Influence of Government Expenditure Policies and Tax Rate on GDP in an Agent-Based Artificial Economic System

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Abstract. An agent-based model of an artificial economic system that includes government has been developed, and the influences of public policies on GDP and the related emergent behavior of macroeconomic phenomena were analyzed. It was revealed that GDP increases with an increase in the ratio of efficient expenditure policy, such as that pertaining to market purchasing. Average price increases (decreases) as GDP increases (decreases), and the influence of tax rate on GDP, depends on the nature of public spending. Most estimation results are found to be quite consistent with real data, if it is assumed that public spending includes inefficiency exceeding 10%.

Keywords. Agent-based computational economics, government, expenditure policy, GDP, tax rate.

1 Introduction

Agent-based modeling (ABM) is widely used in social simulations, because it is a class of modeling method used to explain or understand social phenomena via a bottom-up approach [1,2]. The application of ABM in macroeconomic systems constitutes an important research field, because macroeconomic systems are very complex and relate to many social phenomena. ABM is expected to offer a new way of understanding the mechanisms behind the behavior of a complex macro-level economy. In principle—and as suggested in the literature [3]—it might even be possible to utilize ABM to understand or evaluate the effectiveness of economic policies such as those pertaining to tax reductions and public spending. Prior studies on ABM and macroeconomic systems are considered to be one of two types: research that mainly focuses on the emergence of macroeconomic phenomena and its mechanisms [4, 5], and that mainly focuses on the development of the models of a multiple-market economy as a whole, while taking into account the structure of a real economy in as much detail as possible [6,7].

Although considerable research has focused on various aspects, not much research has focused on the role of government and the influence of public policies on GDP. In a previous study [8], the authors constructed a simple artificial economic model comprising consumers, three types of producers, and a bank, and found that this simple

model reproduces fundamental economic behavior such as a loose equilibrium in price, a business cycle caused by capital investment, the influence of money supply on GDP, and the like. In the present study, an agent-based model of an artificial economic system that includes government was developed, based on the authors' previous model. Using that model, the influences of public policies on GDP and the related emergent behavior of macroeconomic phenomena have been analyzed. The findings are compared with those of a real system, to determine whether the model reproduces real-life phenomena.

2 Simulation Model

The agent-based model of an artificial economic system in the present study comprises consumers, producers, a bank, and government as autonomous decision-making agents, as shown in Equation (1) and Figure 1. It is assumed that producers are divided into three types of agents: retailers who produce final products for consumers, wholesalers who produce and supply raw materials for retailers, and an equipment-maker who supplies equipment for the production of other types of producers. Consumers, meanwhile, are divided into private employees who work for a private company and public employees who work for the government.

$$\begin{aligned} &Agent = \{C, P, B, G\}, P = \{R, W, E\} \\ &C : Consumer, P : Producer, B : Bank, G : Government \\ &R : Retailer, W : Wholesaler, E : Equipment\text{-}maker \end{aligned} \tag{1}$$

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

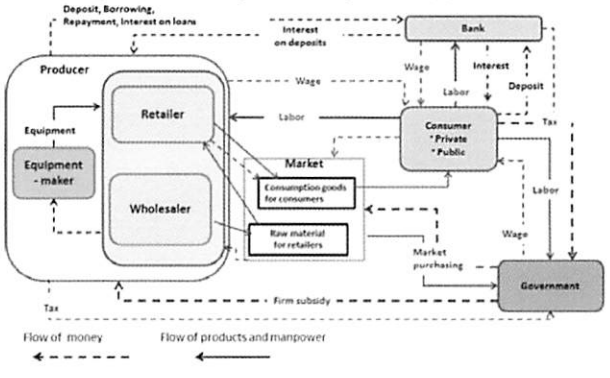

Fig. 1. Outline of the model

$$
\begin{aligned}
MC_C^i &= MC_C^{i-1} + MD_C^{i-1} r_{withdraw} - Expenditure^{buy^{i-1}} + bx^{i-1} + a_0 \\
MD_C^i &= MD_C^{i-1}(1 - r_{withdraw}) + (1-b)x^{i-1} - a_0 + Interest_C^{i-1} \\
MD_P^i &= MD_P^{i-1} + \{Sales_P^{i-1} + Interest_P^{i-1} - (Cost_P^{i-1} + \sum_{k \in \{C\}} wage_k^{i-1}) - Repayment_P^{i-1}\}(1 - cTaxrate) \\
MC_G^i &= MC_G^{i-1} + Tax\,revenue^{i-1} - \sum_{k \in \{C\}} wage_k^{i-1} - Expenditure^{policy^{i-1}}
\end{aligned}
\tag{2}
$$

where,

$x^i = wage^i(1 - iTaxrate)$, $wage^i = Const\,wage^i + Bonus^i$

$Consumption\,budget^i = a_0 + bx^{i-1} + MD^i r_{withdraw}$, $Expenditure^{policy} = Market\,purchasing + Firm\,subsidy$

$Tax\,revenue^i = \sum_{k \in \{C\}} (wage_k^{i-1} iTaxrate) + \sum_{k \in \{P\}} \{Sales_P^{i-1} + Interest_P^{i-1} - (Cost_P^{i-1} + \sum_{k \in \{C\}} wage_k^{i-1})\} cTaxrate$

i: Fiscal period , suffix: Agent type

MC: Cash possessed by agent , MD: Deposit of agent in the bank

$r_{withdraw}$: Ratio of withdrawn money to total deposit , $Interest$: Balance of interest paid by the bank

$Cost$: Expenditure of retailer to buy raw materials , $Expenditure^{buy}$: Expenditure of consumer to buy retail product

$cTaxrate$: Corpration tax rate , $iTaxrate$: Income tax rate

$Repayment$: Repaid amount of money per period

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

2.1 Consumer Agent

Consumer agents work at one of the producers—or at the government, in the case of public consumers—whereupon they receive wages, pay tax in line with their income, and buy products supplied by retailers according to their utility functions and with the limited cash at hand. "Cash at hand" is defined as the sum of the Keynesian consumption function and the money withdrawn from the consumer agent's bank accounts according to the withdrawal ratio as shown in Equation (2). When there are goods of the same class available in the market at different prices, the consumer is assumed to select and purchase the cheapest one among them; the utility of each class of product is given in Equation (3), where a weight is randomly assigned to each consumer with a uniform distribution.

$$
\begin{aligned}
&utility = weight \times u(\xi) \\
&\quad u(\xi) = 0,1,1.2,1.25,1.25,\cdots \ if\ \xi = 0,1,2,3,4\cdots \quad , \quad weight: weight\,of\,utility
\end{aligned}
\tag{3}
$$

2.2 Producer Agent

Producers hire consumers as employees, pay wages, make production plans, produce products of several types, supply and sell those products in the market, pay tax in line

with their profits and deposit and withdraw money from the bank at every fiscal period. Wages comprise a fixed salary that is randomly assigned to each employee between a lower and an upper limit, and a bonus is given when the profit of the producer is positive. The amount of bonus is defined as the bonus ratio times the producer's surplus money, and it is uniformly assigned to each of the employees.

2.2.1 Retailer and Wholesaler

The retailers and wholesalers decide both the amount and price of each class of product, where the price is increased or decreased depending on the amount of goods in stock at the end of the previous period. The amount of production is decided, such that the probability of the occurrence of being out of stock is less than 5%; this is estimated based on the total sales during the most recent 10 periods. When the estimated price is lower than the running cost per product, the minimum price is set to be the running cost. On the other hand, when the estimated amount of production is less than 70% of the production capacity, the minimum amount of production is set to be that amount. The production capacity Y is defined by a Cobb–Douglas type function as shown in Equation (4), where K is the number of pieces of equipment for production, L is the number of employees, and α is 0.25.

$$Y = AK^{\alpha} L^{1-\alpha} \tag{4}$$

Retailers and wholesalers each initially have one unit of equipment; they increase that number during the simulation by buying equipment from the equipment -maker when the production at maximum capacity continues for longer than a certain critical length of time. All of the necessary amount of money for investment is financed by the bank, and it is constantly repaid each period, for a constant number of consecutive repayment periods. Additional investment during the repayment periods is assumed to not be allowed.

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

In addition, retailers require one unit of raw material for the production of one unit of product, and they buy the necessary amounts of material in the market according to their production plans. When the amount of material available in the market is less than the required number, the amount of products to be produced is limited to that amount.

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

2.2.2 Equipment-Maker

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

2.3 Bank Agent

The bank keeps the surplus money of other agents in their respective bank accounts, and lends money as long-term loans to producers, in line with their demands for investment, charging a 3% interest rate. The bank also pays wages to its employees and pays tax to the government, in line with its interest income. The bank also lends money as short-term loans to producers, in line with their requirements when they become short of working capital. In the present study, the initial amount of funds in the bank is set to be very large, so that there is no limitation on lending money to meet the demand of producers, except the additional requirement that arises when long-term loans are not fulfilled during the repayment stage.

2.4 Government Agent

The government collects tax from producers and consumers in the form of corporation tax and income tax, respectively; it also pays wages to public employees and spends money on public spending, according to the expenditure policy of each fiscal period. Corporation tax is only collected when the profit of the producer is positive, and the tax rate is assumed to be constant. Income tax is collected in line with consumer's income, and that tax rate is also assumed to be constant. The wages of public employees are determined in each fiscal period, so that it equals the average value of private employees' wages, including fixed wages and bonuses.

As expenditure policies, market purchasing, firm subsidy, and the combination of these two are tested, while assuming extreme cases of efficiency in public spending.

Market purchasing is an expenditure policy where the government directly purchases goods in the market, at the market price. When there are goods of the same class available in the market at different prices, the government selects and purchases the cheapest one among them. This policy corresponds to the extreme case of efficient government spending, where the government places job orders with firms in a completely competitive situation, at a price level identical to that expected in the market

Firm subsidy is an expenditure policy where the government evenly distributes funds to producers, without imposing any limitation to their use. This policy corresponds to the extreme case of inefficient spending, where the government places job orders with firms at a much higher price level than that expected in the market, or pays money for jobs that have no public meaning in the society.

3 Simulation Conditions

A simulation program was constructed using C++, with object-oriented programming. The numbers of agents were 100, 20, 3, 1, 1, and 1, for consumers, retailers, wholesalers, an equipment-maker, a bank and a government respectively. The influence of the government's expenditure policies, the tax rate, and the consumption function of consumers on the macroeconomic behavior of the system—e.g., GDP, average price, etc.—are analyzed and compared to those of the nongovernment condition.

The simulation conditions are given in Table 1; they are divided into three subta-

Table 1. Simulation conditions.

(a) Parameter values of the base run

Maximum fiscal periods	360
Number of consumers	100
Number of retailers	20
Number of wholesalers	3
Number of equipment maker	1
Number of bank	1
Fixed salary	7000~7500
Bonus ratio	0.95
Number of product class	12
Class of product with positive utility	3 of 6
Withdrawal ratio	0~0.5
Weight of utility	0.3~1.1
Loan interest	3%
Deposit interest rate	0.50%
Repayment period	120
Investment value	500000
Critical flag number for investment	10
Critical flag number to quit production	20
Critical flag number for dismissal	5
The lower limit of production	70% of its capacity

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

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

(c) Variable parameters as experimental levels

	Without government	With government
Number of government employees	0	3
Number of retailer employees	88	85
Number of wholesaler employees	9	9
Number of equipment maker employees	2	2
Number of bank employees	1	1
Income tax rate		10~40%(10% intervals)
Corporation tax rate		10~40%(10% intervals)
Budget ratio of firm subsidy		0~1(0.1 intervals)
Budget ratio market purchasing		0~1(0.1 intervals)

bles; the fixed parameters whose values are constant, the initial conditions whose values may change during each simulation run, and the simulation parameters which are constant but change for each simulation run to clarify their influence on macroeconomic behavior in the present artificial economic system. As shown in Table 1(a), each simulation run includes 360 periods, and the producers' repayment period is assumed to be 120 periods. The government's expenditure policies and the tax rate change with the experimental conditions, as shown in Table 1(c), and their influence on GDP or other economic factors are investigated. Among these values, the number of agents, the bonus rate, and the initial capital of agents are determined, so that they are almost minimal under a condition of stable fund circulation.

4 Simulation Results

4.1 Emergent Properties in the Present Artificial Economic Systems

Before analyzing the influence of public expenditure and tax rate on GDP, the emergent behavior of macroeconomic phenomena such as the distributions of various factors are analyzed. Figure 2 shows the chronological change in GDP and the Gini coefficient of consumers under the nongovernment condition. It is noted that GDP shows cyclical up-and-down movements over time, representing business cycles.

The period of a long-term business cycle almost coincides with the repayment period. The primary cause of these business cycles is discussed in the authors' previous work [8] and is considered a result of the finance and repayment of funds by producers for capital investment. Capital investment occurs as a result of emergent behavior stemming from interaction among agents via the market. Although the initial assets of consumers—denoted in Table 1 as "Consumer's deposit" is given as a uniform random number between 30,000 and 50,000, inequality in terms of consumers' assets emerges, and the Gini coefficient varies from 0.2 to 0.6 during the simulation (Figure 2(b), lower graph). It is also noted that the Gini coefficient's peak values occur when the GDP reaches the local maximum, although their behaviors are not very similar.

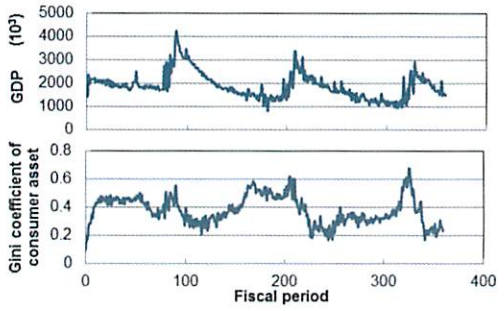

Fig. 2. (a)Cyclical changes in GDP(upper graph) and (b)Gini coefficient (lower graph) under the nongovernment condition.

4.2 Influence of Government Expenditure Policies on the Macroeconomic Behavior of the Artificial Economic System

Under the condition of a constant tax rate, the influences of two types of government expenditure policies on GDP are analyzed and calculated; the GDP level under this condition is compared to that under a nongovernment condition. Two types of expenditure policies are market purchasing and firm subsidy, which are defined as extreme cases of efficient and inefficient public spending, respectively.

Figure 3 shows the change in GDP over time and the average price of products in the market, where these factors subject to the expenditure policy of market purchasing and firm subsidy are compared to those under a nongovernment condition. It is noted in Figure 3(a) that during the whole periods, the level of GDP is larger in the case of market purchasing and smaller in the case of firm subsidy than is the case in the nongovernment condition. The average price of products shows behavior similar to that of GDP. It is also noted in Figure 3(b) that there is a tendency for the price to increase (decrease) as the GDP increases (decreases); thus, the present model suggests that inflation (deflation) occurs when the GDP is increasing (decreasing).

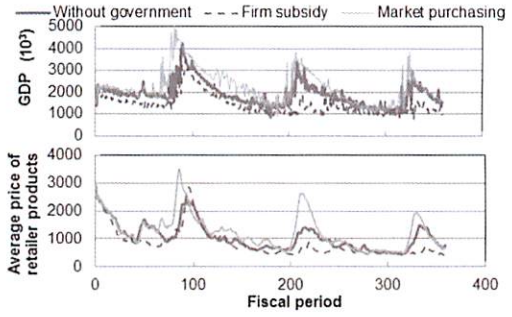

Fig. 3. Influence of government expenditure policies on (a) GDP (upper graph) and (b) average price of retailer products (lower graph)

4.3 Influence of Tax Rate on GDP

The influence of the income tax rate and the corporation tax rate on GDP is analyzed for various ratios of market purchasing, since the influence of a tax rate is dependent on public spending. Here, the "ratio of market purchasing" is defined as the amount of expenditure for market purchasing, divided by the sum of the amount of expenditure for market purchasing and firm subsidy. The marginal propensity to consume is assumed to be 0.7, and the GDP averaged over 360 periods is used as the GDP value.

The influence of tax rate on GDP is shown in Figure 4, for various ratios of market purchasing. In the case of a 100% ratio of market purchasing, the GDP increases with an increase in the income tax rate, as shown in Figure 4(a). This tendency is thought to occur because the money that is to be transferred to the consumers' bank accounts in the form of deposits is collected by the government and consumed in buying products in the market, thus increasing market demand.

In the case of 0% market purchasing—which means 100% firm subsidy—the GDP remarkably decreases with an increase in the income tax rate. This tendency is considered to occur because government funds obtained by collecting tax are transferred to the firm's bank account, almost without increasing consumers' incomes or the money supply in the market. It is noteworthy that this negative correlation between GDP and the income tax rate is observed in Figure 4(a) when the ratio of market purchasing is less than 90%. This result suggests that if the negative correlation between GDP and the income tax rate is observed in the real system, it may mean that the government expenditure includes an inefficiency of public spending that exceeds 10%.

The influence of corporation tax is shown in Figure 4(b) for various ratios of market purchasing. Unlike the influence of the income tax rate, GDP increases with an increase in the corporation tax rate, regardless of the ratio of market purchasing. The reason for this tendency as well as comparison of the present results with real data, will be examined in the next section.

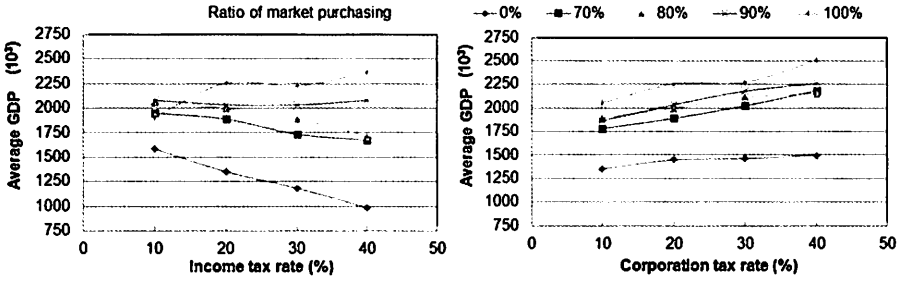

Fig. 4. (a) Influence of income tax rate (left graph) and (b) influence of corporation tax rate (right graph) on GDP, averaged over 360 periods

4.4 Influence of Marginal Propensity to Consume on GDP

The influence of the marginal propensity to consume on GDP is analyzed for various ratios of market purchasing, where the income tax rate and the corporation tax rate are

both fixed at 20%. It was confirmed, as shown in Figure 5, that GDP increases with an increase in the ratio of market purchasing; also, it decreases with a decrease in the marginal propensity to consume, regardless of the ratio of market purchasing. The GDP level exceeds that of the nongovernment condition when the ratio of market purchasing exceeds either 70% or 80%, depending on the marginal propensity to consume. It was also revealed that the effect of the multipliers of the reduction in the income tax rate on GDP decreases with a decrease in marginal propensity to consume.

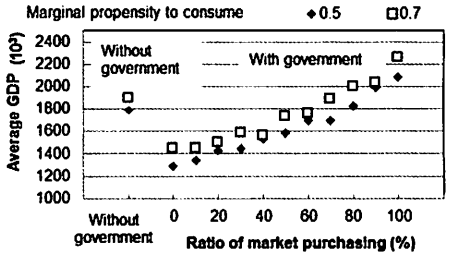

Fig. 5. Influence of marginal propensity to consume on GDP, averaged over 360 periods.

5 Discussion

As shown in Figure 3, there is a tendency for the price to increase (decrease) as the GDP increases (decreases). This tendency is compared with real data. Historical data pertaining to the GDP and consumer prices of G7 countries for more than 10 years are available from the International Monetary Fund world economic outlook database [10]. Figure 6 shows the relationship between the GDP growth rates and increases in the rates of consumer prices in every fiscal period in the simulation results (Figure 6(a)) and in real data in Japan during the 1980–2010 period (Figure 6(b)).

As shown in Figure 6, positive correlations between the GDP growth rate and the rate of increase in consumer prices are observed both in the simulation results and in real data from Japan. Similar positive relationships are observed in every G7 country,

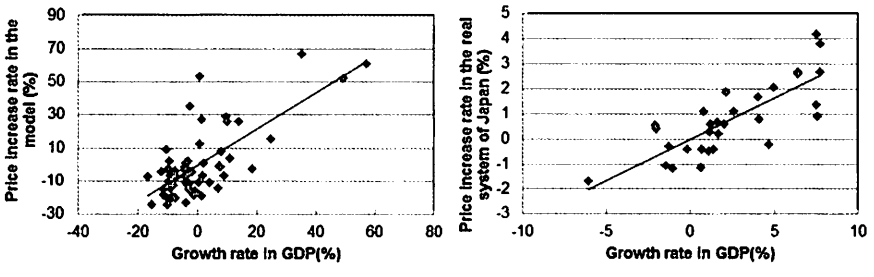

Fig. 6. Relationship between increasing rate of average price and GDP growth rate in (a) the simulation system (left graph), and (b) a real system obtained via a macroeconometric model (right graph)

although the slopes differ among countries [10]. Thus, it is concluded that the calculated relationship between the GDP growth rate and the rate of increase in consumer prices agrees qualitatively well with real-life data.

The influence of the income tax rate and the corporation tax rate on GDP, as calculated in the present study, has been compared with observed tendencies in the real economic system; results drawn from the "The ESRI Short-Run Macroeconometric Model of the Japanese Economy" (here after referred to as "the ESRI model") [11] are used as real-life data. Tables 2 and 3 show the estimated multipliers of GDP when the income tax rate or the corporation tax rate, respectively, is reduced for three years by the amount corresponding to 1% of nominal GDP [11].

As shown in Table 2, a reduction in the income tax rate results in an increase in GDP, in both the simulation results (Table 2(a)) and in Japan's actual system (Table 2(b)). The multipliers of tax reduction for GDP range between 0.2 and 1.2 in the real system; these values are close to the calculated values, assuming that government expenditure in the real system has an inefficiency in public spending that exceeds 10%. From this view point, the present results on the influence of the income tax rate on GDP agrees well with the tendency seen in the real data, if it is assumed that public spending by the government includes some degree of inefficiency. This might be feasible because, when the government places a job order with a firm, that firm may have a strong incentive to create a contract that charges higher prices, while public employees have, generally speaking, a comparatively weak incentive to reduce prices.

As for the influence of the corporation tax rate on GDP, on the other hand, there are large differences between the calculated and real-life results, as shown in Table 3. Namely, a reduction in the corporation tax rate in the real system results in an increase in GDP (Table 3(b)), while the calculated results show a completely opposite tendency (Table 3(a)) where GDP decreases with a decrease in the corporation tax rate.

In order to clarify the reason for the discrepancy between calculated and real-life results on the influence of a corporation tax reduction on GDP, we examine the estimated results of the ESRI model [11]. According to the ESRI model, it is found that a corporation tax reduction results in a significant increase in private firms' fixed capital formation, a decrease in the unemployment ratio, and an increase in household income. This implies that a corporation tax reduction may stimulate firms to invest in equipment and buy fixed capital, which would result in a reduced unemployment rate and an increase in consumer income. However, the present model does not take into account these factors. Namely, as explained in section 2.2.1, decision-making for the retailer and wholesaler with respect to investments is subject to a limitation, i.e., additional investment during the repayment periods is assumed to be not allowed. It is also noted that in the present model, the tax rate does not have any influence on investment decision-making. In addition, any fixed capital investment other than production equipment, the existence of unemployed consumers, and foreign direct investment [12] are also not taken into account in the present model.

Therefore, it is thought that, in real life, a reduction in the corporation tax rate results in an increase in GDP, because such a reduction may stimulate firms to invest in equipment and buy fixed capital, and thus reduce the unemployment rate and increase

consumer income. To reproduce this positive influence of a corporation tax reduction on GDP, it is considered important that the model take into account fixed capital investments, their dependence on the tax, rate and the existence of unemployed consumers.

Table 2. Estimated multipliers of GDP and tax revenue when the income tax rate is reduced (a) in the present model (left), and (b) in the real system (right).

(a) Simulation results

Market purchasing rate	Multiplier due to income tax reduction (1% of GDP)	
	GDP	Tax revenue
0%	2.38	-3.22
10%	2.79	-3.29
20%	1.85	-3.29
60%	1.35	-3.77
70%	1.07	-3.86
80%	0.74	-3.95
90%	0.13	-4.04
100%	-0.52	-4.12

(b) Data in the real system obtained by macroeconometric model

Year	Multiplier due to income tax reduction (1% of GDP)	
	GDP	Tax revenue
2005	0.24	-5.71
2006	0.85	-4.28
2007	1.17	-3.89
Average	0.75	-4.63

Table 3. Estimated multipliers of GDP and tax revenue when the corporation tax rate is reduced (a) in the present model (left) and (b) in the real system (right).

(a) Simulation results

Market purchasing rate	Multiplier due to corporation tax reduction (1% of GDP)	
	GDP	Tax revenue
0%	-0.46	-4.25
10%	-0.56	-4.39
20%	-0.36	-4.44
60%	-1.30	-4.96
70%	-1.41	-4.99
80%	-0.97	-4.83
90%	-1.68	-5.23
100%	-0.55	-5.18

(b) Data in the real system obtained by macro econometric model

Year	Multiplier due to corporation tax reduction (1% of GDP)	
	GDP	Tax revenue
2005	0.45	-5.71
2006	0.97	-4.93
2007	1.10	-4.60
Average	0.84	-5.08

6 Conclusion

An agent-based model of an artificial economic system that includes government has been developed, based on the authors' previous model. Using the model, the influences of public policies on GDP and the related emergent behavior of macroeconomic phenomena have been analyzed, and the three following key results were obtained.

1) As a result of analyzing the influence of expenditure policies on GDP, it was found that by employing market purchasing and firm subsidy as extreme cases of efficiency in public spending, market purchasing has a positive influence on GDP and firm subsidy has a negative influence.

2) GDP increases with an increase in the ratio of market purchasing, and the GDP level exceeds that of the nongovernment condition when the ratio of market purchasing exceeds either 70% or 80%, depending on the marginal propensity to consume.

3) It was also found that GDP increases with a decrease in income tax rate when the ratio of market purchasing is less than 90%, while GDP increases with an increase in the corporation tax rate, and the average price increases (decreases) when GDP increases (decreases).

These results were compared with real data, and it was found that the obtained results of the present study reproduce the features of the real economy as observed in Japan, except for the influence of the corporation tax rate—if it is assumed that public spending features an inefficiency in public spending that exceeds 10%. The calculated influence of the corporation tax rate on GDP is not consistent with the real data, maybe because the present model does not take into account fixed capital investments, their dependence on the tax rate, and the existence of unemployed consumers.

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