Chapter 4
Model Structure of Agent-Based Artificial Economic System Responsible for Reproducing Fundamental Economic Behavior of Goods Market

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Abstract Agent-based modeling (ABM) features its capability not only to deal with the heterogeneity of agents but also to elucidate the causal mechanism of social phenomena. The latter can be done by clarifying the model structure required to reproduce the phenomenon through systematic computer experiments. This article presents some examples of such studies that uncovered the causal mechanism of the goods market's fundamental economic behaviors, including price equilibrium, business cycles, the effect of tax cuts in both income and corporate taxes. The condition of the validity of ABM and the causal mechanism of business cycles are also discussed.

Keywords Agent-based model · Model structure · Fundamental economic behavior · Price equilibrium · Supply chain · Business cycles · Tax reduction · Causal mechanism · Validity

4.1 Introduction

Many social problems depend on government policy. In democratic societies, government policy should essentially aim to allow people of all levels to lead spiritually and materially rich and safe lives. Economic policy should be determined to effectively promote the economy, taking into account various aspects of problems such as the growth rate of , inflation rate, unemployment rate, as well as wealth inequality. However, this is not the case in reality. Most countries have various social problems, including remarkable wealth inequality between rich and poor and the issue of social welfare, which appear to be becoming increasingly serious. Japanese

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economy fails to increase GDP for more than 30 years, being unable to overcome the deflation, despite of remarkable monetary easing policy. Why is it so difficult to overcome the problem?

Underlying these problems is the fact that the true causal mechanisms of various phenomena in society are not well understood and shared among people, and the policy-making process is likely to be designed for those who have vested interests or powers. To realize a truly democratic society, it is therefore desirable to correctly understand the causal mechanisms underlying the emergence of social and economic phenomena, based on which social and economic policy by the government is scientifically backed.

In both natural and social systems, there exists a cause and causal mechanism for the occurrence of each phenomenon. In the fields of natural science and engineering, hypotheses and equation-based models concerning these causal mechanisms have been proposed based on observation of the behavior of various phenomena, which are verified by a series of controlled experiments. Thus, natural science and engineering comprise accumulated knowledge and data on the causal mechanisms of various phenomena. The background that various hypotheses have been proved by experiments, owing to which the causal mechanism of each phenomenon has been clarified, is that natural phenomena behavior is universal and unchanged over time and space. For example, an apple falls down due to the gravity, and the speed of the falling apple obeys the Newton's law of motion. This causal relationship is verified by experiments and valid all over the world without depending on the historical time. The same is true for various laws of nature. Because of this principle, hypotheses concerning causal mechanisms could be proved true or not by researchers worldwide without depending on time and space in the field of natural science.

Conversely, in the fields of social science and economics, various phenomena are caused by decision-makers' behaviors and their interactions, which change with time and place and depend on the heterogeneity of individual's intentions. In principle, it is therefore impossible to conduct controlled experiments such as those for natural phenomena in the social world. This implies that a traditional equation-based model approach is in principle insufficient to clarify the causal mechanism of social phenomena, because equation-based model is essentially based on the assumption on the causal mechanism of the phenomenon, which cannot be validated due to the impossibility of controlled experiment. Furthermore, the causal mechanisms between the causes and effects related to social phenomena are too complicated to be represented in the form of equation-based model, because the human behavior that causes changes in the state of society depends on the state of society itself, and the manner of dependence varies across individuals. Therefore, there is a limit to expressing such mechanisms with a simple set of equations in the case of social phenomena.

On the contrary, agent-based modeling (ABM) could be a powerful approach for elucidating the causal mechanisms of social phenomena, because it is a bottom-up type modeling method where only behavioral rules of individual decision-makers called agents are assumed without any assumptions relating to aggregate variables

and causal mechanism. ABM is a modeling method where an artificial society is constructed on a computer, assuming the actions of multiple decision-makers. Then, a macro phenomenon emerges as a result of agents' actions and interactions. The causal mechanism of each phenomenon that emerges in the artificial society on a computer could be the same in the real world, because each of the aggregate phenomena is caused due to the agents' actions and their interaction, the principle of which is the same as in the real world. For this reason, if the assumed input conditions only include individual behaviors of decision-makers, without including aggregate factors, (i.e., if the model is entirely bottom-up), it is, in principle, possible to build a model so that the causal relationship emergent in the artificial society could be same as that in the actual system. The validity of the model is evaluated by the extent how close the model reproduces every feature of the macro phenomenon in question in the real world.

The history of ABM dates back to John von Neumann's "theory of self-reproducing automata" (von Neumann 1966). Cellular automata devised based on this theory are considered to provide the roots of ABM. One of the earliest models is Thomas Schelling's ethnic segregation model (Shelling 1969). Subsequently, "Growing Artificial Societies" written by Epstein and Axtell (1996), "Simulation for the Social Scientist" by Troitzsch Gilbert and Troitzsch (2005), and "Agent-Based Models" by Gilbert (2008) were published. Gilbert (2008) proposed the idea that a model can be roughly classified into abstract, middle range, and facsimile models in terms of the degree of precision, meaning that the first step of building an agent-based model is the abstract model followed by the middle range and facsimile models. Moreover, criticisms regarding the validity of ABM have been reported, including the argument that ABM cannot specify the necessary conditions for reproducing a specific macro phenomenon because of its inherent functional complexity (Marks 2007).

Based on the background of this history, many researchers seem to consider that although ABM is effective in offering hints on the emergent mechanisms of phenomena in the real world, it is not sufficiently reliable for elucidating the causal mechanisms to replace the traditional approach of economics. Thus, ABM has received little recognition as a promising methodology worth being used to decide public policies. Moreover, the potential of ABM for elucidating the social phenomenon stated above has not been well recognized in the literature except for one paper entitled, "Economy needs agent-based modeling" by Farmer and Foley (2009).

However, as many modelers have probably experienced, ABM emerges different macro phenomena with different input conditions that are assumed. For example, suppose the emerged phenomenon in ABM under a particular set of behavioral rules differs from that in the real world in its feature. In that case, modelers might change the input conditions until the model reproduces the features of a macro phenomenon in question. It is also noted that not all factors of the input condition change the characteristics of the macro phenomenon that is the output, even at a qualitative level. Among the factors for a specific input condition, the set of factors that are indispensable for the emergence of the macro phenomenon is considered the

cause of the macro phenomenon in question; therefore, there is a causal relationship between the input condition that consists of a set of indispensable factors and the macro phenomenon. The input condition comprises agents' types, behavioral rules, and attribute variables. Because combining these factors can provide a model structure simulating a real system, let us refer to the input condition as a model structure below.

Suppose we perform a series of computer experiments that systematically change the model structure until the model reproduces every feature of the macro phenomenon in question. Then, by conducting this procedure, we can elucidate the model structure indispensable for reproducing the characteristics of a macro phenomenon observed in the real world. In such a model, the causal relationship between the model structure and the macro phenomenon in the model can represent the causal relationship in the real world. Next, by considering why factors in the model structure clarified by computer experiments are indispensable, it is possible to gain a better understanding of the causal mechanism of that phenomenon.

The author has found that there are indispensable model structures for reproducing various socio-economic phenomena. Considering why the model structure was indispensable confirmed that the extracted causal mechanism was reasonable.

This chapter describes the model structure of an agent-based artificial economic system responsible for reproducing fundamental macroeconomic phenomena. Those phenomena include price equilibrium, supply chain, business cycles, positive effects of a tax cut for income, and corporate taxes, which are research examples for elucidating the causal mechanism of fundamental macroeconomic behaviors.

Among these phenomena, the positive effects of a tax cut for income tax and corporate tax are the phenomena whose indispensable factors for the reproduction in ABM are the most systematically elucidated, followed by the business cycles.

4.2 The Model

The details of the model are described in the form of ODD protocol shown in the Appendix. The outline of the model, the action sequence, and behavioral rules of agents are shown below.

4.2.1 Outline of the Model

The agent-based model of the artificial economic system in the present study includes consumers, producers, a bank, and a government as autonomous decision-making agents. The type of agents and their behavioral rules are shown in Table 4.1, which are changed depending on the experimental levels. Consumers are divided into three types of agents: workers as the base type, executives who are included or

Table 4.1 Outline of agents and their behavioral rules

Agent	Type	Output to be supplied	Product type to purchase	Outline of behavioral rules
Consumer	Worker	The labor force for firms	Consumer goods	Consumers work and obtain the wage from the producer, bank or government, pay tax, and purchase consumer goods. A part of the income will be deposited in the bank account as per the Keynesian consumption function. Buying consumer goods is performed according to the utility which each consumer uniquely holds. Consumers transact in the stock market, aiming to increase their assets when the model includes the stock market
	Executive	Management for firms		
	Public workers	The labor force for government		
Enterprise				Enterprises employ consumers, get profits from operating activities, and pay wages and tax
Producer				Producers supply and sell products in the goods market
	Retailer	Consumption goods	Consumer goods	Retailers and raw material makers decide both the quantity and price of each class of product to be produced based on the number of goods in stock. If necessary, they invest in equipment based on the demand to expand production capacity
	Raw material maker	Material goods	Materials, equipment Consumer goods Equipment	
	Equipment maker	Equipment	–	
Bank	Bank	The fund for producers' investment	–	The bank keeps the surplus money of other agents in their respective bank accounts and lends money to firms for investment
Government	Government	Redistribution of wealth	Consumer goods	The government collects tax from other agents, pays wages to public workers, and spends the remaining money on public expenditure

not in the model in the analysis of the effect of corporate tax reduction and public workers when the government is taken into account in the study of the effect of tax reduction. Producers are divided into three types of agents, i.e., retailers, raw-material makers, and an equipment maker, as shown in Table 4.1. Markets are also divided into three types: a goods market as the base type, which includes the markets for consumer goods and material goods, a stock market when it is taken into account in the analysis of business cycles, and a labor market when it is taken into account in the study of the effect of tax reduction.

Each agent is heterogeneous in its state variables including initial value of bank deposits as well as in the other parameters included in their behavioral rules.

4.2.2 *Sequence of Actions*

The set of activities of each agent constitutes period-based units, where one period is assumed to correspond to 1 month in the real system. During each period, agents act according to the sequence of eight steps. At the end of the series of actions in each period, a GDP value is calculated based on an input-output table obtained by summing each agent's account data. The eight steps dictating the agents' actions are as follows:

1. Agents pay any unpaid tax from the previous period. After paying taxes, agents create a budget plan for consumption, paying wages, or public spending.
2. Raw-material makers decide on the quantity and price of products to be produced, produce several types of raw materials, and supply these to the material goods market.
3. Retailers decide on the quantity and price of products to be produced, purchase raw materials in the material goods market, produce several types of consumer goods, and supply these products to the consumer goods market.
4. Consumers, retailers, raw-material makers, and the government purchase products in the consumer goods market.
5. Each firm pays wages to employees and executive compensation to the executives while the government pays salaries to public workers.
6. Retailers and raw-material makers consider expanding production capacity based on total sales in the previous periods, and, if necessary, they decide to invest to increase production capacity by buying new equipment from the equipment maker. When the labor market is taken into account in the model, employing a new worker is another alternative for them to expand production capacity, which is to be chosen depending on the financial merit.
7. When the model includes a stock market, consumers buy or sell stocks aiming to increase their financial assets.
8. Each agent settles its accounts using the double-entry bookkeeping method. They calculate their income and profit for the current term and then determine the amount of tax to be paid based on these figures.

4.2.3 *Outline of Agent's Decision-Making Rules*

4.2.3.1 Behavioral Rules of Consumers

Consumers create a budget for consumption $E_b{}^t$. This budget is calculated by adding after-tax income $I^t(1 - r_{i\_tax})$, which represents the Keynesian consumption function (Keynes 1936), to the money withdrawn from the deposit described as their bank deposit D^t multiplied by a withdrawal ratio r_{wd} at each fiscal period t. The formula for the budget is shown in Eq. (4.1). Here, r_{i_tax} is the income tax rate, a is the consumer's autonomous consumption, and b is the marginal propensity to consume as per the Keynesian consumption function. The withdrawal ratio r_{wd} is selected randomly for each agent during each period.

$$E_b{}^t = a + bI^t\left(1 - r_{i_{tax}}\right) + r_{wd}{}^t D^t \tag{4.1}$$

When purchasing products in the consumer market, consumers select goods based on their utility and affordability (as determined by the utility function for each class of products and the agent's budget constraint, respectively). Moreover, when a stock market is included in the model as an experimental level to analyze the reproducibility of business cycles, consumers buy or sell stocks aiming to increase their financial assets. The details of the consumers' action rules in the stock market are described in the author's previous study (Takashima et al. 2014).

4.2.3.2 Behavioral Rules of Producers

The retailers and raw-material makers both decide the quantity and price of their product at the beginning of each period. The price of each product is increased or decreased depending on the number of goods they held in stock at the end of previous period. The quantity to be produced is decided in such a way that the probability of being out of stock must be less than 5%; this is estimated based on total sales from the last ten periods.

The production capacity Y is defined by the Cobb–Douglas function (as shown in Eq. (4.2)), where K is the number of units of capital equipment, L is the number of employees, and α is assumed to be 0.25. Besides, A is a bounded proportionality constant representing the total factor productivity that is randomly assigned being assumed to be unique to each producer i.

$$Y_i\,(K, L) = A_i K^{\alpha} L^{1-\alpha} \tag{4.2}$$

Retailers and raw-material makers initially have one unit of equipment and a specified number of employees. They will invest to increase their production capacity by buying an equipment from the equipment maker when their products produced at maximum production capacity continued to be sold out at each period during a specified number of periods. When the model includes the labor market as

an experimental level, they have two choices for performing investment: buying a piece of equipment from the equipment maker or employing a new worker from the labor market, depending on the financial merit.

When investing in equipment, they may finance the funds by either borrowing from the bank, issuing new shares in the stock market, using their internal funds, or using some combination thereof. The funds financed by the bank are repaid with interest in equal-sized payments each period for a constant number of consecutive periods. An upper limit of the number of loans is placed on total investment so that, during the repayment period, additional financing will be limited. The equipment makers produce equipment following the requirements from retailers and raw-material makers as long as it is within their production capacity. In the present study, the price of the equipment is assumed constant. The details of the decision-making rules for investment and financing were described in the author's previous study (Takashima et al. 2014; Takashima 2014; Ogibayashi and Takashima 2019), as well as the ODD protocol described in the Appendix.

One executive and several workers are initially assigned to each of the producer agents. The producers pay wages to workers and wages plus executive compensation to the executive in each period. The executive compensation comprises a salary, a bonus, and long-term incentives. Wages comprise a fixed salary and a bonus, which are randomly assigned to each employee between a lower and an upper limit. The bonus is assumed to be paid only when the producer's profit is positive.

4.2.3.3 Behavioral Rules of the Bank

The bank lends money in the form of long-term loans to producers (in line with their demands for investment), charging a 3% interest rate. The bank also lends money to producers in the form of short-term loans so that they may meet their requirements when their working capital to pay fixed wages and or purchase raw materials becomes sufficiently depleted. In the present study, the bank is initially given a massive quantity of funds so that there is no limitation on lending to producers, except in the case where the firm applying for a loan has already borrowed funds being during the repayment period, and the number of loans has already reached the upper limit. This limitation of borrowing especially restricts the investment when the upper limit of the number of loans is assumed to be one, which is two in the case of the base model.

4.2.3.4 Behavioral Rules of Government

The government collects corporate and income taxes, pays wages to public employees, and uses the surplus funds for public expenditure, as dictated by their expenditure policy. Public employees' salaries are calculated in each fiscal period so that they are equal to the average income of private employees.

Government expenditure is assumed to consist of market purchasing and firm subsidy. Market purchasing is an extreme form of efficient public expenditure in which the government directly purchases goods at the market price with the same behavioral rules as the consumers. In the case of public investment, this policy corresponds to the government placing job orders with firms at the market price in an entirely competitive situation. The subsidy for firms is an extreme form of inefficient public expenditure in which the government distributes funds to producers, without any limitations on their use. In this case, most of the funds distributed could be transferred to the bank account without being used in the market. This policy corresponds to the government placing job orders at a value far above the market price or paying money for jobs that have no economic value.

The ratio of the expenditure for the subsidy for firms to the total spending is defined as the inefficiency of government expenditure.

4.3 Simulation Conditions

4.3.1 Simulation Conditions for Reproducing Price Equilibrium

The type of agents included in the model are consumers and retailers. The income of each consumer is randomly assigned as a constant value defined at the start of simulation to evaluate whether the price of each class of products tends to become a constant value after the multiple periods. Their behavioral rules are essentially same as described in Sects. 4.2.3.1 and 4.2.3.2. Namely, the consumers buy the products supplied by retailers every period to maximize the individual's utility within the limit of disposable income. The disposable income is assumed constant at the beginning of every period. The weights of utility for each class of product are randomly assigned to each agent and the exponent of the number of products for the utility is assumed -2. If the products of same class are available in the market with a different prices, the consumers buy the products of lowest price. Thus, the consumer's buying strategy is low-price oriented.

Each retailer increases or decreases the price and the number of products depending on the number of stocks at the end of the previous period. More precisely, the producer increases the price if the number of stocks equals zero and decreases it if that number exceeds zero and the price is lower than the average price in the market. Thus, the producer's adjustment of production and pricing for each class of product is stock-control oriented. Moreover, the quantity to be produced is decided in such a way that the probability of being out of stock must be less than 5%; this is estimated based on total sales from the last ten periods.

The case where the decision-making of price change does not depend on the average price in the market is also analyzed as an experimental level and the increasing and decreasing rates are also experimentally changed.

The case where the production quantity is changed with a constant increasing or decreasing rate is also analyzed as an experimental level.

4.3.2 Simulation Conditions for Reproducing the Effect of Supply Chain

In this case, a raw-material maker is added as additional type of producer who produces raw material products for retailers. Therefore, the retailers buy raw-material products from the raw material market and produce the products for consumers and supply them to the retail market. The production capacities of retailers and raw-material maker are randomly assigned to each producer, and their upper and lower limits are changed experimentally. Each consumer is randomly assigned to each retailer or raw-material maker as a worker and the wage for each consumer is paid by the retailer or the raw-material maker, i.e., the employer. The wage is paid to each of the worker which is decided every period depending on the total sales, and the total sales of retailers is the sum of the money paid by consumers for buying the products in the retailer market.

Thus, the consumer's income varies every period and the funds circulate among retailers, raw-material makers, and consumers.

4.3.3 Simulation Conditions for Reproducing Business Cycles

In this case, an equipment maker and a bank are added as additional types of agents. The behavioral rules of the equipment maker and the bank are described as in Sects. 4.2.3.2 and 4.2.3.3. The behavioral rules of investment and financing are added as producers' decision-making processes. Each agent settles the account each period using double-entry book keeping. By summing up those account data, the input-output table and GDP values are calculated at the end of each period in the similar manner in the real world. The factors regarding investment in equipment and the means of financing said equipment are changed as input conditions to find the necessary model structure for reproducing periodic change in GDP (i.e., a business cycle).

The changes in consumers' wages and the amount of money spent on investing in equipment are also analyzed. The criteria of the producers' decision-making on investment as experimental levels include the case based on demand, the case without investment, the case with random investment at a fixed interval, and the criterion based on internal rate of return as shown in Table 4.2. In the case based on internal rate of return, the producers decide to invest when the internal rate of return is expected to be greater than the interest rate which is assumed to be constant. This criterion on investment corresponds to the case of decision-making

Table 4.2 Simulation conditions for the analyses of business cycles

			Basic model	Analysis of investment rules	Analysis of financing rules	Analysis of MEC model
Action rule	Producer	Decision-making rule of equipment investment	Based on demand	No investment/random	Based on demand	Based on an internal rate of return
		Rule of financing	Bank financing and internal funds	Bank financing	Using internal funds/issuance of stock	Using internal funds
		Rule of executive compensation	Without	Without		
		Deletion of equipment	Without	Without		With
		Price of equipment	Fixed	Fixed		Variable
		Upper limit on the number of loans	Limited (one)	Limited (one)		Unlimited
	Consumer	Rule of withdrawal deposit	With	With		
	Government	Taxation	Without	Without		
Market		Goods market	With	With		
		Stock market	Without	Without	Without/with	Without
		Labor market	Without	Without		

based on the marginal efficiency of capital (MFC) proposed by Keynes (Keynes 1936). Here, the internal rate of return is calculated using the expected value of the investment's marginal productivity, the price of the product, and the operating ratio of the equipment. The life of the equipment is assumed to be 60, and the price of the equipment is assumed to be $EP^{t+1} = EP^t(1 + 0.1\,(O^t/Y))$, where EP^t is the price of the equipment in period t, O^t is the number of equipment orders received in period t, and Y is the production capacity of the equipment maker (Takashima and Ogibayashi 2014). The means of financing the funds for buying one unit of equipment as experimental levels include the case with bank financing, the case with internal funds, the case with the issuance of stock and the combination of them. In the base model, funds for investment are assumed to be financed from the bank in half and internal funds in half.

Thus, the factors relating to the model structure changed in this case are decision-making rules on investment and financing rules for investment, the number of experimental levels of which are four in the former and three in the latter, respectively.

The simulation conditions for the analysis of business cycles are summarized in Table 4.2.

4.3.4 *Simulation Conditions for Reproducing the Effect of Income Tax Reduction*

A government and executives are added to the base model as additional types of agents and consumers are divided into the public and private workers and executives. Paying tax is added to the base model as additional behavioral rules for consumers who pay income tax and for firms who pay corporate tax. Paying executive compensation is also added as an additional behavioral rule for firms. The firms' decision-making on investment is assumed to be based on demand, and the necessary funds are assumed to be financed from the bank in half and internal funds in half. The upper limit of the number of loans is assumed as two. The behavioral rules of government are also added to the base model which are characterized by the inefficiency of government expenditure as defined in Sect. 4.2.3.4. The inefficiency of government expenditure is changed between 0 and 100% with 10% intervals.

The parameter values which are changed to analyze their influences on GDP are the following. First, the income tax rate is varied between 10% and 30% with a 5% interval, and the executive compensation is changed from 0 to 0.5. The withdrawal ratio is varied between 0 and the maximum value, which is assumed to be 0.2, or 0.5 or 0.8. Changing the withdrawal ratio corresponds to altering the marginal propensity to consume as given in Eq. (4.1).

4.3.5 *Simulation Conditions for Reproducing the Effect of Corporate Tax Reduction*

The base model is the same as in Sect. 4.3.4. Paying executive compensation for firms is changed as being included or not as an experimental level. The upper limit of the number of loans is also changed from one to three as an experimental level to clarify the influence of the mitigation of credit rationing on the positive effect of corporate tax reduction on GDP. The inefficiency of government expenditure is changed between 0 and 100% with 10% intervals.

In this study, the influence of the inclusion of a labor market is also analyzed as one of the experimental levels, because it is well known that corporate tax reduction results in reducing unemployment in the real system (Sakuma et al. 2011) which could contribute the emergence of the positive influence of corporate tax reduction. In the model taking into account the existence of labor market, it is additionally assumed that the firm can decide either to invest in equipment or to employ a new worker depending on the financial merit when it needs to expand the production capacity. In the latter case, the firm puts a help-wanted advertisement in the labor market to employ a new worker. On the other hand, if a firm goes bankrupt, the workers in the firm become out of work, applying for a new job in the labor market, while getting unemployment benefits from the government. The details of the behavioral rules of producers when there is a labor market are described in the author's previous study (Ogibayashi and Takashima 2014).

The parameter values changed to analyze the influence of the factors mentioned above on GDP are the following. For the analysis of corporate tax reduction, the corporate tax rate is varied between 10% and 30% with a 5% interval, the income tax rate is assumed to be 20%, executive compensation is changed as 0.75, 0.85, and 0.95, and the withdrawal ratio is changed between 0 and 0.5. In addition, the inefficiency of government expenditure is varied between 0% and 100%, with a 10% interval for both analyses.

Thus, the factors relating to the model structure changed in this experiment are:

- The inefficiency of government expenditure
- The inclusion of executive compensation
- The use of internal funds for investment
- The upper limit of the number of loans (i.e., mitigation of credit rationing)
- The inclusion of the labor market

The simulation conditions for the analysis of income tax and corporate tax reductions are summarized in Table 4.3.

The factors represented by the yellow area shown in Table 4.3 are systematically changed in the simulation to elucidate their effect on the tendency of the emergence of the positive influence of the reductions in income tax rate and corporate tax rate on GDP.

Table 4.3 Simulation conditions for the analysis of income tax and corporate tax reductions

		Influence of income tax		Influence of corporate tax	
		Inefficiency of government expenditure	Rule of agents	Inefficiency of government expenditure	Rule of agents
Agent	Consumer	150			
	Retailer	30			
	Raw material maker	6			
	Equipment maker	1			
	Bank	1			
	Government	1			
Rules of producers	Rule for investment	Based on demand			
	Rule for financing	Loan and internal funds	Loan/loan and internal funds	Loan and internal funds	Loan/loan and internal funds
	Rule of executive compensation	With	With/without	With	With/without
	The upper limit on the number of loans	Limited (one)	Limited (one)/limited (three)	Limited (one)	Limited (one)/limited (three)
Rules of consumers	The rule of withdrawal deposit	With	With/without	With	With/without
Rules of government	Inefficiency of government expenditure	0~100% (10% interval)	30%	0~100% (10% interval)	30%
	Income tax rate	10%, 20%, 30%	10%, 20%, 30%	Fixed 20%	Fixed 20%
	Corporate tax rate	Fixed 20%	Fixed 20%	10%, 20%, 30%	10%, 20%, 30%
Market	Goods market	With			
	Stock market	Without			
	Labor market	Without	With/without	Without	With/without

4.4 Simulation Results

4.4.1 *The Necessary Model Structure for Reproducing Price Equilibrium*

Under the condition where the consumers buy products of cheaper and more preferable ones from the viewpoint of utility within the limit of disposable income and the producers increase or decrease the number to produce and the price of products depending on the number of unsold products at each period, the average price, and the number of products supplied tend to become a constant value without depending on their initial values when consumer's income is assumed constant as shown in Figs. 4.1 and 4.2 (Takashima 2014). Under this condition, the number of products supplied tends to become the number of bought products, and the price changes to become a constant value accordingly as shown in Fig. 4.3 (Ogibayashi and Takashima 2010).

Namely, in addition to the heterogeneity in the agents' behaviors and attribute variables, the consumer's low-price oriented buying strategies and producer's stock-control oriented strategies of adjusting the number to produce and the price of the products are the indispensable factors in the model structure to reproduce the equilibrium of the price and production quantity.

The ways of adjusting the number and the price of products to produce at each time step affect the time required to become the equilibrium state and the variation of the number of stocks. However, they are not indispensable factors of price equilibrium because they do not affect whether the price and production quantity become an equilibrium state or not. Likewise, the average-price-dependent decision-

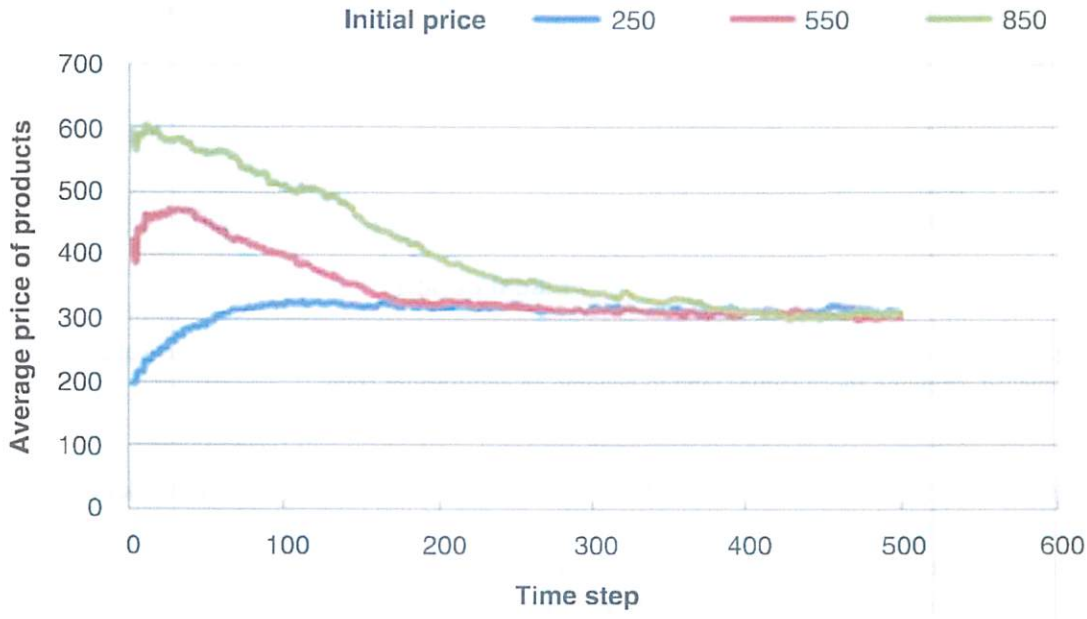

Fig. 4.1 The change in the price during the time step, reaching the equilibrium state

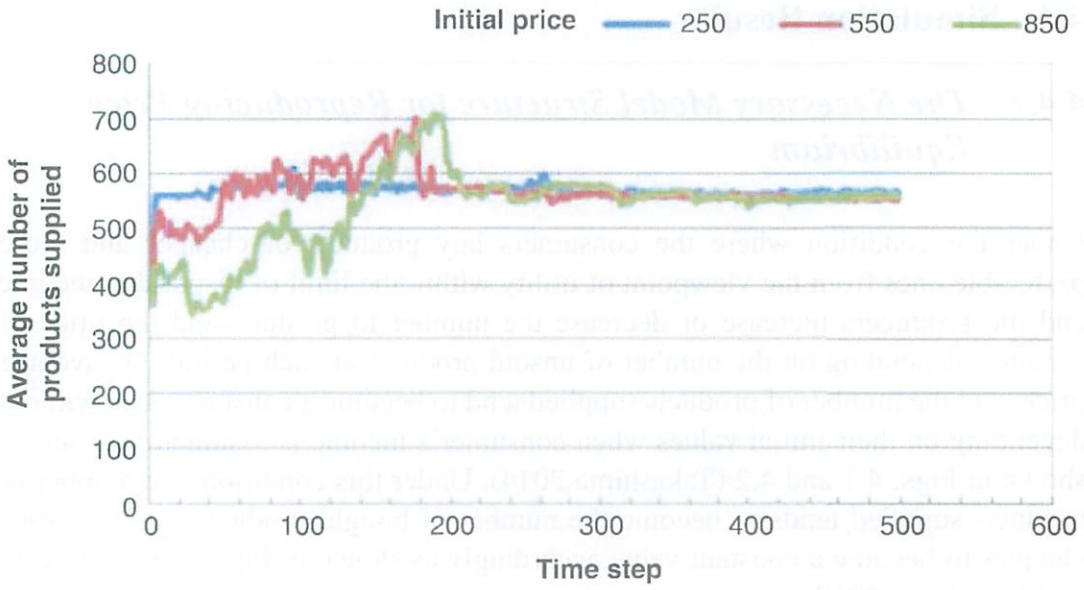

Fig. 4.2 The change in the number of products supplied to the market during the time step, reaching the equilibrium state

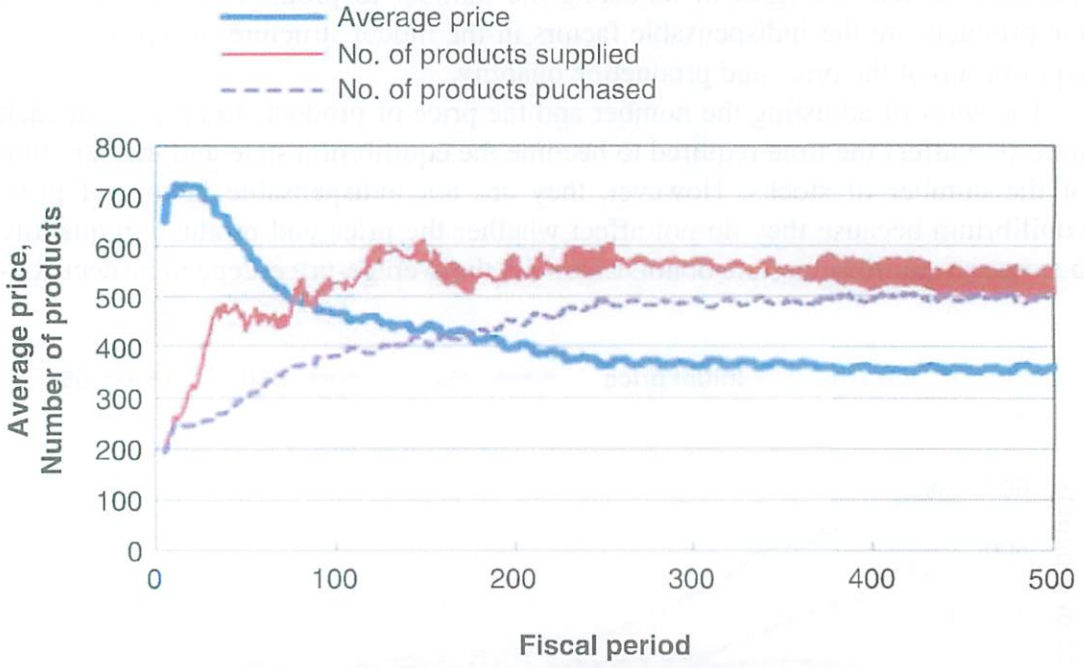

Fig. 4.3 The change in the average price of products and the numbers of those supplied and purchased, showing those values tend to become an equilibrium state

making of the price change influences the variation of the number of stocks of each agent at each time step. However, it is also not an indispensable factor because it does not affect the attainment of price equilibrium.

In this model, the price of products is not unique because each producer decides the price and supplies the products independently. Because of the low-price-oriented

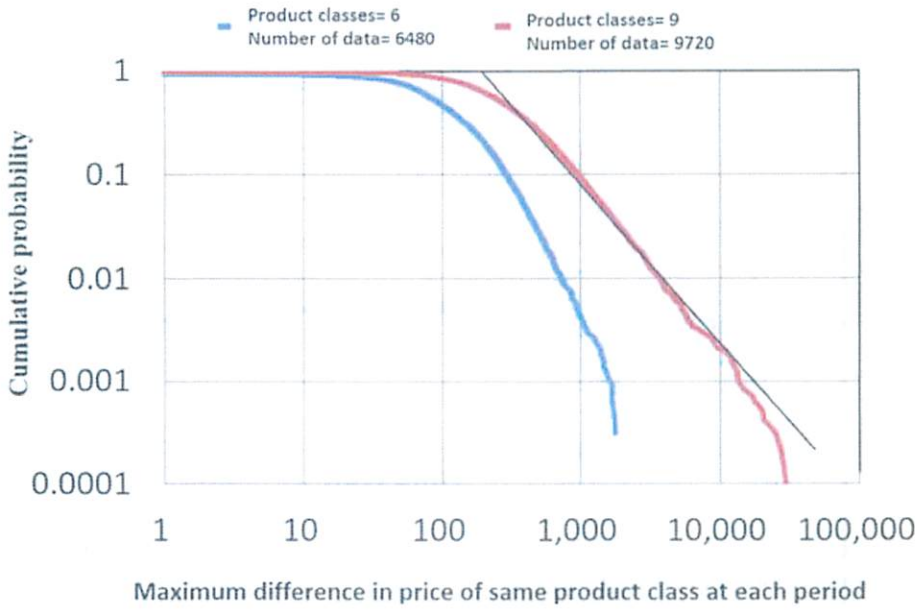

Fig. 4.4 Cumulative probability in the maximum difference in price of same product class at each period, showing the price difference at each period obeys power law distribution

buying strategy of consumers, cheaper products sell out preferentially, and the more expensive products remain unsold in the market at each period. As shown in Fig. 4.4, the maximum difference in the price of products purchased at each period obeys power-law distribution. Figure 4.4 is depicted based on the data presented in the reference (Takashima 2014). The fact that the maximum difference in the price follows power-law distribution suggests that the artificial system of the present model is a complex one.

4.4.2 Necessary Model Structure for Reproducing the Effect of Supply Chain

The feature of the effect of supply chain is that production amount and the price of products of producers of one type depends on the production capacity of producers of another type who supply the raw material to the producer of first type.

Under the simulation conditions described in Sect. 4.3.2, this feature of supply chain is well reproduced by the model as shown in Figs. 4.5 and 4.6. Namely, as shown in Figs. 4.5 and 4.6, the number of products supplied by retailers is dependent on the production capacity of raw-material makers, and the average price of retailers' products increases with a decrease in the production capacity of raw-material makers.

In Figs. 4.5 and 4.6, the set of numbers for the production capacity of raw-material makers such as 20–40, 30–60, 40–80, and 50–100 represent the lower and

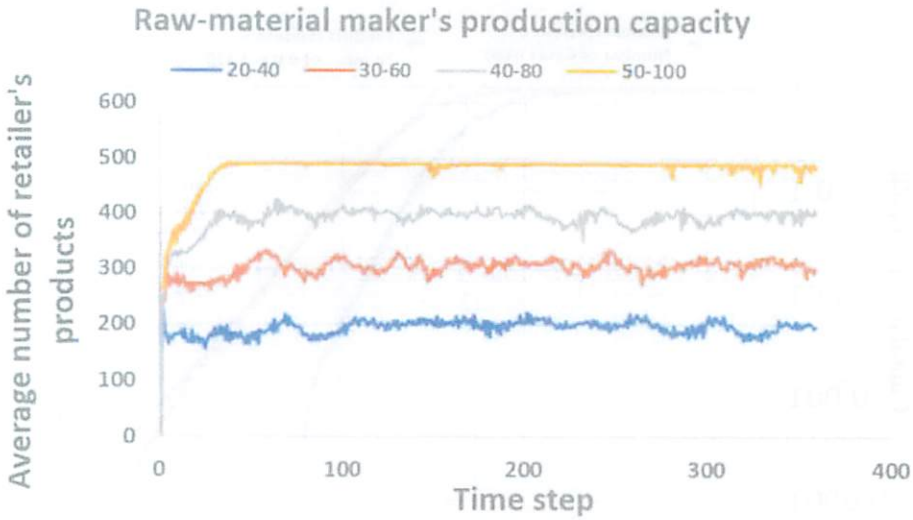

Fig. 4.5 The change in the number of retailer's products with time, showing the effect of supply chain in the number of products in the market

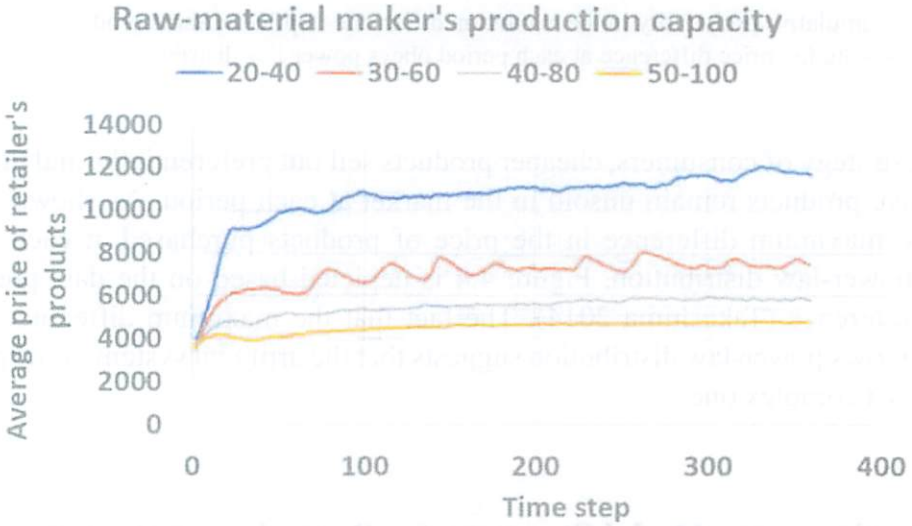

Fig. 4.6 The change in the price of retailer's products with time, showing the effect of supply chain in the price of products in the market

upper limit of the production capacity, between which the production capacity is randomly assigned to each agent.

Note that the difference between this model and the model described for price equilibrium is that this model includes raw-material makers as an additional class of producers and that funds circulate among agents. Namely, as for the fund circulation, the producers pay the wages based on the sales at each step, which becomes the consumers' income. The behavioral rules of consumers and producers are the same as those of the model described for price equilibrium. However, each worker's wage is assumed to be the total sales of the employer per capita for simplicity.

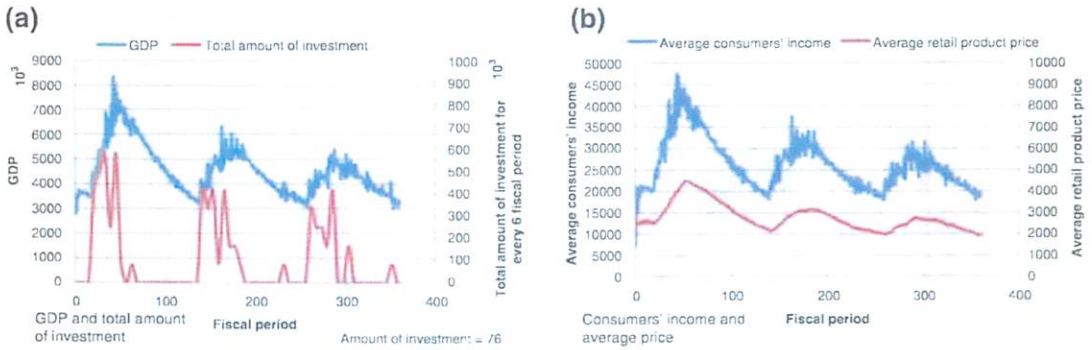

Fig. 4.7 Change in GDP and total amount of investment (**a**) and average consumer income and average consumer price over time (**b**) under the conditions of the base model (bank financing and investment decision-making on the basis of demand)

Thus, in the case of the funds' circulation model, the effect of a supply chain is automatically reproduced without changing the essential behavioral rules of consumers and producers employed in the price-equilibrium model.

4.4.3 The Necessary Model Structure for Reproducing Business Cycles

Figure 4.7a, b (Ogibayashi and Takashima 2019; Takashima and Ogibayashi 2014), and Fig. 4.8 (Ogibayashi and Takashima 2019) show the simulated results under the base model condition, in which it is assumed that investment decision-making is conducted based on demand, and the necessary funds for investment are financed from the bank with fixed repayment periods in half and internal funds in half. Here, it is confirmed that the inclusion of internal funds in addition to the bank financing is not essential because similar results are obtained in the case with bank financing only. Figures 4.7a and 4.8b show that the cyclical changes in GDP, which incorporate the synchronized movements in the average price of consumption goods and average consumer income, are reproduced showing the emergence of business cycles. Moreover, the level of aggregate funds for investment is high during the period of a booming economy where GDP is increasing (see Fig. 4.7a).

As shown in Fig. 4.8 (Ogibayashi and Takashima 2019), an increase in investment also results in an increase in the level of workers' wages at equipment makers during the same period of a booming economy, which induces the following increase in the level of workers' salaries at retailers.

From these results, the business cycle mechanism reproduced by the base model is as follows. In the beginning periods of the booming stage, some firms with strong sales decide to invest in equipment, causing an increase in the wage levels of workers at equipment makers, which induces an increase in demand, wages, and other firms' investment at the aggregate level. After the majority of producers have made their

Fig. 4.8 Change over time in consumer's wage over time under the condition of the base model (bank financing and investment decision-making on the basis of demand)

investments, the total amount of repayment per period becomes more significant than the total amount of borrowing because of credit rationing. This flow of funds from the market to the bank induces a decrease in total sales, workers' wages, and investments, thus resulting in a recession. The details of the behaviors of this flow of funds were described in the author's research article previously (Ogibayashi and Takashima 2019, 2010; Takashima and Ogibayashi 2014).

When we assume that producers either do not invest (i.e., there is no debt) or conduct investment randomly, with no regard to total sales, there is no periodic change in GDP, as shown in Fig. 4.9 (Ogibayashi and Takashima 2019). Therefore, we can conclude that the model must incorporate endogenous decision-making about capital investment based on demand to reproduce business cycles.

Moreover, the model must incorporate a certain level of synchronization in investment among agents because business cycles do not emerge when the investment is randomly conducted in time, as shown in Fig. 4.9. However, this synchronization in investment is automatically established in the case of demand-based decision-making for investment, as shown in Fig. 4.8.

Financing from the bank (i.e., loans) is another responsible factor for reproducing business cycles. As shown in Fig. 4.9, when investment is financed by issuing new shares in the stock market without borrowing from the bank, periodic changes in GDP (i.e., business cycles) do not emerge. The business cycles do not appear in the case of financing by the issuance of stock only because the funds financed by the issuance of stock are not required to pay back, and there is almost no specific restriction for conducting additional investment concerning funding. This result indicates that bank financing for investment where repayment is incorporated is indispensable for reproducing business cycles.

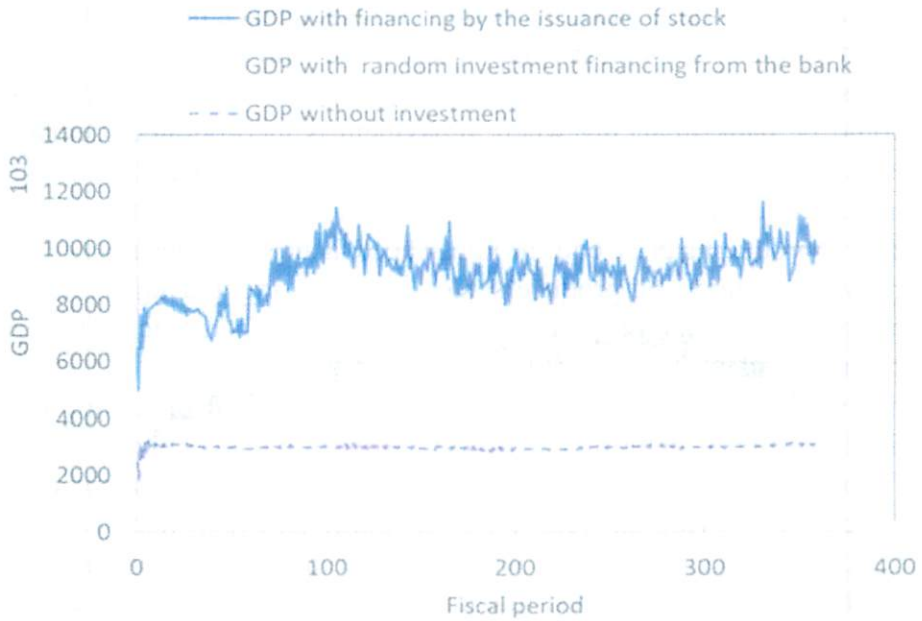

Fig. 4.9 Changes in GDP over time in the cases without investment, with random investment financed from the bank, and with demand-based investment financed by the issuance of stock

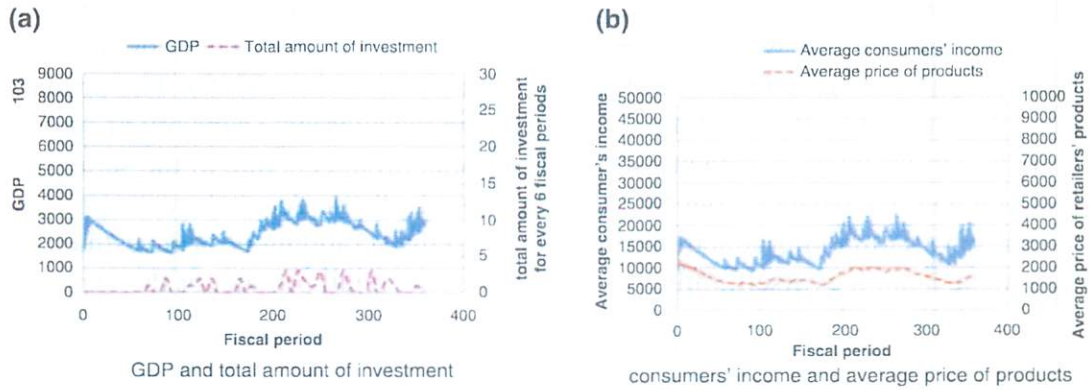

Fig. 4.10 Changes over time in GDP and the total amount of investment (**a**) and average consumers' income and the average price of retailers' products (**b**) in the case with demand-based investment financed only by internal funds

When only internal funds finance the investment, GDP shows slight cyclical variations, as shown in Fig. 4.10a (Ogibayashi and Takashima 2019). Moreover, this variation in GDP incorporates cyclical fluctuations in the average price of products (i.e., consumer price) and consumers' income, as shown in Fig. 4.10b (Ogibayashi and Takashima 2019). This result indicates that the variation in GDP shows a kind of business cycle caused by the requirement for the time interval for firms to raise funds for additional investment. However, financing by internal funds is not a major cause of business cycles because of the following facts, as shown in Fig. 4.10b, c. First, the amplitudes of the variations in GDP and consumers' income and the average price

of products are very small. Next, the period correspondence between GDP and the amount of investment is not clear compared to those with bank financing.

These results indicates that the indispensable factors for reproducing business cycles would be bank financing where repayment is incorporated, demand-based investment decision-making, and a certain level of synchronization among agents in investment. Here, the model must also include indispensable factors in the model structure for reproducing price equilibrium. Those factors are consumers' low price-oriented buying strategy and producers' stock-control-oriented adjustment strategy of the price and number of products, as well as the heterogeneity of agents' behavioral rules and attribute variables.

On the other hand, Keynes proposed that the marginal efficiency of capital (MEC) is the primary determinant of the business cycle (Keynes 1936). This, in turn, implies that the internal rate of return is the essential factor underlying business cycles. Following this reasoning, an additional experiment was conducted in which producers decide to invest when the internal rate of return is expected to be greater than the current interest rate and the funds for investment are assumed to be financed by internal funds only (i.e., without bank financing). Calculated chronological change in GDP and average price of products indicates that the cyclical variations, namely business cycles, do not emerge under this experimental condition, as shown in Fig. 4.11 (Ogibayashi and Takashima 2019). Not that the price of equipment as well as internal rate of return also does not show cyclical variations, as shown in Fig. 4.12 (Ogibayashi and Takashima 2019). The primary reason for this is that there is little to no change in the aggregate capacity of supply. Decreases in production capacity suffered by some producers due to the scrapping of equipment are balanced out by the surpluses of others. As such, without bank financing, variation in production capacity due to the scrapping of or investment in equipment cannot, by itself, influence the price of the retail product or the expected

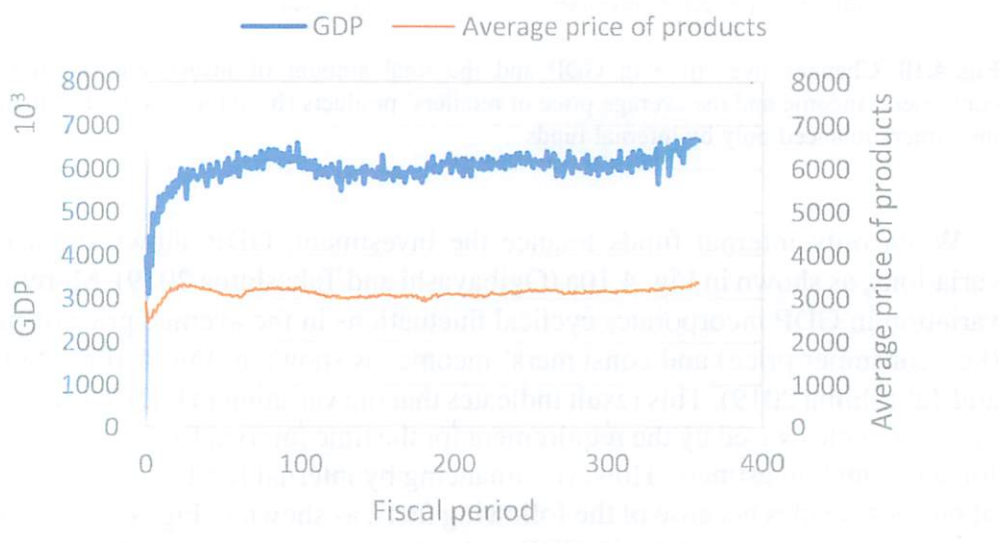

Fig. 4.11 Changes over time in GDP and the average price of products in the case with financing *by internal* funds only, where investment is judged based on the internal rate of return

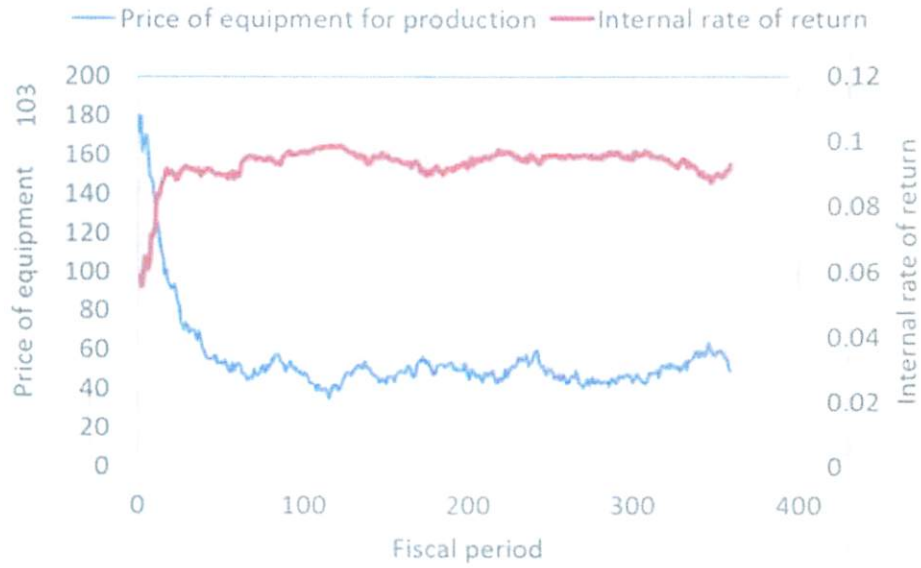

Fig. 4.12 Changes in the price of equipment and internal rate of return over time

return. Therefore, marginal efficiency of capital is not considered a major factor for generating business cycles when there is any degree of surplus in the aggregate production capacity.

Thus, the marginal efficiency of capital proposed by Keynes is not an indispensable factor for reproducing business cycles.

Therefore, as mentioned above, we can conclude that the indispensable factors for reproducing business cycles would be:

- Demand-based decision-making for investment
- Bank financing where repayment is incorporated
  (i.e., credit creation with some restriction)

Now, by considering the reason why these factors are indispensable for reproducing business cycles, we can get better understanding of the causal mechanism of the emergence of business cycles, which is considered as follows.

The bank financing for investment (i.e., credit creation) increases the funds circulating in the market, which increases someone's income and promotes the economy. In contrast, the repayment of funds forces the funds circulating in the market to flow back to the bank, which decreases the circulating funds, decreasing someone's income and deteriorating the economy. Thus, although investment could promote economy by increasing the productivity, the essential mechanism of the business cycles is the flow of funds between the bank and the market.

Note that the model structure required to reproduce business cycles mentioned above is enough to reproduce the positive correlation between GDP growth rate and the increasing rate of consumer price. As can be seen in Fig. 4.7a, b, cyclical changes in GDP incorporate the synchronized movements in the average price of consumer goods as well as the average consumer income. Figure 4.13a (Ogibayashi and

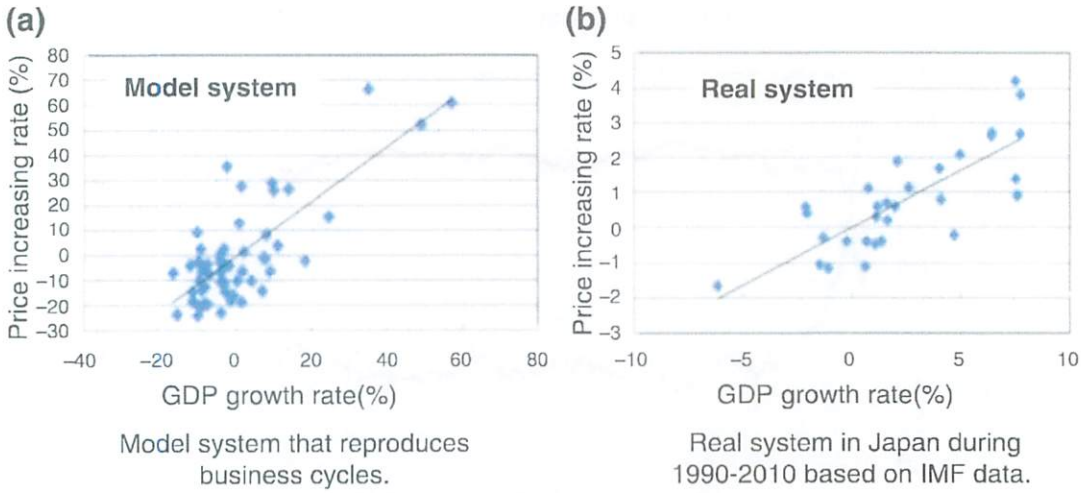

Fig. 4.13 Relationship between increasing rate of average price and GDP growth rate in the model system and the real system in Japan based on IMF data during 1990–2010. (**a**) Model system that reproduces business cycles. (**b**) Real system in Japan during 1990–2010 based on IMF data

Takashima 2013) shows the relationship between GDP growth rate and increasing rate of the average consumer price obtained in the calculation.

On the other hand, chronological data of GDP and consumer prices in G7 countries are available in IMF world economic outlook database (IMF 2010). Figure 4.13b shows the relationship between annual growth rate of GDP and increasing rate of consumer price in Japan during 1980−2010.

Note that the positive relationship between GDP growth rate and the increasing rate of consumer price obtained in the model is very similar with that of real data.

In general, the correlation between two factors observed in the real world does not always represent the real causal relationship, because of the possibility of spurious correlation. Even in the case of the correlation between the factor A and B, both of which is caused by the third factor C, it is almost impossible in the real world to elucidate what is the factor C that is the cause of A and B, because controlled experiment is almost impossible in the real world. However, in the case of ABM where we can conduct controlled experiment, it is possible to find out the causal factor. In the case of Fig. 4.7a, the causal factors of GDP growth and price-increasing rate is the flow of funds between the bank and the market, based on the mechanism mentioned above.

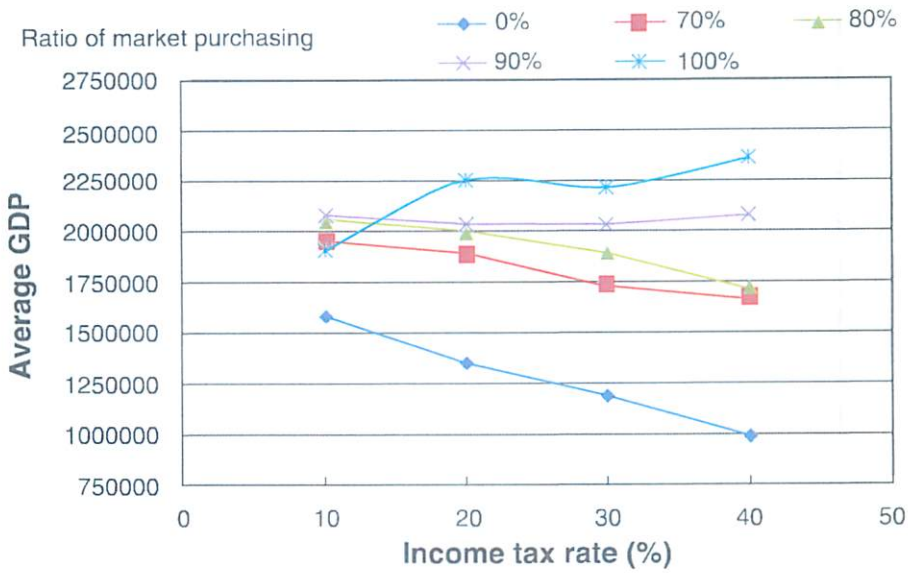

Fig. 4.14 Influence of the inefficiency of government expenditure on the relationship between GDP and income tax rate

4.4.4 The Necessary Model Structure for Reproducing the Positive Influence of an Income Tax Reduction on GDP

The influence of the income tax rate on GDP is analyzed for various ratio of market purchasing or the inefficiency of public expenditure. As the inefficiency of public expenditure is defined as the ratio of firm subsidy to the total public spending as explained in Sect. 4.2.3.4, the ratio of market purchasing is defined as one minus the inefficiency of public expenditure. The calculated relationship between the income tax rate and GDP is shown in Fig. 4.14 (Ogibayashi and Takashima 2013) for various market-purchasing ratios. Note that the negative correlation between the income tax rate and GDP is only reproduced when the market-purchasing ratio is less than 80%, i.e., the inefficiency is more than 20%. The critical market–purchasing ratio at which the correlation changes from positive to negative decreases with a decrease in the substantial marginal rate of consumption of consumers, which is dependent on the withdrawal ratio on bank deposits, decreases. Namely, the negative correlation between the income tax rate and GDP is more likely to occur when the market–purchasing ratio is small enough compared to the substantial marginal rate of consumption of consumers.

Thus, the indispensable factor to reproduce positive effect of income tax reduction is that the government expenditure includes any type of inefficient public spending.

From this result, the causal mechanism of positive effect of the tax cut in income tax is that the tax cut decreases the share of the funds of government and increases that of the consumer, thereby increases the funds spent in the market.

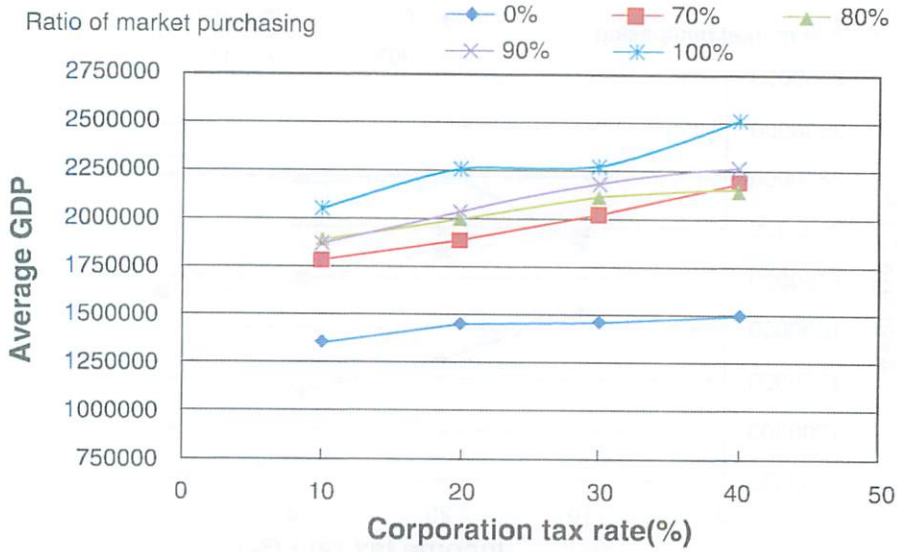

Fig. 4.15 Influence of the inefficiency of government expenditure on the relationship between GDP and corporate tax rate

4.4.5 Model Structure Necessary for Reproducing the Positive Influence of Corporate Tax Reduction on GDP

The influence of the corporate tax rate on GDP is also analyzed for various market purchasing ratios or public expenditure inefficiencies. In the case of corporate tax rate, the correlation between the corporate tax rate and GDP shows consistently positive for the market purchasing ratio from 0% to 100% as shown in Fig. 4.15 (Ogibayashi and Takashima 2013). This result implies that some additional factors are required in the model to reproduce the positive effect of corporate tax reduction.

The reason for the positive correlation shown in Fig. 4.15 is that some additional factors that are not taken into consideration in the base model decreases the efficiency of public expenditure and increases the efficiency of consumers' expenditure. The candidate of such factors might be the executive compensation, firms' investment, financing for investment including relevant restriction of credit creation, and labor market.

These include executive compensation, the use of internal funds for investment, and an increase in the upper limit of the number of loans (i.e., mitigation of credit rationing), and the effect of labor market.

Therefore, the effects of these factors are analyzed by changing the factors one by one.

Figure 4.16a, b (Ogibayashi and Takashima 2019) show the effect of executive compensation, the use of internal funds for investment, and bank financing on the relationship between corporate tax rate and GDP. Here, the upper limit of the number of loans is assumed to be 3, and the inefficiency of government expenditure is assumed to be 0.3. Figure 4.16 shows that the negative relationship between corporate tax and GDP occurs only when executive compensation, the use of internal

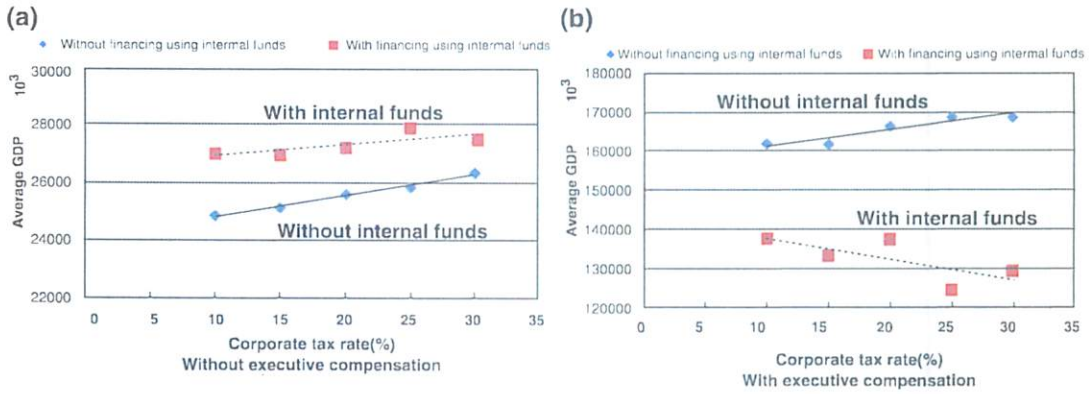

Fig. 4.16 Influence of the inclusion of internal funds rule and executive compensation rule on the relationship between the GDP and corporate tax rate, where assumed inefficiency of government expenditure is 0.3, and the upper limit of the number of loans is 3. (**a**) Without executive compensation. (**b**) Without executive compensation

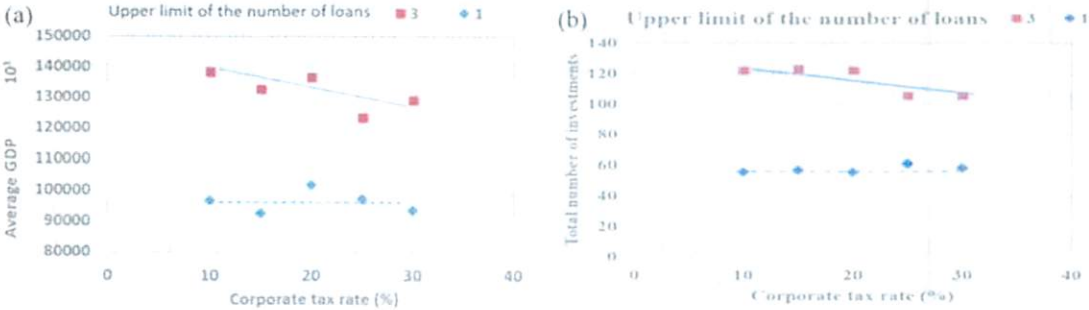

Fig. 4.17 Influence of the upper limit of the number of loans on the relationships between corporate tax rate and GDP (**a**) and total number of investment (**b**)

funds for investment, and the inefficiency of government expenditures are included in the model. An increase in the upper limit of the number of loans (i.e., mitigation of credit rationing) is another necessary condition to reproduce the positive effect of tax reduction.

Figure 4.17 (Ogibayashi and Takashima 2019) shows the influence of the upper limit of the number of loans on the relationships between corporate tax rate and GDP (see Fig. 4.17a) and the number of investments (see Fig. 4.17b) when both executive compensation and financing using internal funds are included in the model, and the inefficiency of government expenditure is assumed to be 0.3.

Note that both the average GDP and the number of investments both show negative correlation with the corporate tax rate only when the upper limit of the number of loans is large enough (i.e., the mitigation of credit rationing is applied). Thus, the mitigation of credit rationing is also one of the indispensable factors to reproduce the effect of corporate tax reduction.

In this study, the influence of the labor market is also analyzed. However, as shown in Fig. 4.18, the negative correlation between GDP and corporate tax rate is consistently reproduced regardless of the existence of labor market if the four factors

Fig. 4.18 Influence of the labor market on the relationship between corporate tax rate and GDP, under the condition that includes all four factors, namely, government inefficiency, executive compensation, the use of internal funds, and the mitigation of credit rationing (i.e., the upper limit of the number of loans is assumed to be 3)

mentioned above are included in the mode. Namely, the positive effect of corporate tax reduction is reproduced without depending on the inclusion of the labor market, if the four factors mentioned above are already included in the model. Thus, the inclusion of the labor market is not a required condition for reproducing the positive influence of corporate tax reduction, indicating that the unemployment rate which could vary due to the tax cut is not the causal factor for the positive influence of tax reduction.

In sum, it is concluded that four factors—the inefficiency of government expenditure, executive compensation, the use of internal funds for investment, and an increase in the upper limit of the number of loans (i.e., mitigation of credit rationing)—must be included in the model to reproduce the negative correlation between the corporate tax rate and GDP. If any one of these factors is not included, the positive effect of corporate tax reduction cannot be reproduced. In other words, among the 16 possible combinations that include or exclude each of these four factors, only one case in which all four factors are included successfully reproduced the positive effect of corporate tax reduction. Although we considered, before the experiment, that unemployment levels could affect the influence of tax reduction, the results show that the negative correlation between GDP and the corporate tax rate is consistently reproduced regardless of the existence of the labor market if the four factors mentioned above are included in the model, as shown in Fig. 4.18 (Ogibayashi and Takashima 2019), indicating that the inclusion of the labor market in the model is not an indispensable condition for reproducing the negative correlation.

Now, let us consider the reason why these four factors are necessary to reproduce the positive influence of corporate tax reduction. It is noted that two of the four

factors, namely the use of internal funds for investment and the mitigation of credit rationing are the factors that promote a firm's investment, which makes the firm's surplus money increased by the corporate tax reduction consumed in the market without being deposited in the bank. Executive compensation is another factor that promotes the firm's surplus money flowing out to the market. Funds that flow out from the bank to the market increase someone's income, increasing consumption, thus increasing GDP. The substantial marginal propensity to consume by the private sector is the ratio of the funds flowing out to the market (e.g., in the form of firms' investments as well as executives' consumptions) to the total amount of firms' surplus funds increased by the tax reduction.

The efficiency of government expenditure, on the other hand, is considered to be a substantial marginal propensity to consume by the public sector.

Therefore, the positive effect of corporate tax reduction is realized when the substantial marginal propensity to consume by the private sector (including both firms and consumers) is greater than that of the public sector. In addition, the four factors mentioned above are collectively required to reproduce the positive effect of corporate tax reduction, because the marginal propensity to consume in the private sector could be larger than that in the public sector only when all of four factors exist in both the model system and the real system.

These findings suggest the followings:

First, the corporate tax reduction increases GDP only when the government's effective marginal propensity to consume (expressed by the degree of efficiency [i.e., one-inefficiency] of government expenditure) is smaller than that of the aggregate private sector. Namely, corporate tax reductions increase GDP when producers' surplus money (increased by the tax reduction) can be spent effectively in the market, in the form of firms' investment and/or consumption by executives and workers. Conversely, the corporate tax reduction does not promote economy, if the firms are reluctant to invest to expand production capacity or to increase productivity.

Second, the inefficiency of government expenditure weakens the economy. In the model, the degree of inefficiency is defined as the ratio of firm subsidies to the total amount of public expenditure. In the actual system, the inefficiencies might be caused by many factors of wasteful expenditure, such as public orders with higher-than-market prices, subsidies to firms in the industry, or rent-seeking behavior (Tollison and Congleton 1995).

4.5 Discussions

4.5.1 The Validity of the Model in ABM

As described in the introduction, ABM has so far received little recognition as a promising methodology that is reliable to use for deciding public policy. Namely,

many researchers seem to consider that although ABM is effective in offering hints on the emergent mechanism of phenomena in the real world, it is not sufficiently reliable for elucidating the causal mechanism to replace the traditional approach of economics.

However, as many modelers have probably experienced, ABM emerges different macro phenomenon if the input condition of the model assumed is different. If the emerged phenomenon in ABM under a certain set of behavioral rules differs from that in the real world in its feature, modelers might change the input conditions until the model reproduces the features of a macro phenomenon in question. Namely, it is quite reasonable to consider that there must be a causal relationship between the input conditions of the model and the emergence of macrophenomenon if the model is entirely bottom-up where any aggregate variables and their relationships are not assumed.

Based on this idea, this chapter describes some examples that revealed the indispensable model structure to reproduce the macrophenomenon in question. The results of this study indicate that the necessary conditions exist for reproducing price equilibrium, the effect of supply chain, positive relationship between GDP growth rate and the increasing rate of consumer price, business cycles, and the positive effect of the reductions of income tax rate and corporate tax rate. Here, the necessary conditions are the sets of factors that characterize the model structure, which can be elucidated by running a series of computer experiments where each of the factors is changed one at a time. These factors are indispensable for the model to reproduce the desired phenomenon, meaning that the phenomenon under concern does not emerge in the artificial society if any one of these indispensable factors is not included in the model.

A typical example is the condition for reproducing the positive effect of corporate tax reduction. As the present research study revealed, four factors are required to reproduce the phenomenon because, among 16 possible combinations involving these four factors, only one case results in the emergence of the phenomenon, namely the case in which all four factors are included in the model.

Moreover, by considering why such factors are required to reproduce each phenomenon, as described, we can gain a better understanding of the causal mechanisms of these social phenomena. The causal mechanisms estimated based on the indispensable factors elucidated by the computer experiments are found to be quite reasonable. The reason for this is discussed below.

A system is a set of interacting objects and is defined as a proper relation on sets (Mesarovâic and Takahara 1989). Social system is an input-output system, where input consists of a set of causal factors and the output is a set of various social phenomena. Because any social phenomenon is considered to emerge from agents' actions and their interactions, the causal factors consist of the type of agents, the behavioral rules of each type of agent and the attribute variables that are included in the behavioral rules. The set of the factors characterizing the agents' actions and their interactions is the system structure, which is defined as a set of categories of agents, their behavioral rules, and relevant attributes variables. Those attribute variables that are responsible for the emergence of macrophenomenon are

included in the agent's behavioral rules. The attribute variables contain numerical values. Note that the numerical values of variables are not crucial for the qualitative reproducibility of the social phenomenon, because the emergence of the macro phenomenon is insensitive to the numerical values of the variables as Mark pointed out (Farmer and Foley 2009). Therefore, numerical vales of the attribute variables are only responsible for the quantitative reproduction of the social phenomenon. In contrast, the attribute variables for which numerical values are set to be more than a minimum value that guarantee the minimum level of the heterogeneity are responsible for the qualitative reproduction of the social phenomenon.

Therefore, it is quite reasonable to consider that, for each of the macrophenomenon, there must be a specific model structure that is responsible for the emergence of a particular macrophenomenon. Here, the model structure consists of a set of behavioral rules for each type of agent and the attribute variables.

In the case of an entirely bottom-up agent-based model, the validity of the model is assessed how close the model reproduces every feature of the phenomenon under concern. If the model reproduces the set of the features of the phenomenon, we can conclude that the indispensable factors in the model structure are the causal factors of the phenomenon. Then, by considering why those factors are required to reproduce the phenomenon, we can gain a better understanding of the underlying mechanisms of the social phenomenon.

This chapter describes the examples of this procedure. Based on those examples that elucidate the set of indispensable factors for reproducing the phenomenon and the estimated causal mechanism, above-mentioned principle in ABM is considered valid for various social phenomena.

Note that the model structure that can reproduce the desired macro phenomena could not be unique because there could be multiple causes. However, this does not undermine the validity of the model mentioned above. If different system structures cause the same phenomenon in the model, multiple causes exist even in the real system. Conversely, if we defined the features of the phenomenon in detail, the cause and the phenomenon could be a one-to-one correspondence. In any case, we can better understand the causal mechanisms of the social phenomena by piling up the knowledge on the indispensable system structure for each of the macro phenomena.

4.5.2 The Causal Mechanism of Business Cycles

According to the review presented by Onwumer et al. (2011) (Ormerod and Rosewell 2009), seven economists have so far proposed the causal mechanism of the business cycles, which are Veblen T.B., Marx K., Schumpeter, J.A., Friedman, M.F., Keynes, J.M., Minsky, H.P., Scherman H.J.

Among these economists, only Veblen and Minsky proposed credit creation as the factor responsible for the business cycles (Ormerod and Rosewell 2009). Namely, as the cause of business cycles, Veblen suggested the repetition of the over-expansion of credit and subsequent credit contraction, and Minsky proposed

the repetition of borrowing for investment and over-borrowing that collapse in investment. On the other hand, Keynes proposed the changes in the marginal efficiency of capital due to the expectations and price changes as the cause of business cycles (Ormerod and Rosewell 2009).

According to the present research, the essential mechanism of business cycles is the repetition of the borrowing from the bank and repayment to the bank accompanied by investment. The former causes the flow of funds from the bank to the market, thereby promoting the economy. While the latter causes the flow of funds from the market to the bank, thereby deteriorating the economy.

This mechanism is very close to the idea of Veblen and Minsky. But, in contrast, Keynes's idea of the marginal efficiency of capital is not the primary mechanism of the business cycles.

Thus, this result suggests that ABM can evaluate whether economic theories are true or not.

Therefore, ABM could be a promising methodology to elucidate the causal mechanism of various social problems to overcome them. Furthermore, it is expected that ABM could help the government design public policies based on the piled-up knowledge on the causal mechanism of the social issues, which could be a key process to establish a genuinely democratic society.

4.6 Conclusion

The indispensable conditions of the model structure for reproducing price equilibrium, the effect of the supply chain, business cycles, and the positive impact of income tax and corporate tax reductions are analyzed using an agent-based model.

In addition, based on the indispensable factors, the causal mechanisms of these phenomena are estimated, which are found to be quite reasonable.

The results are summarized as follows:

1. The factors indispensable to reproduce price equilibrium are consumers' low-price-oriented buying strategy and producers' stock-control-oriented adjusting strategy of the price and quantity of the products.
2. The factors indispensable to reproduce the business cycles are the bank financing (i.e., credit creation), where repayment is incorporated, producers' demand-based investment decision-making. This model structure also reproduces the positive correlation between GDP growth rate and increasing rate of consumer price.
3. The factors indispensable to reproduce positive effect of income tax is the inefficiency of government expenditure.
4. The factors indispensable to reproduce the positive effect of corporate tax reduction are the inefficiency of government expenditure, executive compensation, internal funds for investment, and an increase in the upper limit of the number of loans (i.e., mitigation of credit creation).

5. Based on these findings, this study proposed causal mechanisms of business cycles and the positive effect of tax reduction. Business cycles emerge due to the repetition of the flow of funds between bank and market. This flow is caused due to borrowing and repayment from and to the bank accompanied by investment. The positive effect of tax reduction emerges when the substantial marginal propensity to consume in the private sector is more significant than that in the public sector.
6. This study proposed new perspectives on the validity of ABM based on these findings, the essence of which is the following. In the case of an entirely bottom-up model in ABM, it is possible to identify the indispensable factors for qualitatively reproducing each macro phenomenon. Here, input factors of the model are expressed by the model structure defined by the agents' categories, behavioral rules, and relevant attributes variables. We can elucidate the necessary factors in the model structure by running a series of systematic computer experiments where the elements are changed one by one, with other factors being kept constant. By considering why such factors are required to reproduce the phenomenon, it is possible to better understand the causal mechanism of the phenomenon.

Acknowledgments The author would like to thank Dr. Kousei Takashima who is the coauthor of most of this research that are cited in the references.

Appendix: Overview, Design Concepts, and Details Protocol

This appendix describes the model in terms of the Overview, Design Concepts, and Details (ODD) protocol by Grim et al. (2006).

Purpose

The purpose of this model is to experimentally elucidate the underline mechanism of the complex macroeconomic phenomena. The model also aims to clarify the conditions under which the model structures reproduce these phenomena in an agent-based artificial economic system where macroeconomic indicators emerge as a result of agents' actions and interactions. In the present study, the purpose of this model focuses on elucidating the model structure to reproduce the positive influence of corporate tax reduction on GDP and to obtain a clearer understanding of the mechanism behind this effect.

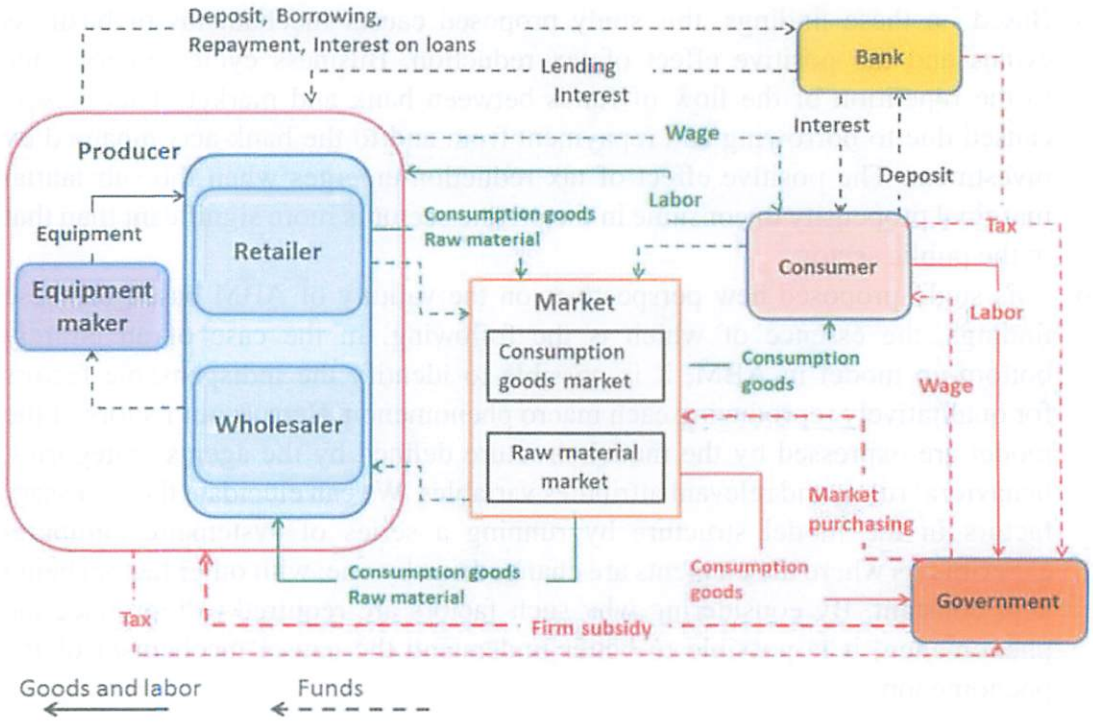

Fig. 4.19 Outline of the entities and their relationships

Entities, State Variables, and Scales

The entities included in this model are agents, goods, and markets, which are the minimum requirements of a macro economy of a nation. Agents include the following: consumers, comprising workers, and executives of private sector firms and public workers; producers, comprising retailers, raw-material makers, and an equipment maker; a bank; and a government. Goods include consumption goods for any agents, raw-material goods for retailers, and equipment as capital goods for retailers and raw-material makers. The market is divided into a consumption goods market and a raw-material goods market. We assume that capital goods transactions take place directly between equipment makers and buyers. Figure 4.19 shows the relationship between these entities, including the flows of goods, labor, and funds among the agents.

The entities included in this model and their characteristics are described in Table 4.4.

State variables are divided into those for agents and those for other entities. Each agent belongs to a different category, according to its behavior, such as agents in general, buyers, enterprises, and producers. State variables for agents are divided into those for an agent's behavioral category and those peculiar to each type of agent. State variables for each behavioral category are described in Table 4.5, and the state variables peculiar to each type of agent are described in Table 4.6. The state variables of other types of entities are described in Table 4.7.

Table 4.4 Entities included in the model and their characteristics

Entities	Descriptions
Agent	Characterized by agent id, agent type, cash it holds, deposit it holds, common behavioral rules as a buyer, a seller, and an enterprise
Consumer	Works for one of other agents, get wages, pay income tax, and purchase consumption goods
Retailer producer	Produces consumption goods, ships them to the market, employs workers, pays wages and corporate tax. It also buys consumption goods
Raw material maker	Produces raw material goods, ships them to the market, employs workers, pays wages and corporate tax. It also buys consumption goods
Equipment maker	Produces equipment based on the orders from retailers and raw material makers, employs workers, pays wages and corporate tax
Government	Collects tax from other agents, employs public workers, pays wages, and supplies subsidies to the firms as public expenditure
Bank	Keeps deposits from consumers and firms, finances funds for investment
Goods	Characterized by 12 types of product classes, price, seller's id, and buyer's id. There are no behavioral rules for goods
Consumption goods	Produced and supplied to the market by retailers, bought by several types of buyers
Raw material goods	Produced and supplied to the market by raw material makers, bought only by retailers. One-to-one correspondence is assumed between raw material goods and consumption goods, representing the smallest supply chain
Equipment	Produced by an equipment maker according to the requirement for investments from retailers and raw material makers
Market	Characterized by a set of goods objects. Goods remained unsold at a time period are recognized by the corresponding seller agents at the beginning of next period as goods in unsold stock
Consumption goods market	Consumption goods are supplied by retailers and bought by buyers, including consumers, retailers, raw material makers, and the government. An event of buying one of the goods is synchronously recognized by a corresponding seller agent, resulting in the payment by a buyer
Raw material goods market	Raw material goods are supplied by raw material makers and bought by only retailers. Transactions are conducted with the same algorithm as in the case of consumption goods

Table 4.5 State variables for agents' behavioral category

		Characteristics of state variable			
Category of entity	State variable	Initial setting	Difference among agents	Change in time step	Description
Agent in general	*Agent id*	Sequential	Different	Invariable	Identification number of agents
	Agent type id	Specified	Same or different	Invariable	Specified number of agent type for consumers, retailers, raw material makers, an equipment maker, a bank and the government
	Cash	At random	Different	Variable	Cash possessed by an agent, which varies each time step
	Deposit	At random	Different	Variable	Deposit possessed by an agent in the bank, which varies each time step
Buyers	*Weight of utility for each product class*	At random	Different	Invariable	The weight of utility for each product class of goods to purchase, initially assigned at random between 0 and 1 for each agent. Non-zero value is assigned for all of the product classes in case of government and for 2 classes in case of other agent types of buyers
	The number of goods purchased	–	Different	Variable	The number of goods purchased for each product class, which is reset at the beginning of each time step
	Exponent in utility function	At random	Different	Invariable	The exponent of the number of goods to purchase in utility function
Enterprises	*Number of employees*	At random or specified	Different	Variable or invariable	The number of agents working in an enterprise including workers and an executive
	Agent_id of an executive	At random	Different	Invariable	The agent id of the consumer specified as an executive
	Agent_id of workers	At random	Different	Variable	The agent id of the consumer specified as a worker

Enterprises (Continued)	*Fixed wages*	At random	Different	Invariable	The amount of fixed wages to be paid to each employee including an executive
	Bonus ratio	Specified	Same	Invariable	The ratio of bonus to be paid for workers with respect to before-tax profit
	Executive compensation ratio	Specified	Same	Invariable	The ratio of executive compensation paid to the executive with respect to after-tax profit. In this study, executive compensation is assumed to be an extra bonus paid to an executive, which is defined as the executive compensation ration multiplied by after-tax profit of the enterprise
Producers	*Product class id*	At random	Different	Variable	The class id of product to produce
	A list of goods in the market	–	Different	Variable	A list of the objects of the producer's supplied goods in the market. At the beginning of each period, it shows a list of unsold stocks in the market. During each period, it increases with an increment number of produced goods and decreases with an increment number of goods sold during the period
	Dismissal flag	–	Different	Variable	The flag number for decision-making of the dismissal of a worker. When the profit is negative or positive at a certain period, the dismissal flag is increased or decreased by 1. When the dismissal flag reaches a critical flag number of dismissal, the producer fires one employee who is selected at random
	Quit-production flag	–	Different	Variable	The flag number for decision-making regarding production stoppage. When the products of a specific class are all remain unsold at a period, the quit-production flag is increased by 1. When it is not, it is decreased by 1. When it reaches a critical flag number to quit production, the producer stops its production

Table 4.6 State variables peculiar to each type of agent

Entity	State variable	Characteristics of state variable			Description
		Initial setting	Difference among agents	Change in time step	
Consumer	*Working place*	At random	Different	Variable	The agent id of the enterprise or government the consumer works for
	Marginal propensity to consume	Specified	Same	Invariable	The proportionality constant of disposable income after tax for the budget for purchasing consumption goods
	Basing consumption	Specified	Same	Invariable	The minimum budget for purchasing consumption goods when withdrawal of deposit is assumed to be zero
	Withdrawal ratio	At random	Different	Variable	The ratio of money withdrawn from the deposit to purchase consumption goods. It is randomly assigned for each agent at every period during the simulation
Retailer and raw material maker	*Purchasing ratio*	Specified	Same	Invariable	Percentage of accumulated profit for buying consumption goods. The budget for consumption is determined as the purchasing ratio multiplied by accumulated profit
	Proportionality constant of production function	At random	Different	Invariable	The proportionality of cobb Douglas's production function, which represents the total factor productivity of each producer
	Investment flag	–	Different	Variable	The flag number for deciding investment. It increases or decreases by one depending on the producer's own unsold stock in the market
	Upper limit of the number of loans	Specified	Same	Invariable	The upper limit for the number of issuance of long-term loans at a time, the funds of which are required for investment and financed by the bank. They cannot invest in equipment when their number of loans has already reached this value

Equipment maker	*Price of equipment*	Specified	–	Invariable	The price of one unit of equipment
	Maximum number of production per each period	Specified	–	Invariable	The upper limit of production per period. When it receives orders more than this value, it does not meet the requirement of producers and rejects the order
Bank	*Repayment period*	Specified	–	Invariable	Repayment period of long-term loan
	Interest rate on loans	Specified	–	Invariable	Lending interest rate on loans for producer's investment
	Interest rate on deposits	Specified	–	Invariable	Interest rate on deposits of producer and consumer
Government	*Income tax rate*	Specified	–	Invariable	Income tax rate levied on consumer's income
	Corporate tax rate	Specified	–	Invariable	Corporate tax rate levied on producer's profits
	Salary for public workers	–	–	Variable	Salary for a worker who works for government, which is determined as the average of wages per capita including bonus in the private sector
	Ratio of market purchasing	Specified	–	Invariable	Ratio of the budget for purchasing goods in the market to the total public expenditure
	Ratio of firm subsidy	Specified	–	Invariable	Ratio of the budget for subsidizing firms with no limitation of its use to the total public expenditure

Table 4.7 State variables of other types of entities

		Characteristics of state variable		
Entity	State variable	Initial setting at creation	Change in time step	Description
Consumption goods	*Product class number*	Specified by the producer	Invariable	The id number of product class determined by the producer
	Price	Specified by the producer	Variable	The price of the product determined by the producer at every period
	Seller's number	Specified by the producer	Invariable	The agent id number of the producer who produced the product
	Buyer's number	Specified by the buyer when being purchased	Invariable	The agent id number of the agent who bought the product. It is determined when it was bought
Material goods	*Product class number*	Specified by the producer	Invariable	The id number of product class determined by the producer
	Price	Specified by the producer	Variable	The price of the product determined by the producer at every period
	Seller's number	Specified by the producer	Invariable	The agent id number of the producer who produced the product
	Buyer's number	Specified by the buyer when being purchased	Invariable	The agent id number of the agent who bought the product. It is determined when it was bought
Market	*A list of consumption goods*	–	Variable	A list of consumption goods currently available in the market
	A list of material goods	–	Variable	A list of material goods currently available in the market

Tables 4.5, 4.6, and 4.7 present the characteristics of the state variables: the initial settings, differences among agents, and how values change with a change in time step. The initial settings are the values assigned to the state variables of the objects when the objects are created. The difference among agents shows whether the values are the same or different among the agents. The change in time step indicates whether the values are time dependent.

Process Overview and Scheduling

The present model consists of three submodels: a fund circulation submodel, a price equilibrium submodel, and an investment submodel. The fund circulation submodel constitutes the fundamental structure of the model in which the latter two submodels are implemented. The model consists of three processes: initialization, where the objects of the entities are created and initialized; the sequence of seven actions performed by agents during each time step; and the calculation of the average GDP and other statistical data of macroeconomic indicators. The seven steps comprise the actions at the beginning of every time step, the production of raw materials, the production of consumption goods, purchasing of consumption goods, payment of wages, actions for investment, and the actions at the end of every time step. The pseudocode that describes this process is given in Fig. 4.20, and the sequential events conducted by each type of entity during each time step are described in Fig. 4.21.

Design Concepts

Basic Principles

The general concept underlying the model design of ABM is that the behavior of an artificial economic system can mimic the real-world behavior if the model structure and the structure of the real systems have a homomorphic relationship. This relationship is considered to be fulfilled when the structural factors of the modeled system are essentially the same as those of the real system with respect to the relevant macroscopic economic phenomenon. Therefore, ABM can be useful in describing the mechanism of a macroeconomic phenomenon by performing controlled experiments in which only one factor of interest varies at a time, while holding other factors constant. In this way, ABM clarifies the structural conditions necessary for the model to reproduce the macroeconomic phenomenon being studied.

```
for period=0 to period bound
  if period=0 then
    Initialize agents, set parameters, set initial conditions.
    Agents do actions in the similar way as period>0 with some exceptions.
  else
    1. Agents pay unpaid tax for the previous period, make a budget plan for expenditures.
    2. Raw material makers decide the amount and price of products.
       They produce raw materials of several types, supply them to the market.
    3. Retailers decide the amount and price of products, purchase raw materials.
       They produce products of several types, supply them to the market.
    4. Agents except for the equipment maker and the bank purchase products in the market.
    5. Retailers and raw material makers judge the necessity of investment on the basis of
       total sales in the previous periods. If necessary, they invest in equipment.
    6. Each firm pays wages and executive compensation for workers and the executive.
       Government pays wages for public workers.
    7. Each agent settles its accounts, calculating income or profit for the current term,
       based on which the amount of tax to be paid is determined.
    If necessary, each retailer dismisses a worker on the basis of profits for previous periods
       or decides to stop production of a certain type of products on the basis of its total sales.
  Calculate GDP and input-output table by summing the accounts data of all agents.
end for
Calculate average GDP for all periods.
```

Fig. 4.20 Pseudocode of the model

	Sequential events of each type of agent during a fiscal period						
	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
	Start of processing	Material goods production	Consumption goods purchasing	Consumption goods purchasing	Wage receiving or paying	Investment	End of processing
Consumer	Tax payment, Budget planning			Consumption goods purchasing	Wage receiving		Settlement of accounts
Raw material maker	Tax payment, Budget planning	Production	Sales receiving	Consumption goods purchasing	Wage paying	Investment & financing	Settlement of accounts
Retailer	Tax payment, Budget planning		Material purchasing, production	Sales receiving	Wage paying	Investment & financing	Settlement of accounts
Equipment maker	Tax payment, Budget planning				Wage paying	Equipment production & selling	Settlement of accounts
Bank	Tax payment, Budget planning				Wage paying	Funds lending	Settlement of accounts
Government	Tax collection, Budget planning			Consumption goods purchasing	Wage paying		Settlement of accounts

Fig. 4.21 The sequential events in each time step for each type of entity

Emergence

The modeled artificial systems should include heterogeneous and autonomous agents. Their behavioral rules might be similar, but the values of their state variables should be different. Therefore, the heterogeneous agents behave differently and interact with each other. Macroscopic phenomena emerge from these actions and interactions, which affect the microscopic behavior of the agents, resulting in a micro–macro link in the dynamics of the systems. In this way, artificial economic systems can behave as complex systems.

Adaptation

Retailers and raw-material makers adjust the price and number of products they supply to the market by gauging the demand in the market. To do so, they observe the number of stock items that remain unsold at the end of each time step. These producers also use the market demand to adjust their production capacity and number of employees. In this way, the artificial economic systems in this study possess an internal adaptation mechanism.

Objectives

Consumers and producers hold their own objective functions, such as maximizing utility or profits.

Prediction

Retailers and raw-material makers predict the total sales of their goods based on the sales figures from the ten most recent periods. Based on this prediction, they decide on the amount of production in the next time step so that the probability of goods being out of stock is less than 5%. When they decide to invest in equipment, they first predict the financial benefit of the investment by estimating the increase in profit gained from a one-unit increase of equipment and the subsequent increase in production capacity.

Sensing

Retailers and raw-material makers gauge the market demand by observing the amount of goods still in stock at the end of each time step. They also calculate the optimal number of employees based on the profit of the current term, as well as the potential financial benefit of increasing or decreasing the number of employees and, therefore, their production capacity.

Interaction

The price equilibrium is loosely attained by the interaction between agents' purchasing actions and producers' actions when adjusting their production levels and product prices. In addition, the circulation of funds and the emergence of various macroeconomic indicators, such as GDP, are the result of the actions of agents and their interactions. The investment behavior is also a result of the interaction between buyers and producers.

Stochasticity

Various state variables are randomly defined at the start of the simulation or during the simulation. Typical examples are agents' initial funds, state variables that distinguish agents (e.g., product classes), production capacities, utility weights, and a consumer's workplace. These are defined using random numbers with a uniform distribution.

The order of agents' actions for the same type of agent is also defined by shuffling the set of agent id numbers using a uniform random number at every time step.

Observation

At the end of each time step, each agent settles its account using the double-entry bookkeeping method. An input-output table for the artificial system is defined by summing the calculated data for all agents. The macroeconomic indicators, such as GDP, tax revenue, total funds for each type of agent, total salaries paid by producers, and the total number of investments, are calculated based on the input-output table and other account data of the agents. In addition, statistical data, such as the total number of goods produced or bought during each time step, the average price of products, and the amount of funds circulated between the bank and other types of agents, are also calculated at the end of each time step. The average values of these data for the overall simulation can also be obtained and used for various types of analysis.

Initialization

All state variables of the agents are initialized when the agent objects are created. These initial values are described in Tables 4.8 and 4.9. An agent id is sequentially assigned for each agent, but this number is only used to distinguish agents. Each agent object is initially assigned randomly to one of the types of agents. Public employee's salaries are calculated in each fiscal period so that they are equal to the average income of private employees.

Table 4.8 Initialization of state variables for agent's behavioral category

Category of entity	State variable	Descriptions	Initialization
Agents in general	*Agent id*		Sequentially assigned
	Agent type id		Randomly assigned
	Cash	– Consumer	30,000–50,000
		– Retailer and raw material maker	80,000–160,000
		– Equipment maker	200,000–220,000
		– Bank	96,000,000–104,000,000
		– Government	10,000
	Deposit		0
Buyers	*Weight of utility for each product class*	– Consumer	0–1
		– Producer and government	0
	Exponent in utility function		–2
Enterprises	*Number of employee*	– Retailer	4–5 at random
		– Raw material maker	3
		– Equipment maker	2
		– Bank	1
	Fixed wages		7000–7500
	Bonus ratio		75%
	Executive compensation ratio		95%
Producers	*Product class id*		2 classes are randomly assigned for each agent between 1 and 6 at the start of simulation
	Dismissal flag	Dismissal flag	0
		Critical flag number for dismissal	5
	Quit-production flag	Quit-production flag	0
		Critical flag number to quit production	20

Table 4.9 Initialization of state variables peculiar to each type of agents

Entity	State variable	Descriptions	Initialization
Consumer	*Working place*		Randomly specified
	Marginal propensity to consume		70%
	Basic consumption		3000
	Withdrawal ratio		0–50%
Retailer and raw material maker	*Purchasing ratio*		70%
	Proportionality constant of production function	– Retailer	8–10
		– Raw material maker	50–150
	Investment flag	– Investment flag	0
		– Critical number for investment	20
	Upper limit of the number of loans		3
Equipment maker	*Price of equipment*		500,000
	Limit number of production per each period		4
Bank	*Repayment period*		120
	Interest rate on loans		3%
	Interest rate on deposits		0.50%
Government	*Income tax rate*		20% (standard)
	Corporate tax rate		20% (standard)
	Salary for public workers		Unspecified
	Ratio of market purchasing		60% (standard)
	Ratio of firm subsidy		40% (standard)

Input Data

No data from the real system is used as input data for the simulation.

Submodels

Funds Circulation Submodel

This submodel constitutes the fundamental structure of the model, the outline of which is described in the pseudocode presented in Fig. 4.20. The basic principles of the circulation of funds and additional behavioral rules are presented below.

Basic Principles of Fund Circulation

Consumers work for one of the other agents, receive wages, buy consumption goods produced by retailers, and pay income tax to the government. Retailers produce consumption goods using raw material goods supplied by raw-material makers, where minimum units of supply chain processes are implemented in the model. The behavioral rules for the strategies of consumer purchasing and producers' production are described in the price-equilibrium submodel. Retailers and raw-material makers invest in equipment when doing so will increase their profit. The investment strategies are described in investment submodel.

The government levies income tax and corporation tax, pays wages to public employees, and conducts public expenditure, comprising market purchasing as an extreme case of efficient public spending and firm subsidies as an extreme case of inefficient public spending.

In this way, funds circulate among agents in the artificial economic systems as a result of agents' actions and interactions.

Related Behavioral Rules

1. *Agents' behavioral rules for determining their consumption budget.*

   Every agent, other than the bank, determines a consumption budget at the beginning of each time step. The definitions of the budget are different each type of agent.

   For the consumer agent:

$$E_b^t = a + bI^t + r_{\mathrm{wd}}^t D^t$$

where $E_b{}^t$: Consumer's consumption budget; a: Basic consumption; b: Marginal propensity to consume; I^t: after-tax income; r_{wd}: Withdrawal ratio; D^t: Bank deposit.

For the producer agent: Purchasing ratio multiplied by the amount of internal funds.

For the government agent:

$$E_b^t = E_{\text{all\_}b}^t - \text{wage}_G^t$$

where E_b^t: Total public expenditure budget; $E_{\text{all\_}b}^t$: Total amount of tax revenue; wage_G^t: Total salaries paid to public employees.

The budgets for market purchasing and for firm subsidies are defined as the ratio of the respective amount of public expenditure to the total budget.

2. *Payment of salaries.*

2-1 Salaries paid by enterprises.

Each enterprise agent pays a fixed salary, a bonus, and executive compensation.

The total amount paid as salaries depends on both the before-tax profit and accumulated profit, as given below:

$$E_w^t = \begin{cases} W_f & \text{if} \quad \pi^{t-1} < 0 \\ W_f + W_b^{t-1} & \text{if} \quad \pi^{t-1} > 0 \text{ and } \text{AC} < 0 \\ W_f + W_b^{t-1} + \text{EC}^{t-1} & \text{if} \quad \pi^{t-1} > 0 \text{ and } \text{AC} > 0 \end{cases}$$

where $E^t{}_w$: Total salary amount; W_f: Fixed salary; W_b: Bonus; EC: Executive compensation; AC: Accumulated profits.

The total amount of salaries paid to workers or to executives is given below.

$$W_C^t = W_f + W_b^{t-1}/\text{ne} \text{ for workers}$$

$$W_C^t = W_f + W_b^{t-1}/\text{ne} + \text{EC}^{t-1} \text{ for executives}$$

where $W^t{}_C$: Total salaries paid to workers or to executives; ne: The number of employees.

2-2 Salaries paid by the government

The government pays fixed salaries to public workers based on the previously determined budget for wages.

3. *Agents' behavioral rules for settling accounts at the end of each time step*

3-1 The rules for consumers

Consumers define the amount of income tax to be paid based on their income and remember this as the amount of unpaid tax:

$$\mathrm{Tax}_i = W_C^t \, r_{i\_\mathrm{tax}}$$

where Tax_i: The amount of income tax; r_{i_tax}: The income tax rate.

A part of consumers' income, including unpaid tax, is kept on hand as cash and deposited in the bank, as given below:

$$\mathrm{deposit} = (1-b)\left(W_C^t\left(1 - r_{i\_\mathrm{tax}}\right)\right) - a$$

3-2 The rules for producers

Producers define their profit based on total sales and total expenses:

$$\mathrm{Pr}_p^t = S^t - \left(W_f + \sum \mathrm{co}^t + \mathrm{int}^t + \mathrm{dep}^t\right)$$

where Pr_p: The profit before bonus; S: Total sales; Σco: Total expenses for raw materials; int: Interest to be paid; dep: Depreciation expenses.

Producers define the amount to be paid as bonuses to employees based on the profit before bonuses, as given below. They remember this as the amount of unpaid bonuses:

$$W_b^t = \mathrm{Pr}_p^t r_{\mathrm{bonus}}$$

where r_{bonus}: The ratio of bonus.

Based on this value, they define their before-tax profit as given below:

$$\mathrm{Pr}_{a\_\mathrm{tax}}^t = \mathrm{Pr}_p^t \, (1 - r_{\mathrm{bonus}})$$

where $\mathrm{Pr}^t{}_{a\_\mathrm{tax}}$: The before-tax profit.

Then, they calculate the amount of corporation tax to be paid and remember this as the amount of unpaid tax:

$$\mathrm{Tax}_c = \mathrm{Pr}_p^t \, (1 - r_{\mathrm{bonus}}) \, r_{c\_\mathrm{tax}}$$

where Tax_c: The amount of corporation tax; r_{c_tax}: The rate of corporation tax.

Based on this value, they define their after-tax profit and executive compensation, and remember this as unpaid executive compensation:

$$\mathrm{EC}^t = \mathrm{Pr}_p^t \, (1 - r_{\mathrm{bonus}}) \left(1 - r_{c\_\mathrm{tax}}\right) r_{\mathrm{exec}}$$

where r_{ecex}: The ratio of executive compensation.

Extracting the executive compensation from their after-tax profit enables producers to define their accumulated profit, as given below:

$$\text{Ac}^t = \text{Ac}^{t-1} + \text{Pr}_p^t \, (1 - r_{\text{bonus}}) \left(1 - r_{c\_\text{tax}}\right) (1 - r_{\text{ecex}})$$

3-3 The rules for the government.

The government defines the total amount of tax revenue and expenses, and passes the resultant money on to the next period.

4. *Others*

4-1 The rules for dismissal

At the end of each time step, the retailer fires one of its employees if its dismissal flag reaches a critical value. The employee to be fired is selected at random and is assigned to the producer with the largest accumulated profit.

4-2 The rules for stopping production and for bankruptcy

At the end of each time step, the producer stops production of a certain class of product if its flag reaches a critical value. When a producer stops all its product classes, it then goes bankrupt, and a new producer object is created with new initial variables.

Price Equilibrium Submodel

The present model mimics the price equilibrium in the market according to the following two principles.

Lowest-Price-Oriented Purchasing Strategy by Buyers

All buyers purchase consumption goods within the limits of their consumption budget. If there are products within the same product class, but with different prices, they will select the cheapest of them. The consumption goods bought are indexed by buyer's id and are removed from the market and moved to the buyer.

In addition, consumers purchase products to maximize their utility within the limit of their consumption budget.

$$\max u = \sum_i w_i x_i^{\alpha} \quad \text{s.t.} \sum_i p_i^t x_i \leq E_b^t$$

where w_i: The weight of utility for each product of class i; x_i: The number of products to purchase; p_i: The price of a product; α: An exponent of x_i.

Stock-Control-Oriented Production Strategy by Sellers

1. The behavioral rules used by producers to determine the price of their products.
   The price of a product is defined according to the number of products in stock and the amount bought in the market.

$$p^t{}_i = \begin{cases} (1+\gamma_i)\, p^{t-1}{}_i & \text{if} \quad s_i^{t-1} = 0 \\ (1-\gamma_d)\, p^{t-1}{}_i & \text{if} \quad s_i^{t-1} > 0 \text{ and } p^{t-1}{}_i < p_{\text{avei}}^{t-1} \end{cases}$$

   where γ_i: The ratio of a price increasing; γ_d: The ratio of a price decreasing; $s^{t-1}{}_i$: The amount of goods in stock at the end of previous period; $p^{t-1}{}_{\text{avei}}$: The average price of goods bought in the market in the previous period.
2. The strategy for amount to be produced (the production plan).
   (a) The number of products to be produced in a given period is defined so that the probability of goods being out of stock is 5%:

$$q_{si}^t = q_{\mu i}^t + 1.65 q_{\sigma i}^t$$

   where $q^t{}_{si}$: Target number of goods in stock; $q^t{}_{\mu i}$: Average sales during the past ten periods; $q^t{}_{\sigma i}$: Sigma of total sales during the past ten periods
   (b) Producers decide on the number of products to produce according to the number of products in stock, adjusting their target as shown below.

$$q^t{}_i = \begin{cases} q_{si}^t\,(1+\varepsilon) & \text{if} \quad s_i^{t-1} = 0 \\ q_{si}^t\,(1-\varepsilon) - s_i^{t-1} & \text{if} \quad s_i^{t-1} > 0 \end{cases}$$
$$\text{If } q^t{}_i > Y_i\,(K, L) \quad q^t{}_i = Y_i\,(K, L)$$

   where $q^t{}_i$: The amount of production; ε: The ratio of changing amount of production; $Y_i(K, L) = A_i K^{\alpha} L^{1-\alpha}$: Production capacity; K: The number of units of equipment for production; L: The number of employees; A: A proportionality constant.

Investment Submodel

Producers' Behavioral Rules for Investment Decisions

The retailer or raw-material maker decides to invest when the three conditions listed below are fulfilled. Once the agent decides to invest, it becomes a candidate for investment and is included in the list of candidates owned by an equipment maker.
Conditions for investment:

1. The investment flag number exceeds a critical value for investment.

2. The financial benefit from an increase in one unit of equipment is positive, as given below.

$$\Delta\pi_K = \max_i \left[\left(p_i^t - c_i^t \right) \{ Y_i (K+1, L) - Y_i (K, L) \} - (r_0 + 1/N) F \right] > 0$$

where p_i: The price of goods of product of class i; c: The variable cost per unit product; r_0: The borrowing interest rate; F: The borrowed money required to buy one unit of equipment; N: The repayment period.

3. The accumulated profit at the end of current term is greater than half the necessary funds for investment.

The Behavioral Rules for Equipment Makers

The equipment makers randomly select one of the candidates for investment and sell that agent a unit of equipment. If there is more than one candidate, the equipment maker continues to produce and sell until the number of equipment units reaches the equipment maker's production capacity.

Producers' Behavioral Rules for Financing and Buying Equipment

The selected retailer or raw-material maker purchases one unit of equipment. Before purchasing, the agent finances half the necessary funds using internal funds from accumulated profits and the other half from the bank. After purchasing, the retailer or raw-material maker renews its production capacity by increasing the number of units of equipment by one in the Cobb–Douglas-type equation.

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