{k_1}^{k_2}(t)$ from currency k_1 to currency k_2 in day t is represented as the following equation (8).

$$F_{k_1}^{k_2}(t) = (1-\gamma)\cdot F_{k_1}^{k_2}(t-1) + \gamma \cdot R_{k_1}^{k_2}(t-1), \tag{8}$$

where $R_{k_1}^{k_2}(t)$ is the actual exchange rate from currency k_1 to currency k_2 in day $t-1$, and γ is a positive constant ($0<\gamma<1$). When foreign exchange agent h buys currency k_2 in currency k_1 in day t, foreign exchange agent h decides order rate $Bid\_rate_{k_1,h}^{k_2}(t)$ based on forecast exchange rate $F_{k_1}^{k_2}(t)$ as the following equation (9).

$$Bid\_rate_{k_1,h}^{k_2}(t) = F_{k_1}^{k_2}(t)\cdot(1+margin_h), \tag{9}$$

where $margin_h$ is a positive constant. Foreign exchange agent h decides an order amount based on the amount of possessed currency. When foreign exchange agent h buys currency k_2 in currency k_1 in day t, foreign exchange agent h decides order amount $Bid\_amount_{k_1,h}^{k_2}(t)$ as the following equation (10).

$$Bid\_amount_{k_1,h}^{k_2}(t) = amount_{k_1,h}/(NumCurrency-1), \tag{10}$$

where $amount_{k_1,h}$ is the amount of possessed currency k_1 that foreign exchange agent h holds, and $NumCurrency$ is the number of currencies, which is equal to the number of countries. Equation (10) means that the foreign exchange agent distributes the amount of possessed currency k_1 into $NumCurrency-1$ equally and buys a currency using one of them. The foreign exchange agent buys currency k_2 in currency k_1 only if an exchange fills both order rate and amount.

Market Structure

A*sealed-bid auction* and a *negotiated transaction* are adopted as auction method in this model. A *sealed-bid auction* is used for food trade on the domestic market and currency exchange on the international market. An auctioneer gathers the orders from agents and determines the market-clearing price. In these markets, two constraints must always be satisfied: i) no buyer pays more than his bid, and ii) no seller sells for less than his offer. Subject to the above constraints, the price maximizing the amount of trading food is adopted as the market-clearing price. Subsequently, agents trade food or currencies at this price.

Table 1: Production capability of production agents.

Agent No.	Food	Currency
1	9	3600
2	12	3300
3	15	3000
4	18	2700
5	21	2400
6	24	2100
7	27	1800
8	30	1500
9	33	1200
10	36	900

Table 2: Margins of trade agents and foreign exchange agents.

Trade Agent

No.	Margin
1	0.005
2	0.025
3	0.045
4	0.065
5	0.085
6	0.105
7	0.125
8	0.145
9	0.165
10	0.185

Foreign Exchange Agent

No.	Margin
1	0.1
2	0.14
3	0.18
4	0.22
5	0.26
6	0.32
7	0.36
8	0.40
9	0.44
10	0.48

A $negotiated\ transaction$ is used for food trade in the international market. Buyers and sellers are matched up randomly and trade at different prices. Each agent can negotiate with at most one other agent per day. The transaction price is the intermediate price of a seller and a buyer.

Simulation Settings

An artificial international trade market model is implemented by the X-Economy system. In this simulation, we set three countries (A, B, C), and the three countries have the same production capability. There are 10 production agents and 10 trade agents in each country. There are 10 foreign exchange agents in the international market. Table 1 shows the production capability of production agents. Table 2 shows the margins of trade agents and foreign exchange agents.

The initial prices of food are 100 in country A, 101 in country B, and 102 in country C. If the initial prices of food in all countries are equal, trade agents have no incentive to trade because there is no spread between countries. The only difference in parameters of the three countries is the initial price of food in the domestic markets. The initial exchange rate of any domestic currencies is 1.0. In international markets, pairs of agents are randomly selected and a trade of food and currency is made in each matched pair. This selection (matching) process is the only source of randomness in this simulation. The period of one trial is set for 10,000 days, and this trial is conducted 50 times under different random seed. Other important parameters are shown in Table 3.

Table 3: Parameter settings of agents.

Production Agents	
$Reserve\ level$:	300
Initial currency inventory:	30000
Initial food inventory:	300
Food consumption per day:	10
$\alpha = 1.5\ b_{00} = 4\ b_{01} = 8\ b_{0\infty} = 16$	
Trade Agents	
Initial currency inventory:	10000
Initial food inventory:	0
$Minimum\ tolerance\ ratio$:	10%
$Minimum\ holding\ ratio$:	30%
$\beta = 1.5$	
Foreign Exchange Agents	
Initial currency inventory of each currency:	10000
Initial forecast rate of each currency:	1.0
$\gamma = 0.03$	

Simulation Results

As a result of simulation, the key currency was always emerged in all trials. The numbers of the emergence of key currency are 15 in country A, 22 in country B, 13 in country C. Regardless of the key currency country, a similar tendency of market behaviors was found in each trial. Figures 3–8 show the typical fluctuations of macro behaviors in the market, i.e., average currency credibilities of trade agents, exchange rates, $production\ ratio$ of production agents, and amounts of currency held by foreign exchange agents. In these graphs, the horizontal axis indicates day.

Figures 3–5 show the average currency credibilities of trade agents in each country. In these graphs, the vertical axis indicates the average currency credibility. In this trial, currency credibility C became the highest among trade agents in all countries. In Figures 3 and 4, the currency credibility of an trade agent's own country decreased and that of country C increased monotonously. In Figure 5, although the currency credibility of an trade agent's own country decreased at first, it reversed to increase from about the 500th day. In this trial, currency C became the key currency because the definition of the key currency was satisfied, i.e., average currency credibilities C in all countries reached 100% after the 4000th day.

Figure 6 shows the exchange rates from currency A to B, C to A, and C to B in the international market. Trade agents intend to hold the currency with high currency credibility (C), and to sell the currency with low currency credibility (A, B). The reason is that a trade agent requires the currency with the highest credibility of its own when trade

agent sells food. As a result of the requests for currency C, the exchange rates from currency C rises until the 4000th day, when the currency credibility C reached 100% in each country. The exchange rates from currency C to A and B are always higher than 1.0, and that from currency A to B is almost equal to 1.0.

Figure 7 shows $production\ ratio$, which is the ratio of the amount of currency production to the amount of food of each country and is calculated as

$$\frac{\Sigma_t \Sigma_i production^c_{k,i}(t)/day}{\Sigma_t \Sigma_i production^f_{k,i}(t)/day}, \tag{11}$$

where $production^c_{k,i}(t)$ is the amount of currency produced by production agent i in country k at day t and $production^f_{k,i}(t)$ is that of food. In this graph, the vertical axis indicates the production quantity. Until about the 500th day, the $production\ ratio$ fluctuates quickly. After the 500th day, the proportion of the currency production by the key currency country (C) is higher than that of the other countries.

A high $production\ ratio$ of the production agents in a country indicates that there is a large supply of food to the domestic market and a great demand for the currency of the country from the trade agents of other countries. On the other hand, the low $production\ ratio$ of production agents in a country represents that there is an insufficient supply of food to the domestic market and little demand for the currency of the country from the trade agents of the other countries. The reason is that the trade agent of the key currency country can buy food in its own currency because the trade agents of the other countries must pay in the key currency. Because the trade agent of the non-key currency country could not buy food in their own currencies, they had to acquire the key currency by selling food and their own currencies in order to buy food in the key currency. The trade agents of the key currency country could acquire food simply. Therefore, the supply of food to the domestic market increased in the key currency country. As a result, the $production\ ratio$ of production agents in the key currency country is higher than that of the others.

Figure 8 shows the amounts of currencies A, B and C held by foreign exchange agents. Foreign exchange agents always hold more currencies A and B than currency C. Along with the advance in the exchange rate from currency C, the amounts of currencies B and C increased. The reason is that foreign exchange agents sell the currency with the higher exchange rate (currency C) and buy the currency with the lower exchange rate (currencies A and B) based on the history of the exchange rates.

As a result of 10 trials in the same setting, the key currency could emerge with certainty.

Discussion

We explain the reason for the emergence of the key currency based on the result of simulation.

At the beginning of the trade, no trade agent accepts foreign currency because the currency credibility of the do-

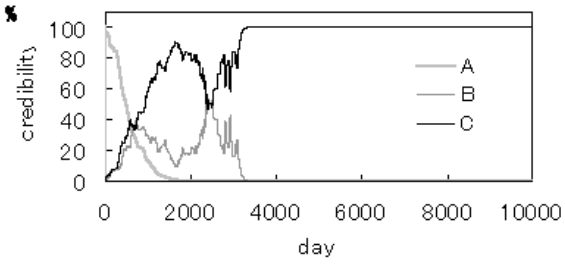

Figure 3: Average currency credibility of trade agents in country A.

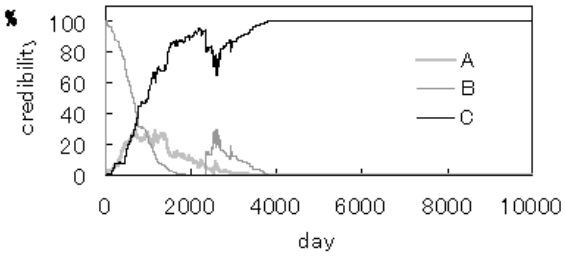

Figure 4: Average currency credibility of trade agents in country B.

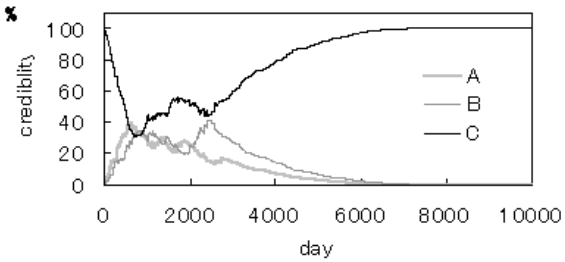

Figure 5: Average currency credibility of trade agents in country C.

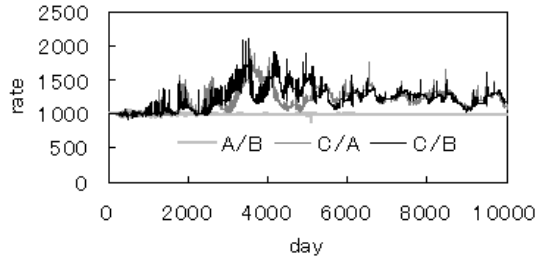

Figure 6: Exchange rate between each pair of currencies in the international market.

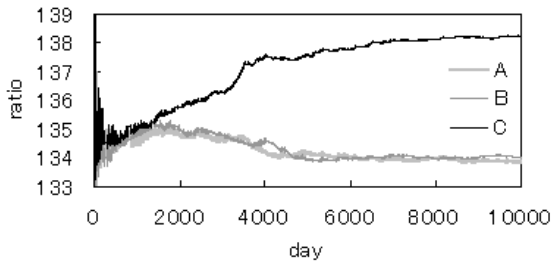

Figure 7: Production ratio of production agents in each country.

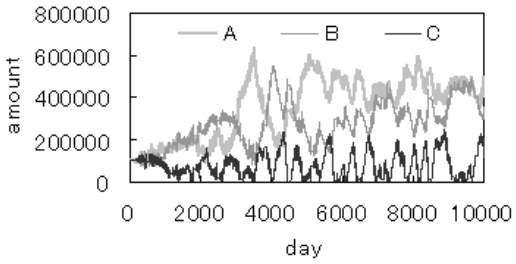

Figure 8: Amount of each currency held by foreign exchange agents.

mestic currency was 100% and those of the foreign currencies were each 0%. When the currency credibility was below $minimum\ tolerance\ ratio$, trade agents refused to receive the currency. Next, when the trade agents of a country sold food on the international market, trade agents selling food (sellers) required trade agents of foreign countries (buyers) to pay in the currency of the sellers' country. Then the currency credibilities of the foreign countries of buyers increased gradually. As a result of the requests of sellers, the currency credibilities of foreign countries of some trade agents exceeded the $minimum\ tolerance\ ratio$. Since trade agents required one certain currency in food trade, the currency credibility of this country increased. Furthermore, as the currency credibility of this country increased, trade agents requiring this currency increased. Once such a positive feedback started working, the currency credibility of only one country continued to increase as the others further decreased. Finally, only one currency was accepted on the international market, and the currency credibility of this country reached 100%, that is, the key currency emerged.

Although the production capabilities and other parameters of all countries were equal except for the initial prices of food in the three countries, the trade agents of all countries paid in only one currency. This simulation setting, since it had not been strictly symmetrical from the start, caused the emergence of the key currency. Therefore, we confirmed that the emergence of the key currency does not require the existence of a country with extensive economic power. Although the relationships among the currencies are symmetrical at the beginning of trade, once a trade agent that receives the currency of a foreign country appears, market symmetry collapses and the positive feedback of using one currency starts to work. Actually, although the production capability and the prices of the countries are the same, if a certain fluctuation exists, the key currency will surely emerge.

Conclusions

In this research, we have observed the emergence of a key currency in an artificial market model with currency credibility. Simulation results of s have shown that even the currency of a country without extensive economic power can become the key currency. One of our future works is to extend the model to include some financial system, i.e., bringing up the model from medieval to modern times.

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