Analysis of the interaction between commodity and stock markets in an agent-based economic system

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Abstract

An agent-based model of an artificial economic system that includes both commodity and stock markets has been developed to analyze the influence of producers' financing strategy for investing in production equipment on the behavior of economic indicators such as GDP, stock prices, and consumer prices. Further, the influence of consumers' investment strategy in the stock market on the rate of return was also analyzed. The results indicates that stock market financing leads to higher GDP than bank financing. This is because the decrease in the repayment burden allows producers to increase the investment frequency, resulting in an increase in consumers' disposable income. When corporate financing strategies coexist from both the bank and the stock market, the co-movement of average stock price with average consumer price is unclear, and shows a time lag between them because of the temporary excessive supply of stocks at the time of investment. In addition, when six types of consumer stock-investment strategies coexist in the market with the same probability, the strategy that considers risk and corporation-profit leads to higher return, while the random strategy, the return oriented strategy, and the moving-average oriented strategy lead to negative returns.

1 Introduction

Agent-based modeling(ABM) is widely used in social simulations, because it is a class of modeling method with bottom-up approach where various social phenomena can be expected to be explained by modeling an artificial system so that it works with similar mechanism as that of real system [Terano, 2008] [Tesfation and Judd, 2006]. The application of ABM in macroeconomic system constitutes one of the important research fields, because many social phenomena relate to and are influenced by the behavior of macroeconomic systems. [Farmer and Foley, 2009]

In the case of ABM for macroeconomic systems, the behavior of macroeconomic system is influenced by various factors such as the demand and supply in the commodity market [Teglio, Raberto and Cincotti, 2010], public policies[Dosi et al., 2008], the behavior of investors in both financial market and foreign exchange market[Ono et al., 2008] [Takahashi and Terano, 2009] [Bruun, 2010], etc. It is, therefore, important to reveal the influence of various factors and calculation conditions on the behavior of the artificial economic system in order to develop a useful model that can be utilized for miscellaneous kinds of problem solvings, reproducing the fundamental aspects of the behavior of economic system. For instance, GDP in an economic system is influenced by the flow of funds not only in the commodity goods market but also in the financial market.

Although considerable research has been reported on the behavior of the system with commodity market or with financial market, not much research has focused on the interaction between commodity and financial markets. In a previous study, the authors constructed a simple artificial economic model comprising consumers, three types of producers, and a bank and found that this simple model reproduces fundamental economic behavior such as a loose equilibrium in price, a business cycle caused by capital investment, the influence of money supply on GDP, and the like[Ogibayashi and Takashima, 2010].

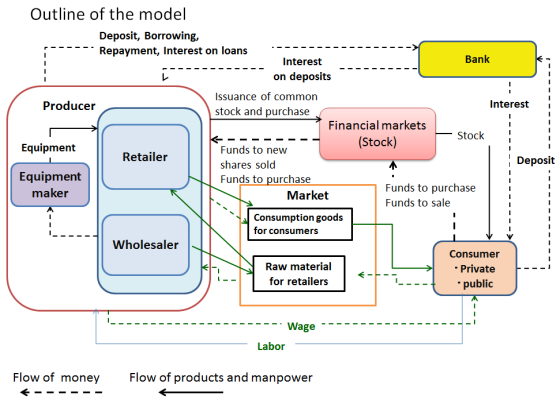
In the present study, an agent-based model of an artificial economic system that includes both commodity and stock markets has been developed based on the authors' previous model and the influence of producers' financing strategy for investing in production equipment on the behavior of economic indicators such as GDP, stock prices, and consumer prices. Further, the influence of consumers' investment strategy in the stock market on the rate of return was also analyzed. Based on the calculated results, the influences of the interaction between commodity and stock markets on the behavior of macroeconomic system and consumers' rate of return in the stock market were discussed.

2 Simulation model

The agent-based model of an artificial economic system in the present study comprises consumers, three types of producers, a bank as autonomous decision-making agents, as shown in Equation (1) and Figure 1. The producers are divided into retailers who produce final products for

consumers, wholesalers who produce and supply raw materials for retailers, and an equipment-maker who supplies equipment for the production of other types of producers.

$$Agent = \{C, P, B\}, \quad P = \{R, W, E\} \qquad (1)$$
$$C : Consumer\ ,\ P : Producer\ ,\ B : Bank$$
$$R : Retailer\ ,\ W : Wholesaler\ ,\ E : Equipment\ maker$$



Figre1.Outline of model

Each agent has its own set of attributes and rules of action, and interacts with the others during the simulation. A set of attributes includes state variables such as amount of deposit, cash, etc., and parameters values such as the withdrawal ratio of deposits, utilities for each class of products, etc. Owing to the interactions among agents during the simulation, macro-level factors such as GDP, average market price of commodities, average stock price, Gini coefficient, etc. emerge as a result of calculations. The cash and deposits of each agent at the beginning of each fiscal period as state variables are given in Equation (2).

$$MC_C^i = MC_C^{i-1} + MD_C^{i-1} r_{wd} - Expenditure^{buy^{i-1}} + b\ wage^{i-1} + a_0 \qquad (2)$$
$$MD_C^i = MD_C^{i-1}(1 - r_{wd}) + (1-b)x^{i-1} - a_0 + Interest_C^{i-1} - Buy_{stock}^{i-1} + Sales_{stock}^{i-1} + Dividend_C^{i-1}$$

$$MD_P^i = MD_P^{i-1} + Sales_{pro_P}^{i-1} + Interest_P^{i-1} - (Cost_P^{i-1} + \sum_{k\in\{C\}} wage_k^{i-1})$$
$$-Repayment_P^{i-1} - Dividend_P^{i-1}$$

where,
i : Fiscal period , suffix : Agent type
MC : Cash possessed by agent , MD : Deposit of agent in the bank
$Expenditure^{buy}$: Expenditure of consumer to buy retail product
Buy_{stock} : Expenditure of consumer to buy stocks
$Sales_{stock}$: Sales of consumer to sales stocks
$Dividend$: Dividend income
$Sales_{pro}$: Sales of producer to sales product
$Repayment$: Agent's decrease in the balance of loaned money
$Cost$: Expenditure of retailer to buy raw materials
$wage^i = Constwage + Bonus^i$
r_{wd} : Ratio of withdrawn to total deposit
$Interest$: Balance of interest paid by the bank

The set of actions of each agent comprises period-based units, where one period is assumed to correspond to one month in the real system. During each period, some of the state variables of the agents will change in value, due to interactions among agents. At the end of each fiscal period, each agent settles its accounts through a double-entry bookkeeping method. By summing up the calculated data of all agents, an input-output table with respect to the artificial system is defined and a GDP value is obtained for each fiscal period. The rules of action for each type of agent are assumed as shown below.

2.1 Consumer Agent

Consumer agents work at one of the producers where they receive wages, pay tax in line with their income, and buy products and stocks within the limit of cash at hand. The details of the rules of actions in the commodity and stock markets are as shown below.

2.1.1 Action rule in the commodity market

Consumers buy products supplied by retailers according to their utility functions defined by Equation (3) within the limit of cash at hand, where a weight of utility is randomly assigned to each consumer with a uniform distribution. When there are products of the same class available in the market at different prices, the consumer is assumed to select and purchase the cheapest one among them.

$$utilty = weight \times u(\xi)$$
$$u(\xi) = 0, 1, 1.2, 1.25, 1.25, \cdots \ if\ \xi = 0,1,2,3,4\cdots \qquad (3)$$
$$weight : weight\ of\ utility$$

The cash at hand is defined as the sum of the Keynesian consumption function and the money withdrawn from the consumer agent's bank accounts as shown in Equation (4).

$$Consumption\,budget^i = a_0 + bx^{i-1} + MD_C^i\, r_{withdraw} \qquad (4)$$

2.1.2 Action rule in the stock market

Consumers buy and sell stocks aiming to get profit in the stock market. It is assumed that they can buy stocks when each of their balance of deposit exceeds 10000 and they can sell stocks of certain firm when they possess them. The budget for buying stocks is defined as shown in Equation (5) where $r_{stock-investment}$ is randomly assigned at the time of investment between 0 and 0.5 with uniform distribution.

$$budget_{stock-investment}{}^i = r_{stock\,investment} MD_C^i (1 - r_{withdraw}) \qquad (5)$$
$$r_{stock-investment} : Ratio\ \ for\ stock\ investment$$

The following 6 strategy for buying and selling stocks are assumed in the present study.

① Moving-average oriented strategy

The consumer assesses the future stock price of a firm according to the moving-average of the stock price for the past n periods and selects and buys stocks sot that their expected profit would be maximized as shown in Equation (6), where $\delta(0.8,1.2)$ stands for a random number of uniform distribution between 0.8 and 1.2 which is specified to each of the consumer with different value.

$$\max ize\ \underset{k}{\pi} = \left(\sum_{j=t-n}^{t} p_{k,j} \right) / n \times \delta(0.8,1.2) - p_{k,t} \qquad (6)$$

where,
π : Expected profit
$p_{k,j}$: Stock price of kth firm at jth period
$\delta(0.8,1.2)$: Random number of uniform distribution between 0.8 and 1.2

② **Corporation-profit oriented strategy**

The consumer buys the stocks with a probability proportional to the earnings per share averaged for n periods as given in Equation (7), where n is assumed 12 in the present study.

$$P_k = A_k / \sum_{i=1}^{m} A_i, \quad (7)$$

P_k : Probability of buying k^{th} firm's share

A_i : earnings per share averaged for n periods, $i \in \{firms\ with\ A_k > 0\}$

③ **Random strategy**

The consumer buys and sells stocks randomly. within the limit of purchasing budget.

④ **Return and risk oriented strategy**

The producer buys and sells stocks so that the sum of the rate of return and inverse of the rate of risk would be maximized as given in Equation (8), where risk is assumed to be assessed by the square of standard deviation of the rate of return and α is the weight constant between 0 and 1.

$$maximize\ \alpha \frac{r_i}{\bar{r}} + (1-\alpha)\frac{\bar{\sigma}^2}{\sigma_i^2} \quad (8)$$

r_i : rate of return of ith firm' stock during 12 periods

σ_i :standard deviation of ith firm' s stock during 12 periods

$\bar{r}$: average rate of return for the firms with poositive profit

$\bar{\sigma}$: average standard deviation of ith stock for firms with positive profit

Thus, the return and risk oriented strategy is divided into 3 strategies depending on the range of the value of α : risk oriented strategy with α being between 0 and 0.3, balance-of-return-and-risk oriented strategy with α being between 0.3 and 0.7 and return oriented strategy with α being between 0.7 and 1.0.

As explained above, the following 6 types of consumers are assumed to coexist with the same probability.

1) Moving-average oriented strategy
2) Corporation-profit oriented strategy
3) Random strategy
4) Risk oriented strategy($\alpha = 0 \sim 0.3$)
5) Balance-of-return-and-risk oriented strategy ($\alpha = 0.3 \sim 0.7$)
6) Return oriented strategy ($\alpha = 0.7 \sim 1.0$)

2.2 Producer Agent

Producers hire consumers as employees, pay wages, make production plans, produce products of several types, supply and sell those products in the commodity market and deposit and withdraw money from the bank account at every fiscal period. The wages comprise a fixed salary that is randomly assigned to each employee between a lower and an upper limit, and a bonus is given when the profit of the producer is positive. The amount of bonus is defined as the bonus ratio times the producer's surplus money, and it is uniformly assigned to each of the employees.

2.2.1 Action rule in the commodity market

The retailers and wholesalers decide both the amount and price of each class of product at production planning, where the price is increased or decreased depending on the amount of goods in stock at the end of the previous period. The amount of production is decided, such that the probability of the occurrence of being out of stock is less than 5%; this is estimated based on the total sales during the most recent 10 periods. When the estimated price is lower than the running cost per product, the minimum price is set to be the running cost. On the other hand, when the estimated amount of production is less than 80% of the production capacity, the minimum amount of production is set to be that amount. The production capacity Y is defined by a Cobb-Douglas type function as shown in Equation (9), where K is the number of pieces of equipment for production, L is the number of employees, and is 0.25. The coefficient A is assigned to each agent randomly between a lower and an upper limit.

$$Y = AK^{\alpha} L^{1-\alpha} \quad (9)$$

Retailer and wholesaler each initially have one unit of equipment. they increase that number during the simulation by buying equipment from the equipment-maker when the production at maximum capacity continues for longer that a certain critical length of time. All of the necessary amount of money for investment is financed from the bank or from the stock market or by the self-financing according to the financing strategy rule given in the next section.

Retailers and wholesalers also have a bankruptcy rule. When a period of no sales with respect to a certain class of products continues for more than a certain critical length of time, the producer ceases production of that class of product. The producer goes bankrupt when he ceases the production of all classes of products.

Retailers also have a layoff rule. When the period of negative profit continues for more than a certain critical time, one of the employees is laid off and assigned to the producer whose amount of accumulated profit is the largest among the producers.

The equipment-maker produces equipment in line with the requirements of the retailers and wholesalers, within its production-capacity limit. In the present study, the price of the equipment is assumed to be constant and production-capacity limit is assumed to be 4 per period. The production capacity of the equipment-maker is assumed to be constant during the simulation.

2.2.2 Financing strategy rule

Retailers and wholesalers finance the necessary amount of money for investing in production equipment from the bank or from stock market or by the self-financing according to the financing strategy rules which is assumed to be the following 5 strategies.

1) bank financing (strategy A), where all of the necessary amount of money is financed from the bank. The borrowed money is constantly repaid each period, for a constant number of consecutive repayment periods which is assumed to be 120 in the present study. Additional investment during the repayment periods is assumed to be not allowed.

2) stock-market-with-bank financing (strategy B), where producers issues new shares and sell them in the stock market. The obtained money in the stock market is used for buying an equipment. If the obtained money is less than the necessary amount of money for investment, the insufficient funds are financed from the bank. After financing from the stock market, the producers pay

dividends to the shareholders every fiscal period where a dividend is defined as the dividend rate times of the face value. The dividend rate is assumed to be 2 % in the present study. When the surplus money of a producer is less than the amount of money required for dividends, the producer can set the dividend rate to be 0%. The producer also can buy its own shares in the stock market within the limit of 5% of its deposit when positive-profit settlement continued for 10 periods.

3) stock-market-with-internal-funds financing (strategy C) , where the producer's obtained money by issuing new shares is less than the necessary amount of money for investment, the insufficient funds are self-financed from its internal funds. Other rule of the producer is the same with that of stock-market-with-bank financing strategy.

4) combination-of-strategy-A-and-B financing (strategy D), where the strategy of minimum cost among strategy A and strategy B is selected for financing.

5) combination-of-strategy-A-and-C financing (strategy E), where the strategy of minimum cost among strategy A and strategy C is selected for financing.

2.3 Bank agent

The bank keeps the surplus money of other agents in their respective bank accounts, and lends money as long-term loans to producers, in line with their demands for investment. The charging interest rate for long-term loans is assumed to depend on the producer's capital ratio so that the lending interest rate is increased with decreasing capital ratio as shown in Table 1. The bank also pays wages to its employees and lends money as short-term loans to producers, in line with their requirements when they become short of working capital. The charging interest rate for short-term loans is assumed to be 1%.

In addition, the initial amount of funds in the bank is set to be very large in the present study, so that there is no limitation on lending money to meet the demand of producers, except for the rejection of lending during the repayment stage.

Table 1 Lending interest rate for long-term loans

Capital ratio	Lending rate
More than 80%	1.50%
50～80%	2%
30～50%	3%
5～30%	5%
Less than 5%	10%

2.4 Market

The market in the present study is composed of commodity market and stock market. Market is the place where agents do economic activities and interact each other.

2.4.1 Commodity market

Commodity market in the present study is the place which deals with the transactions of commodities such as products for consumers supplied by retailers, raw materials for retailers supplied by wholesalers and equipments for production of retailers and wholesalers supplied by an equipment-maker. The transactions such as supply, buying and selling are done by agents every period. Retailers and wholesalers decide both the amount and price of goods based on the amount of goods in stock at the end of previous period. The buyers such as consumers and retailers purchase goods. When there are goods of the same class available in the market at different prices, the buyers purchase the cheapest one among them. Thus, the price of goods purchased is determined every period as a result of interactions among buyers and sellers. On the other hand, equipments are produced on order and the price is assumed to be constant in the present study.

2.4.2 Stock market

Stock market in the present study is the place which deals with the transactions of stocks. Stock market is divided into primary market which deals with the transactions of newly issued shares and secondary market which deals with the transactions of outstanding stocks.

Primary market

Retailers and wholesalers issue new shares to finance the necessary amount of money for investing in production equipment and sell them in the primary market. The face value of a share is assumed to be constant as 1000. The offering price of a share is determined by a method similar to the book building method. Namely, the price of its own shares outstanding in the secondary market is defined as standard price. The price between 0.9 and 1.1 times of standard price is offered to the consumers. Then consumers apply for buying the shares at its limit price within the range of the offered price. Then the minimum limit price in financing the necessary amount of money is defined as offering price of the newly issued shares.

Secondary market

Consumers buy and sell stocks in the secondary market. The producer also can buy stocks of its own shares within the limit of 5% of its deposit when positive-profit settlement continued for 10 periods.

The contract price of stocks is determined so that bidding price is changed until the amount of sell order becomes coincident with the amount of .buy order.

3 Simulation Conditions

A simulation program was constructed using C++ , with object-oriented programming.

Table2 Fixed parameters and initial values of variable parameters

(a) Parameter values of the base run

Maximum fiscal periods	360
Fixed salary	7000～7500
Bonus ratio	0.95
Number of product class	12
Class of product with positive utility	3 of 6
Weight of utility	0.3～1.1
Loan Interest	3%
Deposit interest rates	0.50%
Repayment period	120
Investment value	500000
Critical flag number to quit production	20
The lower limit of production	70% of its capacity
Increasing production capacity flag	10
Number of consumer	300
Number of retailer	60
Number of wholesaler	9
Number of equipment maker	1
Number of bank	1
株式投資最低参加保有資金	10000
額面価格	1000
配当率	2%

(b) Initial conditions whose value may change during each run of simulation

Consumer deposit	30000～50000
Capital of R and W	80000～160000
Capital of equipment maker	200000～220000
Capital of bank	96000000 ～104000000
Price of wholesaler products	130～160
Price of retailer products	2850～3150
A in equation (4) for W	300～200
A in equation (4) for R	18～8

The parameter values which is constant during the simulation is given in Table 2(a), including the number of agents which are 300,60,9,1,1 for consumers, retailers, wholesalers, an equipment-maker and a bank respectively.

The maximum number of fiscal periods for each run of simulation is also constant as 360.

The parameter values given in Table s(b) state variables which are initially assigned randomly between certain values but may change during each run of simulation because of the interactions between agents

The experimental conditions for the analyses of the influences of financing strategy of producers and the investment strategy of consumers in the stock market are given in Table 3.

In the case of the analysis of the influence of financing strategy, the behavior of economic indicators such as GDP, consumer prices and stock prices are calculated under the condition where the financing strategy is specified as one of five strategies for all producer agents and investment strategies of consumers consist of three of six strategies with the same probabilities as shown in Table 3.

In the case of the analysis of the influence of investment strategy of consumers, the average rate of return of each agent in the stock market during 360 periods was calculated as well as the chronological change in economic indicators during the periods. These average rates of returns are again averaged for each investment strategy. The financing strategy of producers is assumed strategy B for all producer agents.

Table3.Parameters of experimental levels

Variable parameters as experimental levels

		Analysis of financing of producer					Analysis of strategy of consumer stock
Ratio of retailer of financing							
	Bank financing	100%	0%	0%	0%	0%	0%
	Stock-market-with-bank financing	0%	100%	0%	0%	0%	100%
	Stock-market-with-internal-funds financing	0%	0%	100%	0%	0%	0%
	Combination-of-strategy-A-and-B financing	0%	0%	0%	100%	0%	0%
	Combination-of-strategy-A-and-C financing	0%	0%	0%	0%	100%	0%
Ratio of consumer of strategy for buying and selling stocks							
	Moving-average oriented strategy	33.3%					16.60%
	Corporation-profit oriented strategy	33.3%					16.60%
	Random strategy	33.3%					16.60%
	Risk oriented strategy	0%					16.60%
	Return-and-risk oriented strategy	0%					16.60%
	Return oriented strategy	0%					16.60%

4 Simulation Results

4.1 Analysis of the influence of financing strategy on economic indicators

4.1.1 Influence of financing strategies on the behavior of GDP

Influence of financing strategies on the chronological change in GDP is shown in Figure 2. Chronological change in the total amount of money for investment is given in Figure 3.

In the cases of bank financing and stock-market-with-bank financing, GDP shows up-and-down movement in periods. This is because, as the both strategies contain bank financing, inflow of funds from the bank into the market and outflow of funds from the market into the bank are periodically occur during the simulation. The inflow of funds into the market occurs due to the investment in production equipment, resulting in an increase in GDP, while outflow of funds from the market occurs due to the repayment of loans, resulting in an decrease in GDP. The basic mechanism of this business cycle is discussed in the authors' previous work[Ogibayashi and Takashima, 2010]. In the case of stock-market-with-internal-funds financing, on the other hand, periodical movement in GDP disappears as shown in Figure 2. .This is because, as this type of strategy does not contain bank financing at all, the inflow and outflow of funds in the market does not occur.

It is also noted in Figure 2 that ,compared with bank financing, stock-market-with-internal-funds financing shows higher GDP. This is because the decrease in the repayment burden, which is brought by financing in the stock market, allows producers to increase the investment frequency as given in Figure 3, resulting in an increase in consumers' disposable income.

It is also noted in Figure 2 and Figure 3 that the stock-market-with-internal-funds financing strategy shows much higher GDP than those of other strategies. This is because, in addition to the effect of decreasing repayment burden, the funds of producers' bank accounts come to recirculate in the market due to the self-financing with internal funds. This, in turn, increases the consumers' disposable income, resulting in the increase in the investment frequency of producers as shown in Figure 3. The decrease in the repayment burden also contributes to the increase in the investment frequency.

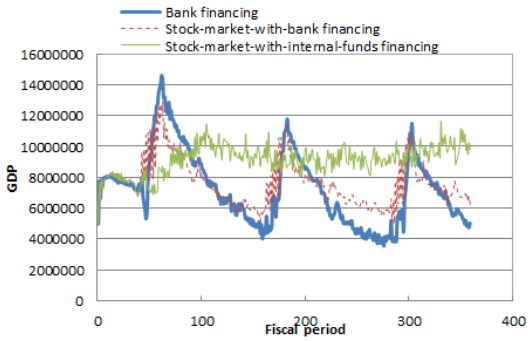


Figure2. Influence of financing strategies on GDP.

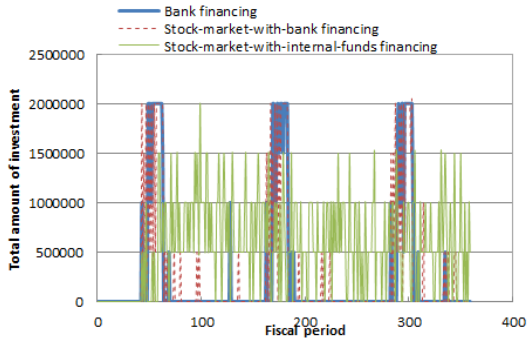


Figure3. Influence of financing strategies on the frequency of investment.

4.1.2 Mutual dependence among GDP, consumer prices and stock prices.

The mutual dependence among GDP, average consumer price and average stock price was analyzed for each financing strategy. In the case of bank financing, a clear relationship between average product price and GDP is observed as shown in Figure 4. This tendency also observed in the real system as pointed out in the authors' previous work[Ogibayashi and Takashima, 2011]. The reason for this tendency is that there is a clear relationship between total sales of producers and total income of

consumers, because consumers' income is paid from the producers' total sales.

In the case of stock-market-with-bank financing strategy, co-movement of average product price and GDP is also observed, but the co-movement of average stock price with average product price is not clear and shows a time lag between them. This tendency is caused because, at the beginning of booming stage, newly issued stocks are temporarily supplied excessively due to the investment in production equipment, causing the decrease in average stock price , while the investment results in the increase of money supply in the market, causing the increase in consumers income and demand, which in turn results in the increase in average product price as shown in Figure 6. Thus, the time lag occurs between average consumer price and average stock price.

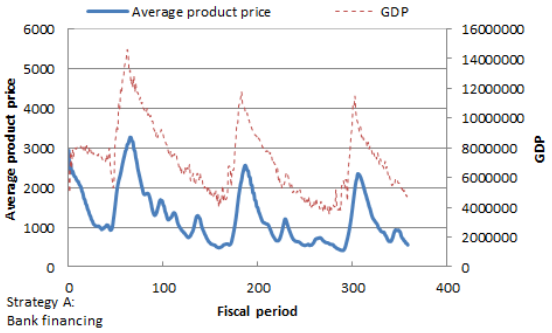


Figure 4. Chronological change in GDP and consumer prices in the case of bank financing strategy.

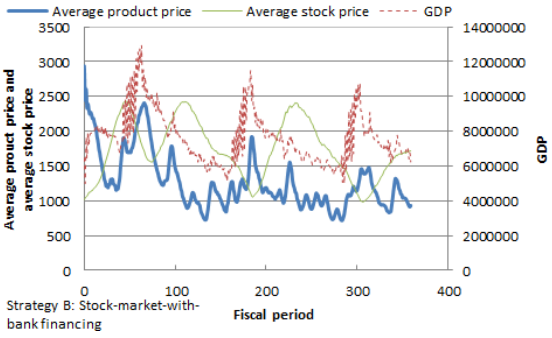


Figure 5. Chronological change in GDP, average product price and average stock price in the case of stock-market-with-bank financing strategy

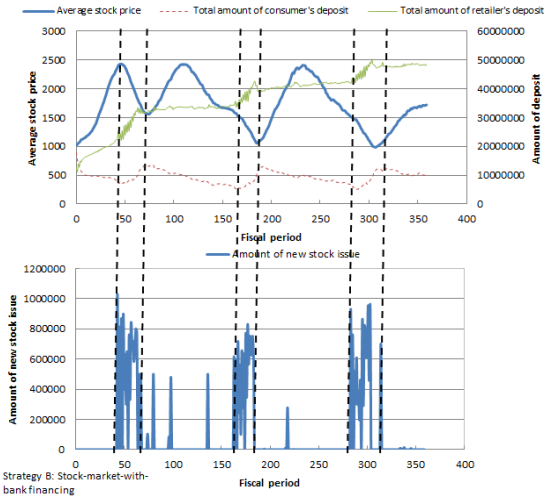


Figure 6. Chronological change in average stock price, consumer's deposit and retailer's deposit(upper) and newly issued shares (lower) in the case of stock-market-with-bank financing strategy

In the case of stock-market-with-internal- funds financing strategy, co-movement of average product price and GDP is also observed as shown in Figure 7. Average stock price, on the other hand, does not show co-movement with average product price and keep increasing with period as shown in Figure 7. This tendency is caused because, in addition to the effect of decreasing repayment burden, the funds of producers' bank accounts come to recirculate in the market due to the self-financing with internal funds. This, in turn, increases the consumers' disposable income, resulting in the increase in the investment frequency of producers. As some part of the consumer's disposable income is used for buying both commodity goods and stocks, it is considered that average prices of products and stocks are determined as result of demand and supply in both markets.

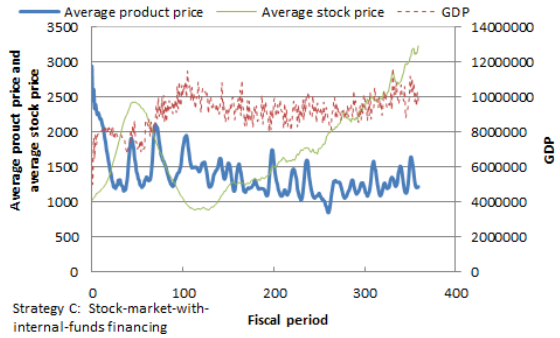


Figure 7. Chronological change in GDP, average product price and average stock price in the case of stock-market-with-internal-funds financing strategy.

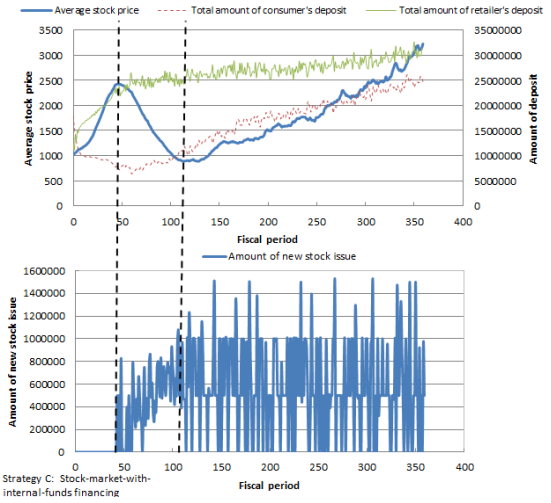


Figure 8 Chronological change in average stock price, consumer's deposit and retailer's deposit(upper) and newly issued shares(lower) in the case of stock-market-with-internal-funds financing strategy.

4.1.3 Influence of mixed financing strategy on the behavior of GDP

Chronological change in GDP is given in Figure 9 for bank financing, financing with combination of strategy A and B (strategy D), and financing with combination of strategy A and C (strategy E), where strategy A is bank financing strategy, strategy B is stock-market-with-bank financing strategy, and strategy C is stock-market-with-internal-funds financing strategy.

It is noted in Figure 9 that stock-market financing increases GDP and internal-funds financing has the largest effect in increasing GDP. The reason for this tendency is the same as explained in 4.1.1. It is also noted that cyclic movement in GDP becomes vague by the addition of internal-funds financing strategy.

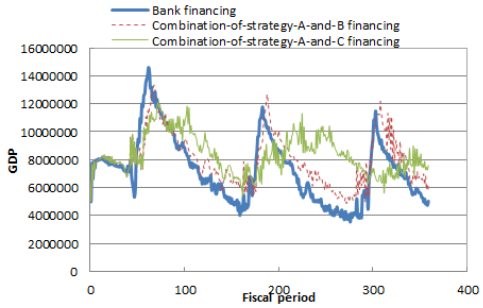


Figure 9. Influence of mixed strategies on GDP

4.2 Analysis of the influence of consumer investment strategy on the rate of return

The influence of investment strategy of consumers on the average rate of return was calculated under the condition of financing strategy B. These average rates of returns are again averaged for each investment strategy of consumers . The financing strategy of producers is assumed strategy B for all producer agents.

The chronological changes in GDP, average product price and average stock price are shown in Figure 10 for reference. As pointed out in section 4.1.2, the co-movement of average stock price with average product price is unclear.

Under this condition, the calculated average rate of return for each investment strategy is calculated as shown in Table 4. It is noted that the risk oriented strategy offered the highest return, followed by the return-and-risk oriented strategy, the corporation-profit oriented strategy, while the random strategy, the return oriented strategy, and the moving-average oriented strategy lead to negative returns.Compared with risk oriented strategy, the rate of return of the corportion-profit oriented strategy seems to be too small. This is considered because the ratio of agents with corporation -profit oriented strategy is only 1/6 in the present study and preferable strategy depends on the ratio of agents with each strategy.

The fact that the strategy that considers risk and corporation-profit leads to higher return seems to be reasonable and suggests that the present model works and reproduces the fundamental aspects of real system. As the preferable strategy depends on the ratio of strategies in the real system, the detail of the study on the relationship between the rate of return and investment strategy will be remained as a future subject.

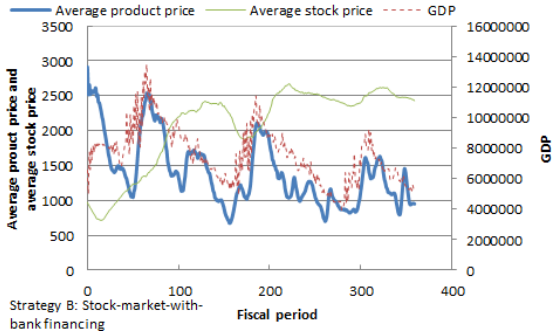


Figure 10 Calculated GDP, average product price and average stock price in the analysis of the influence of consumer investment strategy.

Table 4. Average rate of return for various investment strategies in stock market.

Investment strategy	Rate of return(%)
Moving-average oriented strategy	▲ 0.1
Corporation-profit oriented strategy	1.3
Random strategy	▲ 4.2
Risk oriented strategy	17.0
Return-and-risk oriented strategy	8.7
Return oriented strategy	▲ 6.9

5 Discussion

5.1 Co-movement between economic indicators

As a result of the analysis of the influence of financing strategy on the behavior of economic indicators such as GDP, stock prices and consumer prices, it was found that there is a clear co-movement of GDP with average consumer price, while co-movement of average stock price with average consumer price is not clear and shows a time lag between them, because of the temporary excessive supply of stocks at the time of investment. In other words, the time lag between average stock price and

average consumer price is caused because there is a time lag between the increase in consumers' disposable income and the increase in the supply of stocks.

The co-movement or time lag between the economic indicators, the chronological change in GDP, consumer price, and average stock price is examined in the real system. According to the International Monetary Fund World Economic and Financial Surveys, "World Economic Outlook Database" [International Monetary Fund, 2012], we can see a clear co-movement between GDP and consumer price index as shown in Figure 11 as reproduced in the present model.

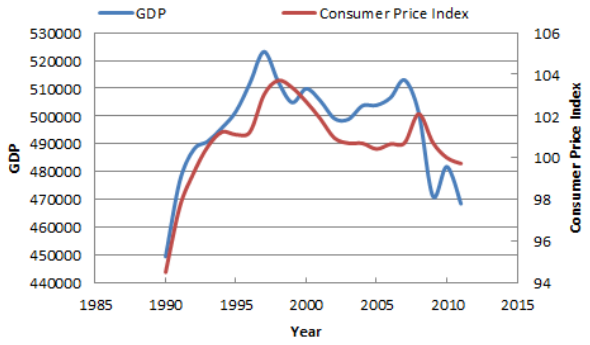


Figure 11. Chronological change in GDP and consumer price index observed in Japanese economy, showing co-movement between GDP and average consumer price.

Figures 12 and 13 indicate the chronological movement of stock price and GDP and average consumer price respectively according to the real data of GDP and average stock price supplied by Nikkei Indexes "Archives: Historical Data(Nikkei 225)" [Nikkei Indexes, 2012]. The co-movement of average stock price with GDP or average consumer price is not clear as shown in Figures 12 and 13. In addition, it is noted that when GDP is increasing between 1990 and 2000, average stock price shows downward trend and there seems to be a time lag between them after 2005. Thus, a time lag between the movement of average stock price and consumer price or GDP seems to frequently occur in the real system. The reason for this tendency is considered that there is a time lag between the increase in consumers' disposable income and the increase in the supply of stocks due to the investment of firms.

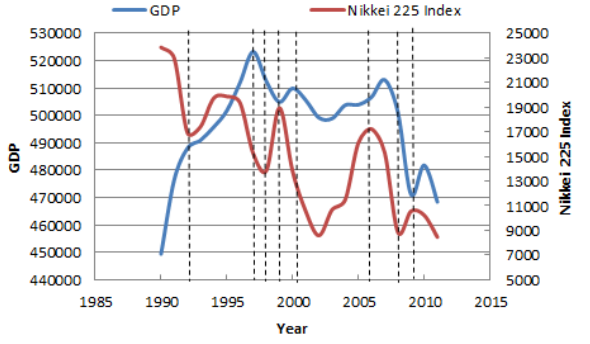


Figure 13. Chronological change in average stock price and GDP observed in Japanese economy.

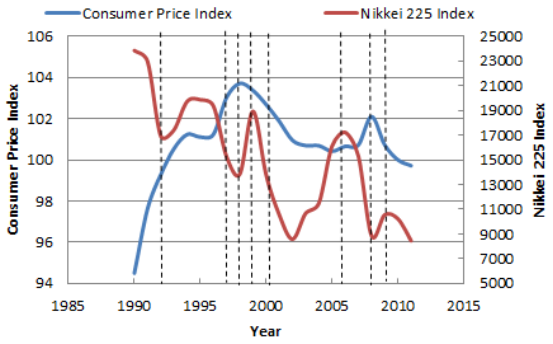


Figure 14. Chronological change in average stock price and consumer price index observed in Japanese economy.

5.2 Interaction between commodity and stock markets

As explained in section 4.1.1, financing from stock market leads to higher GDP than bank financing. This is because the decrease in the repayment burden allows producers to increase the investment frequency, resulting in an increase in consumers' disposable income.It should be pointed out that this tendency is the result of the interactions between commodity and stock markets, because stock-market financing and the consumers' buying stocks are the events in the stock market, while the investment in production equipment and the increase in consumers' disposable income are the event in the commodity market. In addition the increase in the consumers' disposable income leads to the increase in demand not only in the commodity market but also in the stock market. Thus, the event that occurs in the commodity market influences the event in the stock market and vice versa. and the influence of stock-market financing on the economic indicators is the result of the interaction between two markets.

Similarly, the time lag that occurs in the relationship between average stock price and GDP or average consumer price is also the result of the interaction between two markets.

In the real system, many economic indicators are influenced by the interactions among various markets that includes not only commodity and stock markets but also other markets such as bond market, exchange market, import and export markets. It requires tedious work to develop a model that takes into account all of thes markets. The present study, however, suggests that taking account of interactions between markets is very important and, in some cases, indispensable in reproducing fundamental aspects of economic indicators in agent-based modeling.

6 Conclusion

An agent-based model of an artificial economic system that includes both commodity and stock markets has been developed and the influence of producers' financing strategy for investing in production equipment on the behavior of economic indicators was analyzed. further, the influence of consumers' investment strategy in the stock market on the rate of return was also analyzed and following findings were obtained.

1) Financing from stock market leads to higher GDP than bank financing. This is because the decrease in the

repayment burden allows producers to increase the investment frequency, resulting in an increase in consumers' disposable income.In addition, self-financing with internal funds leads to much higher GDP than other strategies. This is because the funds of producers' bank accounts come to recirculate in the market, resulting the increases in consumers' disposable income and investment frequency of producers.

2) When corporate financing strategies coexist from both the bank and the stock market, the co-movement of average stock price with average consumer price is unclear, and shows a time lag between them because of the temporary excessive supply of stocks at the time of investment. The similar tendency is observed in the real system according to the real data of GDP, consumer price and Nikkei 225 index in Japanese economy. The reason for this tendency is considered that there is a time lag between the increase in consumers' disposable income and the increase in the supply of stocks due to the investment of firms.

3) When six types of consumer stock-investment strategies coexist in the market with the same probability, the risk oriented strategy offered the highest return, followed by the strategy that considers both return and risk, corporation-profit oriented strategy, while the random strategy, the return oriented strategy, and moving-average oriented strategy lead to negative returns

4) All of the findings obtained in the present study is the result of the interactions between commodity and stock markets. This suggests that taking account of interactions between markets is very important in reproducing fundamental aspects of economic indicators in agtent-based modeling.

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