

System Structure of Agent-Based Model Responsible for Reproducing Business Cycles and the Effect of Tax Reduction on GDP

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ABSTRACT

Validation is an important issue in the agent-based modelling (ABM) approach. It has been argued in the literature that deriving the necessary conditions for reproducing specific macro behavior is difficult due to the functional complexity of the models. However, based on our experience in ABM, we believe it is possible to define the necessary conditions for reproducing each macro behavior if we use the structure of the system to express the input conditions. Conducting a series of computer experiments to verify this idea, the present study analyzes business cycles and the effect of tax reductions on gross domestic product (GDP) as examples of fundamental macro behaviors of economic systems. The results indicate that the essential model structures for reproducing business cycles and the effects of tax reduction are the inclusions of credit creation for investment and factors relating to the inefficiency of the government's, household's, and firms' expenditures.

Keywords: agent-based modeling; model structure; business cycle; tax reduction; inefficiency of government expenditure; validity of model

Estructura del sistema del modelo basado en el agente responsable de reproducir los ciclos económicos y el efecto de la reducción de impuestos sobre el PIB

RESUMEN

La validación ha sido un tema importante en el enfoque de modelado basado en agentes (ABM). Se ha argumentado en la literatura que derivar las condiciones necesarias para reproducir un comportamiento macro específico es difícil debido a la complejidad funcional de los modelos. Sin embargo, según nuestra experiencia en ABM, creemos que es posible definir las condiciones necesarias para reproducir cada comportamiento macro si utilizamos la estructura del sistema para expresar las condiciones de entrada. Realizando una serie de experimentos informáticos para verificar esta idea, el presente estudio analiza los ciclos económicos y el efecto de las reducciones de impuestos sobre el producto interno bruto (PIB) como ejemplos de comportamientos macro fundamentales de los sistemas económicos. Los resultados indican que las estructuras modelo esenciales para reproducir los ciclos económicos y los efectos de la reducción de impuestos son las inclusiones de la creación de crédito para la inversión y los factores relacionados con la ineficiencia de los gastos del gobierno, los hogares y las empresas, respectivamente.

Palabras clave: modelado basado en agentes; estructura modelo; ciclo comercial; reducción de impuestos; ineficiencia del gasto público; validez del modelo

基于agent建模的系统架构：复制商业周期和减税对GDP产生的效果

摘要

有效性一直是基于agent的建模（ABM）方法中的重要议题。相关文献中曾探讨过：鉴于模型的功能复杂性，获取“复制特定宏观行为”的必要条件并不简单。然而，基于我们对ABM的研究经历，我们相信，如果使用系统架构来表达输入

条件，那么“复制每种宏观行为”的必要条件是有可能被定义的。通过一系列计算机实验来验证该想法，本研究分析了商业周期、和减税对国内生产总值（GDP）产生的效果，将二者作为经济体系的重要宏观行为实例。研究表明，复制商业周期和减税效果，必需的模型架构包括投资信用产生、和分别与政府开支低效、家庭开支低效、企业开支低效有关的各因素。

关键词：基于agent建模；模型架构；商业周期；减税；低效政府开支；模型有效性

1. Introduction

Agent-based modeling (ABM) is a bottom-up modeling method in which we view artificial, computer-generated societies as laboratories where we attempt to grow specific social structures (Epstein & Axtell, 1996). The purpose of these models is to discover the fundamental local or micro-mechanisms that generate macroscopic social structures and collective behaviors (Epstein & Axtell, 1996). Although ABM is a promising methodology that can deal with heterogeneity, individual agents' bounded rationality, and non-equilibrium dynamics in social systems, validation still proves to be a significant issue. As pointed out in the literature (Ormerod & Rosewell, 2009), one common criticism by economists could be stated as follows, “you have presented one set of behavioral rules to explain your chosen phenomenon, but there must be many such sets which produce the same result, so how

do you know yours is correct?” (p. 10). Some economists even go so far as to imply that it is excessively easy to construct an agent-based model that produces desired phenomena. As argued by Marks (2007), the problem behind this criticism is the functional complexity inherent in ABM. It has also been argued that macro behaviors may be insensitive to many micro variables; and, as a result, it would be difficult to derive the necessary conditions for the model to exhibit specific macro behaviors (Marks, 2007). The severity of this problem increases when the model is described with detail and realism, as this requires more variables and higher degrees of freedom (Marks, 2007). For this reason, the model should be as simple as possible, and even then, it would be difficult to achieve quantitative predictions.

When input conditions are expressed by specific values of micro variables or parameters, there is a great deal of freedom, as pointed out in the

literature (Marks, 2007). However, it should also be noted that the freedom of input conditions decreases if they are expressed by the system structure of the model (i.e., model structure) (Ogibayashi & Takashima, 2014). Here, the model structure is defined as the set of the types of agents, their behavioral rules, and the relevant attributes variables. Consequently, it would be considered possible to specify the necessary conditions in the model structure to reproduce the specific macro behavior. This idea is consistent with the argument of Ormerod and Rosewell (2009), who pointed out that the current method used to build ABMs is a process of discovering the behavioral rules for agents that appear to be consistent with the phenomena we observe.

In this context, we believe that, although the model should be as simple as possible (based on the KISS Principle; Terano, 2008), it is also important to consider all of the factors required to reproduce the desired phenomena. That is, the model structure should be the same as, or similar to, the real system for the characteristics to emerge as they do in the real world. The factors essential for reproducing the desired characteristics of the system can be discovered by running a series of computer experiments in which only one constituent element of the model is changed at a time (Ogibayashi & Takashima, 2014).

Although many ABM research studies have focused on macroeconomic aspects, these studies have not fully clarified the structural factors necessary for their reproduction.

Motivated by this deficiency, the authors have constructed a simple, artificial economic model, consisting of consumers, three types of producers, a bank, and a government (some of which were reported in previous studies: e.g., Ogibayashi & Takashima, 2010 & 2014; Takashima, Kato, & Ogibayashi, 2014).

In the present study, some additional simulations are conducted to clarify the model structure necessary for reproducing business cycles and an increase in GDP caused by a tax reduction (which we take as examples of basic macro behaviors in a goods market). A series of simulation experiments are systematically conducted, changing the input conditions one by one, where the simulation program is constructed using C++. The study focuses on finding the model structure necessary to reproduce the above-mentioned macroeconomic phenomena.

2. The Model

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 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 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 as shown in Table 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 as well as in the other parameters included in their behavioral rules.

2.2 Sequence of Actions

The set of activities of each agent constitutes period-based units, where one period is assumed to correspond to one 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 producers 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 producers, 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 producers consider expanding production capacity based on total sales in the previous periods, and, if necessary, they decide to invest in expansion by buying new equipment from the equipment manufacturer. 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.

Table 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 that 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.
				Producers supply and sell products in the goods market.
Producer	Retailer	Consumption goods	Consumer goods, Materials, Equipment	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	Consumer goods, Equipment	
	Equipment maker	Equipment	-	
	Bank	The fund for producers' investment	-	
Bank	Bank			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.

2.3 Outline of Agent's Decision-Making Rules

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 Equation (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.

$$E_b^t = a + bI^t(1-r_{i_tax}) + r_{wd}^t D^t \quad (1)$$

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. Takashima et al. (2014) described consumers' action rules in the stock market in detail.

2.3.2 Behavioral rules of producers

The retailers and raw material producers 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 Equation (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 .

$$Y_i(K, L) = A_i K^\alpha L^{1-\alpha} \quad (2)$$

Retailers and raw material producers initially have one unit of equipment and a specified number of employees. They will invest to increase their production capacity when their products produced at maximum production capacity continued to be sold out 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 manufacturer 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 manufacturer produces equipment following the requirements of retailers and raw material producers as long as it is within their capacity. In the present study, the price of equipment is assumed to be constant. The decision-making rules for investment and financing were described previously (Takashima et al., 2014).

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.

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 the case of the base model.

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.

Concerning expenditure policies, the study tests market purchasing, subsidies for firms, and combinations thereof. Market purchasing is an extreme form of efficient public expenditure in which the government directly purchases goods at the market price. 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.

3. Simulation Conditions

The simulation conditions as experimental levels are divided into two categories, as shown in Table 2: analyses of the reproducibility of periodic changes in GDP (i.e., business cycles) and the positive effects of tax reductions on GDP.

In the former experiment, producers' decision-making processes 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. 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 based on the marginal efficiency of capital proposed by 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 manufacturer. 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 the former experiment are decision-making rules on investment and financing rules for investment, including the experimental levels of four and three, respectively.

In the latter experiment, government and executives are added to the base model as additional 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 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 behavioral rules of government are also added to the base model, which are characterized by the inefficiency of government expenditure, as described in the previous section. 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, Masujima, Maeda, Fukawa, & Iwamoto, 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 parameter values changed to analyze the influence of the factors mentioned above on GDP are the followings. For the analysis of the income tax rate, income tax rate is varied between 10 and 30%, with a 5% interval, corporate tax rate is assumed to be 20%, executive compensation is changed between 0 and 0.5, and the withdrawal ratio is varied between 0 and the maximum value, which is assumed to be 0.2, 0.5, or 0.8. Changing the withdrawal ratio corresponds to altering the levels of the marginal propensity to consume, as given in Equation (1). For the analysis of corporate tax reduction, the corporate tax rate is changed between 10% and 30%, with a 5% interval, the income tax rate is assumed to be 20%, executive compensation is changed to 0.75, 0.85, and 0.95, and the withdrawal ratio is changed between 0 and 0.5. 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 the latter 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), and the inclusion of labor market.

Table 2. *Simulation Conditions for the Experiment in Which Factors Relating to the Model Structure Are Changed As Input Conditions*

		Analysis of reproducing the periodic change of GDP				Analysis of reproducing the influence of tax reduction
		Structure of basic model	Analysis of investment rules	Analysis of financing rules	Analysis of MEC model	
Agent	Government	Without	Without			With
	Executives	Without	Without			With/Without
	Others	With	With			With
Rules of producers	The decision-making rule of equipment investment	Based on demand	No investment / Fixed interval	Based on demand	Based on an internal rate of return	Based on demand
	The rule of financing	Loan and internal funds	Loan	Using internal funds/issuance of stock	Using internal funds	Loan and internal funds
	The rule of executive compensation	Without	Without			With/without
	The deletion of equipment	Without	Without		With	Without
	The price of equipment	Fixed	Fixed		Variable	Fixed
	The upper limit on the number of loans	One	One		Unlimited	One/three
Rules of consumers	The rule of deposit withdrawal	With	With			With/without
Rules of government	Taxation	Without	Without			With
	Inefficiency of government expenditure	Without	Without			With
Market	Goods market	With	With			With
	Stock market	Without	Without	Without	Without	Without
	Labor market	Without	Without			With/without

Those factors relating to the model structure (such as the type of agents, their behavioral rules including relevant attributes variables) are systematically changed one by one in the simulation to elucidate their effect on the tendency of the emergence of business cycles, positive influence of the reductions in income tax rate, and corporate tax rate on GDP.

4. Simulation Results

4.1 The Necessary Model Structure for Reproducing Business Cycles

Figures 1(a), 1(b), and 2 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 is not essential because similar results are obtained in the case with bank financing only. Figures 1(a) and 1(b) 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 Figure 1(a)). 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, as shown in Figure 2.

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 investments, the total

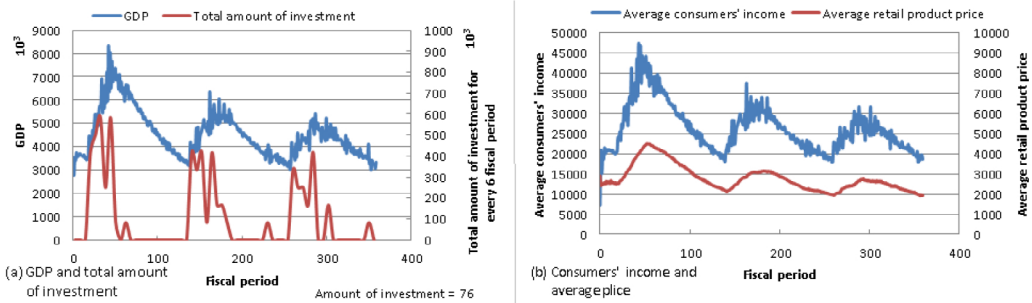


Figure 1. Change in GDP and total amount of investment (Panel a) and average consumer income and average consumer price over time (Panel b) under the conditions of the base model (bank financing and investment decision-making on the basis of demand).

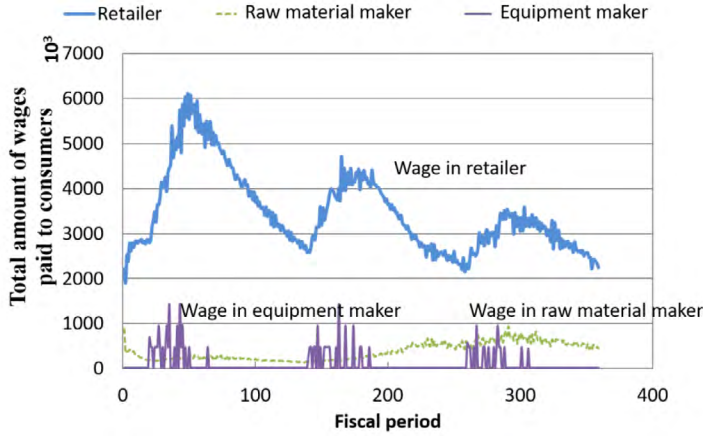


Figure 2. Change over time in consumer's wage over time under the condition of the base model (bank financing and investment decision-making on the basis of demand).

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 this flow of funds were described previously (Ogibayashi & Takashima, 2010).

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, then there is no periodic change in GDP (as shown in Figure 3). Therefore, we can conclude that the model must incorporate endogenous decision-making about capital investment based on demand to reproduce business cycles.

Financing from the bank (i.e., the existence of loans) is another essential condition for reproducing business cycles. When investment is financed by the issuance of new shares in the

stock market without borrowing from the bank, periodic changes in GDP (i.e., business cycles) do not emerge, as shown in Figure 3 (see the case involving financing by the issuance of stock in Figure 3). The absence of business cycles in the case of financing by the issuance of stock is because there is almost no specific restriction for conducting additional investment with respect to funding.

When only internal funds finance investment, GDP shows slight cyclical variations, as shown in Figure 4(a). This variation in GDP incorporates cyclical fluctuations in the average price of products (i.e., consumer price) and consumers' income, as shown in Figure 4(b), indicating that the variation in GDP shows a kind of business cycle that is caused by the requirement for the time interval for firms to raise funds for additional investment. However, financing by internal funds is not considered a major cause of business cycles, because the amplitudes of the

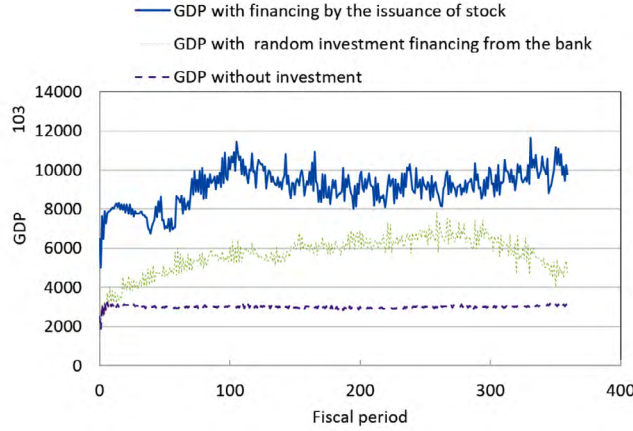


Figure 3. Changes in GDP over time in the cases without investment, with random investment financed from the bank, and with demand-based investment financed by the issuance of stock.

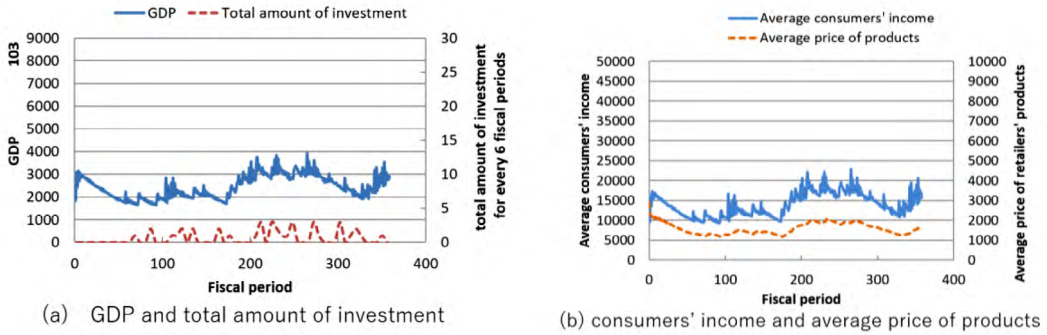


Figure 4. Changes over time in GDP and the total amount of investment (Panel a) and average consumers' income and the average price of retailers' products (Panel b) in the case with demand-based investment financed only by internal funds.

variations in GDP and in consumers' income and price are very small and the period correspondence between GDP and the amount of investment is not clear compared to those in the case with bank financing.

Therefore, in an agent-based model in which producers' production and pricing activities and consumers' buying and working activities are already included, it is concluded that the essential conditions for reproducing

business cycles would be the inclusion of bank financing and demand-based investment decision-making in the model structure.

On the other hand, Keynes (1936) proposed that the marginal efficiency of capital (MEC) is the primary determinant of the business cycle. 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 Figure 5. Not that the price of equipment as well as internal rate of return also do not show cyclical variations, as shown in Figure 6. 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 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.

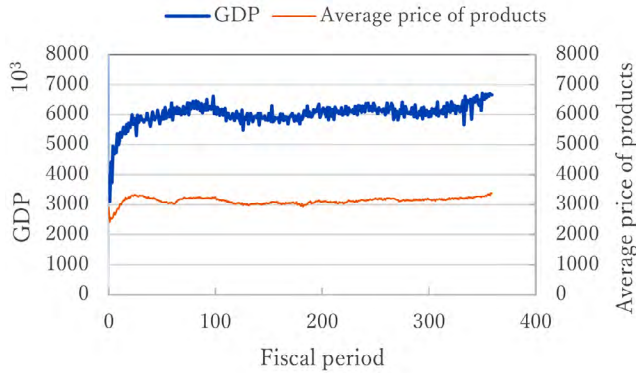


Figure 5. Changes over time in GDP and the average price of products in the case with financing by internal funds only, where investment is judged based on the internal rate of return.

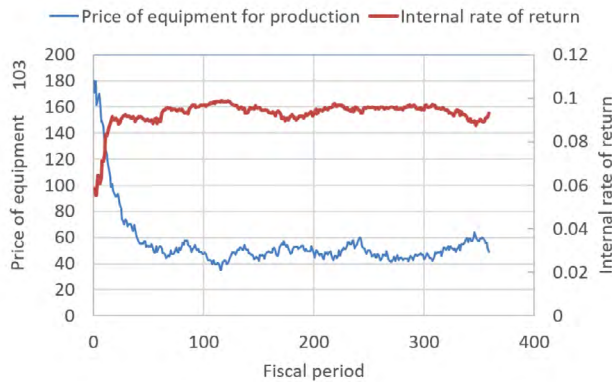


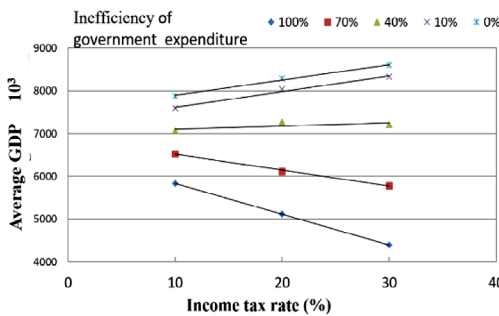
Figure 6. Changes in the price of equipment and internal rate of return over time.

4.2 The Necessary Model Structure for Reproducing the Influence of a Reduction in Income and Corporate Taxes on GDP

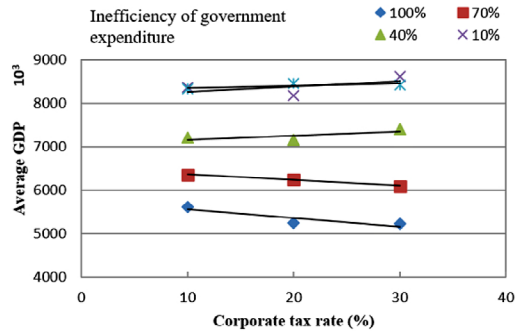
The calculated relationship between the income tax rate and GDP is shown in Figure 7(a). Note that the negative correlation between the income tax rate and GDP is only reproduced when some inefficiency exists in government expenditure. Note also that the critical inefficiency level at which the correlation changes from positive to negative decreases when the substantial marginal rate of consumption of consumers, which is dependent on the withdrawal ratio on bank deposits and the existence of executives, increases. This result indicates that the negative correlation between the income tax rate

and GDP is more likely to occur when the inefficiency in government expenditure is large enough even if the rate of consumption of consumers is small enough.

On the contrary, if government expenditure is 100% efficient, GDP increases with an increase in tax rate as shown in Figure 7(a). As the efficiency (i.e., 1-inefficiency) of government expenditure corresponds to the government's marginal propensity to consume, the reason for this tendency is as follows. If the efficiency in government expenditure is larger than the consumers' marginal propensity to consume, some consumers' money to be deposited in the bank will be transferred to the government by taxation and then consumed in the market, leading to an increase in GDP with an increased tax rate.



(a) Relationship between GDP and Income tax rate



(b) Relationship between GDP and corporate tax rate

Figure 7. Influence of inefficiency of government expenditure on the relationship between GDP and income tax rate (Panel a) and corporate tax rate (Panel b). In the latter case, executive compensation, the use of internal funds for investment, and the mitigation of credit rationing are taken into account.

Thus, it is concluded that a necessary condition for the model to reproduce the positive effect of income-tax reduction on GDP is that some inefficiency exists in government expen-

diture. Moreover, the underline mechanism of the positive effect of tax reduction is as follows. When the substantial marginal propensity to consume of the government is smaller than that of con-

sumers, some consumers' money to be transferred to the government by taxation is consumed in the market due to the income tax reduction, thus leading to an increase in GDP with a decreased tax rate.

In the case of corporate tax, the inefficiency of government expenditure is also a necessary factor to reproduce the negative correlation between the corporate tax rate and GDP (i.e., positive effect of corporate tax reduction on GDP) as shown in Figure 7(b). However, some additional factors are required in the model to reproduce the positive effect of corporate tax reduction.

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). Figures 8(a) and 8(b) 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 ex-

penditure is assumed to be 0.3. Figure 8 shows that the negative relationship between corporate tax and GDP occurs only when executive compensation, the use of internal 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 9 shows the influence of the upper limit of the number of loans on the relationships between corporate tax rate and GDP (see Figure 9(a)) and the number of investments (see Figure 9(b)) 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 negative relationships between the corporate tax rate and GDP and the number of investments are only reproduced when the upper limit of the number of loans is 3 (i.e., mitigation of credit rationing is applied).

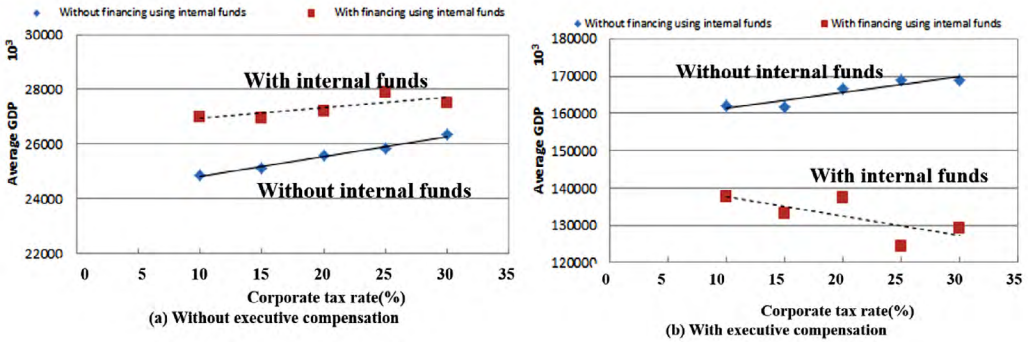


Figure 8. Influence of the inclusion of internal funds rule and executive compensation rule on the relationship between the GDP and corporate tax rate, where assumed inefficiency of government expenditure is 0.3, and the upper limit of the number of loans is 3.

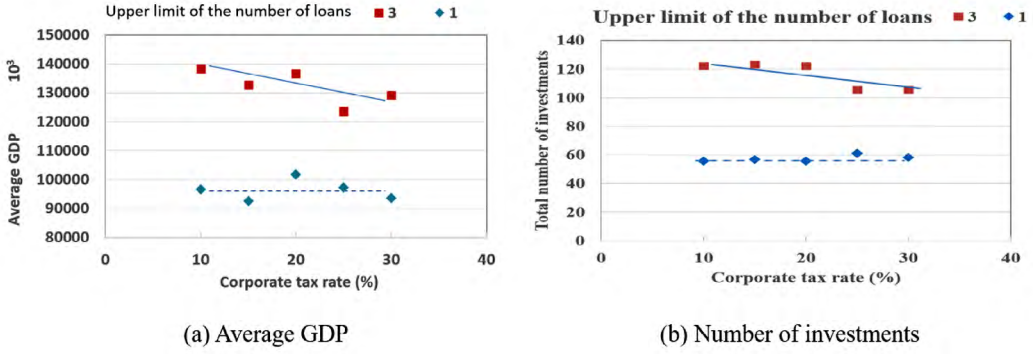


Figure 9. Influence of the upper limit of the number of loans on the relationships between corporate tax rate and GDP (Panel a) and total number of investment (Panel b).

In this study, the influence of the labor market is also analyzed. However, as shown in Figure 10, 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, we conclude that inclusion of the labor market is not a required condition for reproducing the positive influence of corporate 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 Figure 10, 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

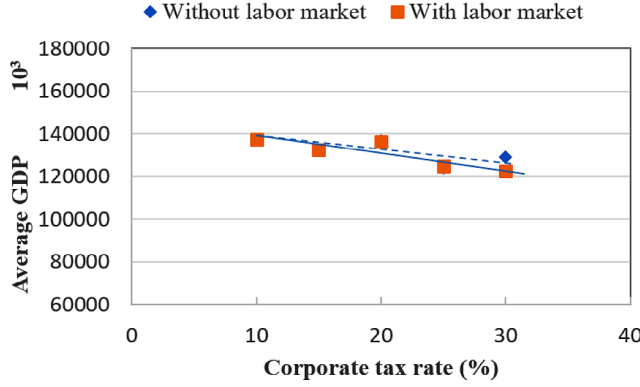


Figure 10. Influence of the labor market on the relationship between corporate tax rate and GDP, under the condition that includes all four factors, namely, government inefficiency, executive compensation, the use of internal funds, and the mitigation of credit rationing (i.e., the upper limit of the number of loans is assumed to be 3).

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 pro-

pensity 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.

This finding suggests the following:

First, when input conditions of the ABM model are expressed by the model structure, it is possible to discover which conditions in the system structure are necessary to reproduce specific macro behavior, using a series of systematic computer experiments. 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.

Second, corporate tax reduction increases GDP only when the government's effective marginal propensity to consume (expressed by the degree of efficiency [i.e., 1-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.

Third, 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, such as public orders with higher-than-market prices, subsidies to firms in the industry, or rent-seeking behavior (Tolli-son & Congleton, 1995).

5. Discussions: The Validity of the Model in ABM

As described in the introduction, the validity of the ABM has been widely criticized. For example, Marks (2007) claimed that, because of the functional complexity of an ABM system, one could not assume that the factors that successfully reproduce the desired macro phenomena are necessary conditions.

On the contrary, the results of this study indicate that the necessary conditions exist for reproducing both business cycles and GDP reactions to tax reductions. 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 as shown by the fact that the phenomenon does not emerge in the artificial society if any one of these factors is not included in the model in ABM. 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 earlier in this paper, we can gain a better understanding of the causal mechanisms of these social phenomena. 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 & Takahara, 1989). In the case of social systems, objects that are responsible for the emergence of social phenomenon are autonomous decision-makers (i.e., agents, such as individuals and organizations), because any social phenomenon is considered to emerge from agents' actions and their interactions. 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. The behavioral rules and relevant attributes may include environmental factors of the system as well as factors

relating to non-human entities, such as markets. Note also 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.

Therefore, because ABM is a bottom-up modeling method, the macro phenomena that emerge in the model system will be similar to those of the real-world system if the system structure of the model defined as described above is similar to that of the real system. This principle holds true because, for any social phenomenon, there must be a causal mechanism where system structure is an input and the phenomenon is the output. In other words, if the factors that characterize the system structure of the model are different from those of the actual system, then the macro phenomena in question will not be reproduced, even qualitatively, in the model.

Therefore, in case of 100% bottom-up model in ABM, we can conclude that the system structure of the model and the causality of any phenomenon in the model are the same as or similar to those of the real system if the phenomenon in question is qualitatively reproduced in the model. Moreover, this causal relationship between the system structure and the phenomenon can be elucidated by running a series of computer experiments, in which one factor relating to the system structure is systematically changed one by one, while other factors are kept constant.

In the present study, the facts that we could specify the conditions of

the model necessary to reproduce business cycles and the positive effects of tax reductions, and that we could reason about the underlying mechanisms of the phenomena, are offered as evidence of the validity of the model in ABM, following the preceding principle.

Note also that the model structure that can reproduce the desired macro phenomena might not be unique because there might be multiple causes for each of the phenomena. However, this does not undermine the validity of the model mentioned above, because if different system structures cause the same phenomenon in the model, it is considered so even in the real system. In any cases, we can gain a better understanding of the causal mechanisms of the social phenomena by piling up the knowledge on the indispensable system structure for each of the macro phenomena.

6. Conclusion

The necessary conditions of the model structure for reproducing business cycles and the positive effects of tax reductions are analyzed using an agent-based model, which includes producers' activities of production, pricing and investment, consumers' buying and working activities, and the government's activities of taxation and expenditure. As a result, the following findings were obtained.

1. The factors necessary to reproduce business cycles are the inclusion of bank financing (i.e., credit creation) and producers' demand-based investment decision-making.

2. The only factor required to reproduce the positive effect of income tax reduction is inefficient government expenditure. Factors required to reproduce the positive effect of corporate tax reduction include inefficient government expenditure, executive compensation, the use of internal funds for investment, and the mitigation of credit rationing.
3. Based on these findings, this study proposed causal mechanisms of business cycles and the positive effect of tax reduction. Business cycles emerge because overborrowing from the bank promotes an economy that is followed by excessive repayment due to credit rationing that worsens the economy. Positive effect of tax reduction emerges when substantial marginal propensity to consume at private sector is larger than that at public sector.
4. This study proposed new perspectives on the validity of ABM based on these findings, the essence of which is the following. In case of 100% bottom-up model in ABM, necessary conditions for qualitatively reproducing each of the macro phenomena can be identified if the input conditions of the model are expressed by the model structure defined by the set of the categories of agents, their behavioral rules, and relevant attributes variables. We can elucidate the necessary factors in the model structure by running a series of systematic computer experiments in which elements are

changed one by one at a time with other factors kept constant. By considering the reason why such factors are required to reproduce the phenomenon, it is possible to gain a better understanding of the causal mechanism of the phenomenon.

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