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Fiscal and Monetary Policies in an Agent-Based Model

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Abstract

In this paper, we aim to assess the impacts of using monetary policies and fiscal transfers on the economy using an agent-based model. The model used is based on the original model developed by Ashraf et al. (2017), where agents endogenously develop trading networks of goods and labor, to study the impacts of the banking sector, and extended by Popoyan et al. (2017) to include different policy rate rules and macroprudential policy. We evaluate different fiscal policies and their interactions with monetary policy on how the economy performs based on aggregates such as total output and inflation, as well as based on granular data such as the wealth and consumption of the agents at specific percentiles. The findings are that consumption-based policies are best for reducing the aggregate effects on GDP, targeted policies are efficient if the government's goal is to help a specific group, and unconditional transfers are the least efficient of the three. In addition, we analyze the effects of implementing monetary and fiscal policies synchronously after a COVID-19-like crisis, and we do not find conclusive evidence that combining the two policies are better than the sum of the individual effects, but it is likely to be necessary to do both in order to get the economy back to its original path in a timely manner.

Keywords: Monetary Policy, Fiscal Policy, Simulation
JEL classification: C63, E52, E62

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1 Introduction

In this paper, we leverage an agent-based model (ABM) to analyze the impacts of monetary and fiscal policies on the economy that has been adversely affected by a COVID-19-like shock. In an economy with a central bank constrained by the zero-lower-bound interest rate, traditional monetary policy may be insufficient to effectively stabilize the economy after a large negative shock. As we have seen in many countries during the COVID-19 pandemic, fiscal stimulus from the government is necessary to try to steer the economy back to their initial growth paths.

To induce a COVID-19-like scenario, we generate a negative shock to the economy by depressing future expectations of income. This decreases demand and results in negative GDP growth and lower inflation. The central bank responds by decreasing interest rates, but it is constrained by the zero-lower-bound, therefore, we allow the government to step in with fiscal policies. Three specific policies are analyzed: unconditional cash transfers to all citizens, conditional cash transfers to the poor, and subsidies for purchases of goods. The three policies are made to proxy three recent policies by Thai government. While not completely unconditional, the "We don't leave anyone behind" (Thai: "Rao-mai-ting-kan") policy reached over 15 million Thais affected by the pandemic ranging from temporary workers and farmers to small shop owners and entrepreneurs. On the other hand, the state welfare card program are more targeted, with strict income and asset requirements. The subsidy for the purchase of goods is based on the "Let's Go Halves" (Thai: "Kon-la-krueng") scheme where payments made to restaurants and small shop owners are subsidized by 50 percent by the government, with a cap of 150 THB per day.

To enable comparisons across scenarios, the fiscal policies are normalized such that the cost to the government are the same. The results are then analyzed at the aggregate level with GDP, inflation, unemployment, and number of bankrupted firms. In addition, since we are introducing conditional cash transfers, it follows that we should scrutinize the distribution effects of the fiscal transfers. The distribution of consumption for all agents are compared across the different policy combinations.

The paper contain 5 subsequent sections. Section 2 gives a brief literature review. In section 3, we provide details on how the agents interact and describe key characteristics of the model. Section 4 details specific events that happen in the simulation and the rules agents follow in order to make decisions. Section 5 contains results from the basic simulation, results from the COVID-19 shocks, and results from different policy combinations used to combat the initial shock. Finally, section 6 contains the conclusions.

2 Related literature

ABM is an analytical tool that has been applied to a wide range of scientific fields. Since the global financial crisis in 2007-2008, there have been a growing literature on the applications of ABM to macroeconomic studies. Gatti et al. (2010) and Lengnick (2013) have argued in favor of micro-founded ABM as an alternative to prevalent dynamic stochastic general equilibrium approach. Due to its microfoundation and flexibility, ABM in macroeconomic field has many applications and variations. One of the primary uses of ABM is to study the effects of various policy options. For example, Raberto et al. (2008) developed a model that consists of real and financial sectors to examine the effects of different monetary policy rules, Dosi et al. (2015) studied the macroeconomic impacts of different fiscal and monetary policies, and Dawid et al. (2017) analyzed the performance of different fiscal policies attempting to close the economic gap between core and peripheral countries in the European Union.

In analyzing the role of banks in the economy, Ashraf et al. (2017) developed a trading network consisting of autonomous agents that interact with each other in a self-organizing manner. Banks provide collateralized loans to businesses who can then adjust their production amounts in line with expected demand. Regarding the role of financial intermediaries, banks are thought to be the 'financial accelerators' as proposed by Bernanke & Gertler (1989); when macroeconomic conditions turn sour, banks can worsen the situation as they decrease lending due to lower collateral prices. However, Ashraf et al. (2017) found that banks' role as 'financial stabilizers' are more pronounced than their role as 'financial accelerators' as their credit provisions allow existing firms to survive through the crisis and allow new firms to replace bankrupted ones.

Given complicated economic issues pertaining to financial stability, central banks need to rely on macroprudential policies in addition to just the policy rate. Interaction between these two tools become of interest to central bankers and is explored by Popoyan et al. (2017). Extended from the model of Ashraf et al. (2017), Popoyan et al. (2017) explored the effectiveness of different monetary policy rules and different combinations of macroprudential policies. They found that monetary and macroprudential policies are complementary and that the most stringent macroprudential policy rules are best for crisis prevention.

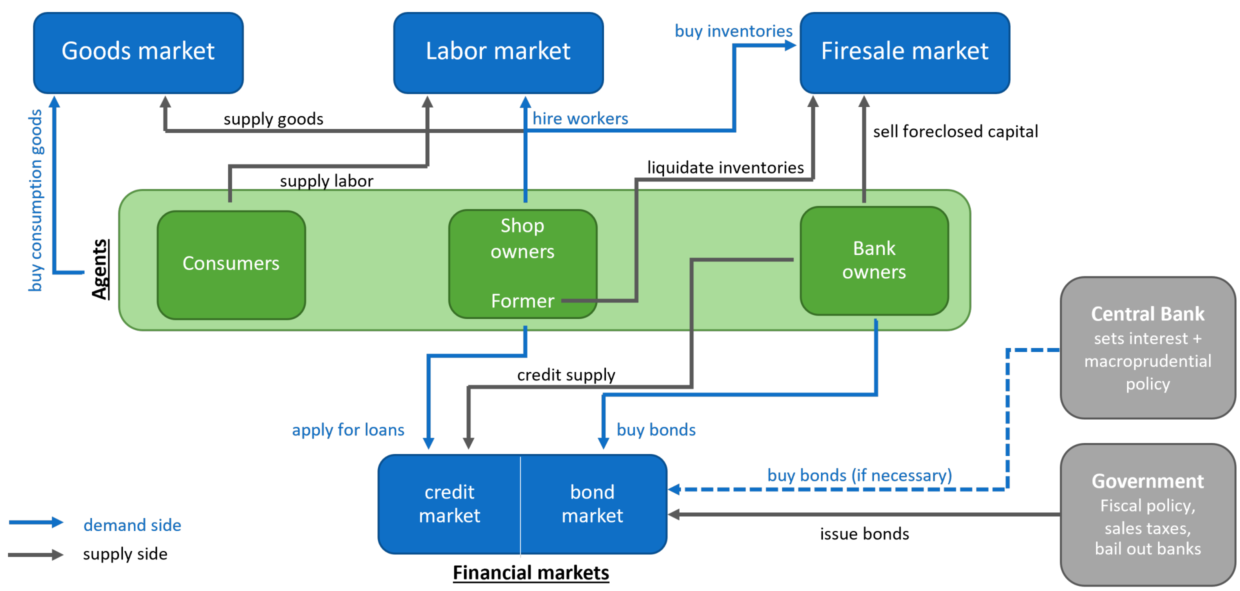
There are two main reasons why we chose to base our model on those of Ashraf et al. (2017) and Popoyan et al. (2017). First, the banking sector is a vital component for the Thai economy as most private borrowings are sourced through bank credits. Second, macroprudential policies have become an increasingly important tool that central banks in many countries, including Thailand, have deployed to tackle trade-offs between maintaining accommodative monetary stance to support growth and raising the policy rate to curb financial stability risks which arise from the low-for-long interest rate environment. These two aspects are even more prominent during the crisis. The recent COVID-19 pandemic highlighted the importance of the banking sector's role in providing much-needed liquidity support to hard-hit businesses and households in Thailand. In addition, other policy measures, including fiscal stimulus and the relaxation of macroprudential regulations, have been deployed in conjunction to minimize the COVID-19 economic impact. Policymakers need to carefully consider the interactions of different policy tools to find the optimal policy mix. As will be evident in the following sections, this paper aims to explore these relationships with the COVID-19 crisis as a background context.

To replicate the economic impacts of COVID-19 pandemic and evaluate different fiscal policies in Thailand as well as its interaction with monetary policy, we extend the model from the previously mentioned papers in several ways. First, the model is calibrated so that the result largely matches macroeconomic data of Thailand. Second, we incorporated a negative demand shock to replicate the COVID-19 impacts on Thai GDP. Third, different fiscal policies which represent the Thai government's actual measures are then applied in the crisis scenario. Finally, we explore the effects of different combinations of fiscal and monetary policies, both in aggregate and micro levels.

3 Model

The overview of the model is shown in figure 1. The agents are shown in green and the markets are shown in blue. Two regulatory agents, the central bank and the government, are shown in gray. The interactions are represented by arrows; black ones connecting suppliers to the markets, and blue ones connecting purchasers to the markets.

Figure 1: Overview of the model



3.1 Role of agents

There are five different agent types in the model: consumers, shop owners, banks, central bank, and the government. The first three agent types can endogenously change roles depending on each individual's circumstances. The agents interact to form the four markets: goods market, labor market, fire-sale market, and financial markets.

In each time frame, a consumer is endowed with one unit of labor and can provide this labor to the labor market. He can also buy goods from the goods market and deposit their surplus cash to the bank owner. Cash-rich consumers can also become entrepreneurs by opening a shop and changing their role to shop owners. Shop owners buy labor from the labor market and translate units of labor into units of goods one-to-one. They also sell goods to the goods market and apply for loans from the credit market. In addition, they have the option to buy cheap goods from the fire-sale market. When shop owners exit the market, their role changes back to consumers. However, some former shop owners may still have goods in their inventory that they produced from before but failed to sell. These former shop owners can sell those goods in the fire-sale market. Bank owners are another group of agents participating in the fire-sale market. They sell foreclosed capital obtained through the seizing of collateral. Apart from receiving deposits from other agents and participating in the fire-sale market, banks also provide credit to firms, buy bonds from the government, and can borrow or lend to the central bank.

In the model, the central bank acts as a stabilizer, attempting to balance the economy by conducting monetary and macroprudential policies. For monetary policy, the central bank sets the economy-wide interest rate by responding to the inflation and output gaps. In addition to monetary policy, the central bank also sets macroprudential policies in enforcing capital adequacy and liquidity coverage ratios on banks. The macroprudential policies' aims are to ensure the smooth operation of the financial system, allowing those in need the access to credit and the ability to take out loans.

The policy rate gets factored into the economy through the agents' calculation of wealth, which is current assets plus an infinite stream of current profits/wages they are receiving. This infinite stream of future cashflow is expected to grow based on expected inflation and is discounted back using future expected policy rates (the details can be found in section 4.8). After calculating wealth, the agents consume a fixed portion of their wealth. Thus, keeping everything else constant, when the policy rate is low, the agents' perceptions of their wealth increase and as a result we can observe an increase in aggregate demand for consumption and a higher GDP.

The changes in consumption demand can lead to changes in prices. Demand is a function of personal wealth, while supply is based on sales in previous periods. The interactions between these variables drive the price dynamics in the economy. When there is excess supply, shop inventories grow. A shop regularly reevaluates the price it sets for goods based on its inventory-to-sales ratio. Similarly, in the labor market, a shop looks at its previous demand for labor and the number of workers it actually hired in previous periods in order to set wages. If the amount hired is lower than the amount demanded, it raises the wage to try to attract more workers.

The government's role in the model economy is to bail out banks and conduct fiscal transfers. If a bank has negative equity, the government injects cash into the bank and another owner steps in to take over the zero-equity bank. Apart from bailing out banks, the government can provide conditional and unconditional cash transfers to agents in the economy and can subsidize sales of goods in the economy. For the conditional cash transfers, we want the government to target the poor, which is proxied by unemployment status. In order to bail out banks and conduct fiscal measures, the government can issue bonds which are held by banks and collect sales tax from the population.

3.2 Model specifications

In line with Ashraf et al. (2017), there is n number of durable goods in the model and the same n number of labor types. Each labor type i is used to produce the i durable good. Each agent has two consumption goods. Each agent can be characterized by being a type (i, j), where i is the labor good he is able to produce, j being his primary consumption good, and $j + 1$ being his secondary consumption good. We do not allow one to consume his own labor good, thus $i \neq j$ and $i \neq j + 1$. With the assumption that there is exactly one agent of each type, there are $N = n(n - 2)$ agents in the economy.

A shop owner is an agent that is allowed to use his own labor to produce good i. He can also hire other agents with the same labor good i. A shop acts as both a place for production using labor and a place for trade. Goods can only be traded through shops; a consumer cannot directly sell his own labor good to another consumer.

There are three possible relationships a consumer can have: an employer-employee relationship with a production shop, a customer-store relationship with his primary consumption goods shop, and a customer-store relationship with his secondary consumption goods shop. A relationship is exclusive in that a consumer can only supply labor to one shop, can only shop at one primary shop, and can only shop at one secondary shop. These relationships change through time, however; namely, the employees are always looking to get better wages and the customers are always attempting to obtain lower prices.

There are M number of banks in the economy. Each bank serves N/M number of clients (including himself) and acts as monopoly within those set of clients. The loan rates and deposit rates are assumed to be the same across the economy, with the loan rate being a fixed percentage point above the policy rate and the deposit rate being a fixed percentage point below the policy rate.

4 Events in the model

4.1 Timeline of events

For the simulation, each run consists of 1000 time periods, with each time period representing one month. In a crude approximation, each month consist of the following eight events in chronological order.

- Shop entry
- Search and matching
- Banks and credit
- Budget planning
- fire-sale
- Labor and goods trading
- Government and central bank
- End of period decisions and calculations

Each event is described in detail in the following subsections.

4.2 Shop entry

In each period, a proportion θ/N of consumers become entrepreneurs wishing to open up new shops. The entrepreneur will only open up shop, if and only if, he meets the following three criteria: liquidity, profitability, and market research.

For the liquidity criteria, the entrepreneur must have enough assets, defined as his cash holdings, his deposits at the bank, and credit line given to him by the bank, to cover setup costs S. The setup costs S is expressed in the number of units of that agent's primary or secondary goods. If the agent were to pass all the criteria and open up shop, this S amount of units will be kept as initial capital on the shop owner's balance sheet until he quits (there is no depreciation in the model). If he had previously opened up shop and not sold this initial capital, he can just use that amount to cover the setup costs. Since loans in this model is assumed to be fully collateralized, this initial capital can be used to obtained the initial credit line. If the bank in that sector is not in trouble, the credit line is equal to the haircut price of the initial capital. This is to be discussed in detail in subsection 4.4. Once it is determined that the entrepreneur has enough liquidity to cover this initial setup costs, he has to find and buy these goods from the market, unless he already had them from before as a previous shop owner. He can obtain the goods from either the fire-sale market or through the trading relationships with his consumption shops.

The entrepreneur assesses her prospects of her new shop using the profitability criteria. Before the profitability can be calculated, the entrepreneur must determine three numbers. She first decides the wage that the shop will pay its workers:

$$w_{i,t} = W_t(1 + \pi^*)^{(\Delta+1)/2} \tag{1}$$

W represents the publicly-known weighted average wage for the whole economy, π^* represents the central bank's target inflation rate, and Δ represents the length of time until the next wage readjustment period (subsection 4.9). Basically the wage is set to be the prevailing wages in the economy adjusted by the expected average inflation rate until the next time the wage is set. Second, she has to determine the amount she expects to sell, y_{trg}, which is a random number between 1 and n. Third, she must determine the price at which she is going to sell her goods. This "markup" μ is a random percentage between 0 and 2 times $\bar{\mu}$, the average markup for the economy. She then sets the price based on the markup and the current sales tax rate, τ.

$$p = \frac{w(1 + \mu)}{1 - \tau} \tag{2}$$

With the wage, price, and sales target, she can calculate the expected profit using the following equation. This equation includes both the accounting profit and the opportunity cost of using the initial money to obtain interest on deposits. If the net profit is greater than zero, the shop owner passes profitability check.

$$\Pi = (\mu - i_D)y_{trg} - (1 + i_D)(F - 1) \tag{3}$$

i_D represents the monthly interest rate on deposits and F represents monthly fixed costs.

For the last criteria, the entrepreneur tests the market by contacting two other random agents. The first random agent is a consumer whose labor good is the same as the entrepreneur. This labor market test is considered successful if the wage the entrepreneur is offering is higher than the wage the random agent received in the previous period. Similarly, a second random agent, whose consumption good is the same as the entrepreneur's labor good, is chosen. The consumer market test is considered successful if the entrepreneur's price is lower than the price the random was paying his previous shop for this consumption good.

If the entrepreneur passes all three criteria, she terminates her previous labor arrangement if she has any and enters the market with the first random agent as her sole laborer and the second random agent as her sole customer. If her wage and price are competitive, she will gain more laborers and customers in the next phase.

4.3 Search and matching

A key part of the model is the representation of frictions in the labor and goods market which translates into the agents' inability to always find the best prices for goods and labor. This subsection outlines the search decisions that happen when agents try to look for better wages and prices.

All unemployed consumers and a portion σ of employed consumers search for new jobs in each period. He does this by asking a random agent with the same labor good what his wage is if the random agent is a consumer (or what the shop's posted wage is if the random agent is a shop owner). If the rate is higher than his own wage, he switches his workplace and gets a new job with the higher wage.

A customer continuously searches for better prices every period. She first looks for a "friend referral" by picking a random friend with the same primary consumption good and check whether the price of either of the friend's shops are lower than hers. If she succeeds in finding a shop that has a lower price than hers, she stops; otherwise, she goes on and tries "direct search." In "direct search," she picks a random shop that sells either of her consumption goods, with a priority placed on the good that she doesn't have a trading relationship. She again compares this random shop price with those of her own and switch when it is favorable for her.

4.4 Banks and credit

The next event consists of bank activities. Banks have to maintain the minimum amount of reserves, usually calculated as a certain portion (ξ) of deposit liabilities, with the central bank. Banks also have to maintain liquid assets according to the liquidity coverage ratio (LCR) requirement. This is defined as high-quality liquid assets (HQLA) to net cash outflow in the next 30 days. In our model, this is calculated as:

$$LCR = \frac{HQLA}{SToutflow} = \frac{cash + bond + reserve}{deposits} \tag{4}$$

If banks cannot meet this LCR requirement, it is allowed to borrow from the central bank to cover this liquidity shortage but will incur a penalty interest rate.

In the next step, banks update the amount of equity they currently possess after the previous month's activities and shop entry. If their equity falls below zero, the owner is forced to exit and becomes a consumer. The government steps in by injecting capital into the bank so that the equity is restored back to zero. The bank's richest customer (excluding shop owners) becomes the new owner.

If the equity is greater than zero, but less than the minimum capital adequacy ratio (CAR), the bank is not allowed to extend new loans. However, it is allowed to roll over existing loans. Since our model is a simplified version of the real world, CAR simplifies to the following equation.

$$CAR = \frac{Tier1Equity + Tier2Equity}{RWA} = \frac{equity}{loans + collateral} \tag{5}$$

Tier 1 capital is just current equity on the balance sheet. The risk weighted assets, simplifies to loans and seized collateral, which are weighted at 100 percent. The other assets on the bank's balance sheet, namely cash, government bonds, reserves, and loans to the central bank all have risk weights of zero. Collateral is valued at the haircut price P_h. In our model, the haircut price is a fraction of the price the bank is able to sell in the fire-sale market.

$$P_h = h \cdot w(1 + \pi^*) \tag{6}$$

h is the haircut ratio, w is the economy-wide average wage, and π^* is the target inflation.

Banks with CAR greater than the required amount can extend new loans. They will first evaluate whether the shops are worthy of additional credit line using the quick ratio (QR) to evaluate liquidity, the return on asset (ROA) ratio to evaluate profitability, and debt to equity (DE) ratio to assess leverage.

$$QR = \frac{CurrentAssets - Inventories}{CurrentLiab} = \frac{deposits + cash - inventories}{loans} \geq \kappa \tag{7}$$

$$ROA = \frac{NetIncome}{Assets} = \frac{\Pi}{deposits + cash - inventories} \geq \psi \tag{8}$$

$$DE = \frac{TotalLiabilities}{Equity} = \frac{loans}{equity} \leq \varrho \tag{9}$$

If the shop meets these three criteria, the bank will update the shop's credit line. The new credit line will be the haircut price of all inventories and setup capital that the shop possess. For new shops, none of these ratios can be calculated. The bank simply sets a target loan approval rate based on how much their capital is higher than the minimum required amount. Each new potential entrant's chance of getting a credit line is randomized based on this loan approval rate (l).

4.5 Budget planning

In this stage, the agents plan their budgets and decide how much to spend on goods. The amount they plan to spend on consumption is a percentage of their wealth. In order to calculate wealth, each agent must first figure out their own permanent income.

$$\Delta Y^p = \lambda(Y_t - Y^p_{t-1}) \tag{10}$$

Y_t is the actual income for that agent. Actual incomes for consumers come from wages; actual incomes for shop owners are from shop profits, and actual incomes for bank owners come from changes in bank equity. The concept of income persistence is used in order to take into account previous income and prevent a large jump in consumption when they suddenly become unemployed or suddenly become rich. After the calculation of permanent income, one can now calculate planned expenditures:

$$E = v(A + Y^p \cdot V) \tag{11}$$

v is the percentage of wealth spent on consumption, and V is the capitalization factor. The capitalization factor is the conversion factor that translates an infinite stream of income into the present value of wealth. It is assumed to be calculated by the central bank and announced to the public. Assets for consumers comprise of cash and deposits; in addition to those two assets, shop owners have to subtract out their outstanding loans. Shop owners whose wealth plus credit line fall below zero are considered to be "bankrupt" and have to shut down their businesses. The bank then seizes collateral, which are shop inventories and fixed capital, and sell them in the fire-sale market. During this process, the bank loses a fraction C_b of seized collateral as foreclosure costs. Simultaneously, all employees of "bankrupt" shops become unemployed and will search for new jobs in the next period.

Next, the agents redistribute their assets so that they have enough cash to spend. For consumers, this is just shifting their wealth between cash and deposits. Bank owners can move between equity and cash as long as the equity is more than the required amount set by the central bank. Shop owners need to take into account their wage bill and also credit line if their assets alone cannot cover both consumption expenditures and wage bill. For shop owners who don't have enough assets and credit lines to cover both the wage bill and consumption, they will prioritize wage bill first at the expense of their consumption. The wage bill is a function of the shop's posted wage and shop's sales target, and can be calculated as follows:

$$WB = wage \cdot (Y^{target} - 1) \tag{12}$$

4.6 Fire-sale

There are two types of sellers in this market: former shop owners with inventory from their past role and banks with seized collateral. The fire-sale market is the cheapest way for shops to obtain inventory to sell. Shops in random order get to enter the fire-sale market and buy from the sellers in queue. To pay for the goods, the buying shop must have enough deposit or a line of credit with a bank whose capital ratio is above the minimum. The price is similar to the haircut price with a different ratio multiplied to.

$$P_h = f \cdot w(1 + \pi^*) \tag{13}$$

f is the fire-sale ratio, w is the economy-wide average wage, and π^* is the target inflation.

4.7 Labor and goods trading

In this step, the trading occurs in the labor and goods markets. In a random order, each agent either trades with his employer in the labor market or trades with stores in the goods market. Bank owners do not trade in the labor market.

Labor market trading happens in the following manner. If the agent is a consumer without an employment relationship, nothing happens. If the agent is a shop owner, no cash changes hand as he exchanges his own unit of labor into one unit of goods. If the agent is a consumer with an employment relationship, he offers his unit of labor to the shop and gets paid the effective wage.

$$w^{eff} = \min\{w, cash_{owner}\} \tag{14}$$

The employee is paid the lower of the posted wage and the shop owner's current cash holdings. If the shop owner's cash is exactly zero, no trading occurs but the labor trading relationship is not terminated at this stage.

Every agent participates in the goods market to fulfill their consumption needs. The agent goes through the following process. First, she learns of her primary and secondary shops' prices p_1, p_2 and current inventories i_1, i_2. She then optimizes by maximizing the additive utility function $c_1^{\epsilon/(\epsilon+1)} + c_2^{\epsilon/(\epsilon+1)}$, where ϵ is the demand parameter, with the budget constraint $p_1 \cdot c_1 + p_2 \cdot c_2 \leq E$, and inventory constraints $c_1 \leq i_1, c_2 \leq i_2$. The agent's view of the shops' prices will increase if the inventory constraints are binding. The government collects sales tax from all sales at this stage.

Two things are worth noting related to this event. First, there are fixed costs associated with production of goods. The fixed costs are expressed in units of goods and the first units of goods are used to cover this fixed costs rather than go to production of goods. Second, the initial setup capital and any leftover inventory after this stage do not depreciate over time and do not require future investments to sustain.

4.8 Government and central bank

In this model, the government injects cash into failed banks, collect taxes, and set tax rates. When a crisis hits, the government also conducts fiscal measures to help support the economy. The specific fiscal measures are described in detail in subsection 5.3

We made a simplification that the central bank policy committee meets in the first two months of every quarter. The central bank sets the economy-wide baseline interest rate based on the Taylor rule with inflation rate and output gap. The interest rate is not updated unless there is a meeting.

$$\ln(1+i) = \max\{\ln(1+i^*) + \gamma_\pi[\ln(1+\pi) - \ln(1+\pi^*)] + \gamma_y[y - \tilde{y}], LB\} \tag{15}$$

where i is the policy rate, i^* is the natural rate plus π^*, the inflation target, γ_π and γ_y are weights on the inflation and output gaps. The inflation rate π is the current year-on-year change in average prices, y is the log of the past 3 month's average GDP and $\tilde{y}$ is the potential GDP based on the Hodrick-Prescott filter of previous and current quarterly GDP numbers. LB represents the lower bound of interest rate, which is set to be zero, unless specified otherwise. Banks then set their deposit and lending rates equal to the interest rate minus a small deposit spread (s_d) and the interest rate plus a fixed loan spread (s_l), respectively.

In order to publish the capitalization factor to allow the agents to mathematically convert a stream of income and current assets, the central bank projects the output gap and inflation gap into the future. The central bank expects the economy to eventually reach steady state and both these gaps will reach zero. In order to project, they multiplied the current gap by a constant, which is less than one for each period going forward. In line with those forecasts, the central bank calculates its Taylor rule based policy rates into the future. With future inflation and policy rates, we can calculate the present value of a stream of cash flow whose growth is the inflation rate and the discount rate being the policy rate. The first stream of cash flow occurs one period into the future, so there is an extra $1/(1+\pi_t)$ multiplied in front as follows:

$$V = \sum_{t=1}^{\infty} \left(\frac{1}{1+\pi_t} \right) \prod_{k=1}^{t} \left(\frac{1+\pi_k}{1+i_k} \right) \tag{16}$$

Note that in the steady state, this follows the dividend discounting model in finance and reduces to:

$$V = \frac{1}{1+\pi^*} \cdot \frac{1}{i^* - \pi^*} = \frac{1}{1+\pi^*} \cdot \frac{1}{r^*} \tag{17}$$

The capitalization factor calculated by the central bank is announced to the public. This is what the agents use to convert their permanent income into present wealth and the channel that links the policy rate to consumer consumption.

4.9 End of period decisions and calculations

At the end of the month, there are still a few decisions that agents have to make and a couple of economy-wide measures to be updated. First, shops have to decide whether to exit or not. We again want to stress that there are frictions in the labor and goods markets which translate into the agents' inability to always find the best prices for goods and labor. One of the frictions in the model is the random exit of shops, even when they are making profits. In the real world, the owner might become too old to operate the shop, or they might be bored and want a new challenge. In our model, a small fraction δ of shops quit and become consumers. All bank loans are repaid if they have enough assets to cover the loan outstanding; if not, banks seize all assets and collateral until all debts are settled or there is no further assets to seize. The exiting shops put all their remaining initial setup capital and inventories into the fire-sale queue and attempt to liquidate them in the next period. All his employees are laid off and must look for a new place to work in the next period.

Next, shops update their sales target. In our model, we let this number be the current period's sales plus two. This makes the shop slightly optimistic, allowing room for them to expand and a buffer in case they are not able to hire all the workers they need. The next event in our chain is wage setting. The standard DSGE model with frictions typically use Calvo pricing as introduced by Calvo (1983). This model somewhat follows a similar train of logic. Each period, only a set of firms get to update their wages. The rule is that firms can only update wages once a year on their anniversaries of their shop birth. The new wage is set as follows:

$$wage_{t+1} = wage_t \cdot [1 + \beta(input^t/input^a - 1)] \cdot [1 + \alpha * \pi^* + (1 - \alpha) \cdot \pi_{t-12:t}] \tag{18}$$

β is the wage adjustment coefficient, $input^t$ is the amount of labor the firm tried to hire in the past year, $input^a$ is the actual labor the firm hired, and α is the weight the firms put on the central bank's target inflation as opposed to the recent trends in inflation. Basically, if the firm is able to fill every position they planned to fill in the previous year, they will increase their wages somewhere in between the previous year's inflation rate and the central bank's target rate. They will also further increase their wages if they are unable to fulfill their hiring needs.

We do allow the firms to adapt and change prices every period. This is due to the more dynamic nature of sales. Firms that update their wages will also update their prices; increasing them by the same percentage. All firms also adjust their prices based on their inventories-to-sales ratio; lowering their prices when inventories accumulate and increasing them when inventories are too low.

$$
\begin{aligned}
p_t = p_t \cdot \gamma_p^{-1} \qquad & \text{if} \quad \frac{inventories_t}{sales\ target_t} \; > \; IS \\
p_t = p_t \cdot \gamma_p \qquad & \text{if} \quad \frac{inventories_t}{sales\ target_t} \; < \; IS^{-1}
\end{aligned} \tag{19}
$$

Next, the economy-wide measures are recalculated and "announced" to all agents. The weighted average wages and prices are calculated based on the events that happened in the goods and labor markets. GDP and inflation rates are also calculated. In the final step, all the amounts that have accrued interest: deposits, loans, bonds, and central bank loans, are updated using the appropriate interest rates. Since all the rates are tied to fixed spreads relative to the central bank's policy rate, they are, in turn, updated to match the new policy rate.

5 Simulation and results

This section is divided into three subsections. The first subsection displays the results and statistics for a regular run. The second subsection describes an expectation shock that drags demand and results in a deep GDP decline that mimics the COVID-19 impact. The third subsection dives into how monetary and fiscal policies can help support the economic recovery from a COVID-19-like shock.

5.1 Results from normal simulations

A small amount of calibration is performed such that the four main aggregate variables and their standard deviations are within the same order of magnitude as their historical values. The four main aggregate variables we focused on are GDP growth (quarterly), inflation rate, unemployment rate, and the policy rate. Historical GDP is the only available quarterly; thus, we aggregate the monthly values into quarters before comparing the model results with historical ones. For inflation, we compare the model's mean to the historical mean of headline inflation rate, but we compare the model's standard deviation with the standard deviation of core inflation. This is due to large swings in the energy component of inflation which is not endogenous to the Thai economy. The official Thai unemployment rates are low due to the agricultural sector, which acts as a fallback choice for a large group of the population. The Bank of Thailand has another time series to count those that are unemployed and underemployed, and we are leveraging this time series instead of the official unemployment rates. Historical data used for comparison are from the period between January 2000 and August 2020.

Results of five different runs are shown in Table 1 and plotted as time series in Figure 2. The values for inflation and unemployment rates are roughly in line with actual data. The model's GDP numbers are lower than actual historical numbers. This is a limitation of the current model where productivity and population are kept constant, implying that in the long run, the growth rate will converge to the inflation rate. The policy rate in the model is also much higher in terms of both the mean and standard deviation. The natural rate of interest r^* is set higher than the current estimates for the Thai economy but since it is in the long-run capitalization factor in Equation 17 in the denominator, setting this value too low can lead to an unstable model. The standard deviation from the model is also higher due to two factors; (1) we do not add an auto-regressive term in Taylor rule and (2) we do not discretize the Taylor rule result so that the interest rate moves in discrete 0.25 percentage point like what happens in the real world.

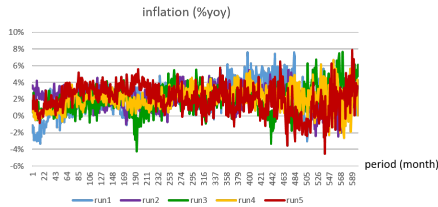
Figure 2 shows how the variables move in the 50 year period. The range of GDP growth is between -9 percent and +12 percent. Unemployment rates seem to have persistence and settle at many different levels or equilibriums.

Table 1: Statistics from 5 runs

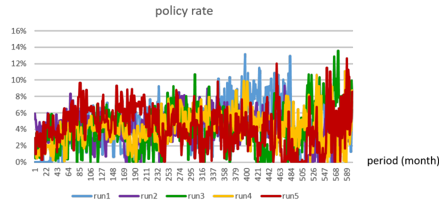
	GDP		Inflation		Policy rate		Unemployment	
	mean	SD	mean	SD	mean	SD	mean	SD
Simulation	2.2%	2.6 %	2.1%	1.5%	4.2%	2.4%	6.6%	1.8 %
Actual	6.2%	4.8 %	1.9%	0.8%	2.2%	1.0%	8.1%	2.0 %

5.2 COVID-19 shocks

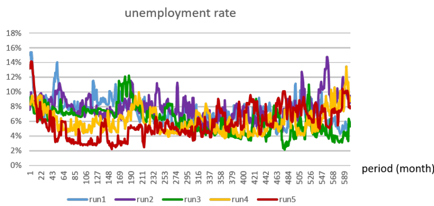
We introduce COVID shocks to the agents' expectations of future income. This is done via a sudden decrease in permanent income. We made the following assumptions. When times



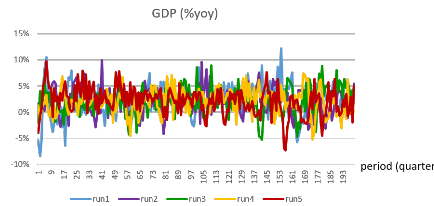
(a) Inflation



(b) policy rate



(c) unemployment rate



(d) GDP (quarterly)

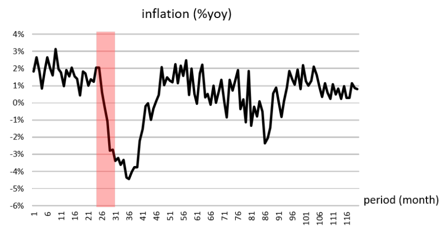
Figure 2: Results for runs without shocks

are bad, agents are not secured about their future and factors in higher unemployment as well as lower future wages and shop incomes. We calibrate parameters so that in the worst time of the crisis period, the nominal GDP growth (YOY%) is similar to those of Thailand in the second quarter of 2020.

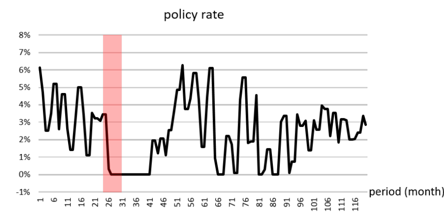
Here, we display results from a single run in Figure 3. The shock generates the expected responses in the aggregate variables; inflation rate and GDP growth rate drop while the unemployment rate soars, the policy rate responds by dropping to the lower bound for many periods after the initial shock. The results are also tabulated in Table 2 in which the averages of key variables are compared for the period 12 months before the shock and 12 months after the initial shock.

Table 2: Average of key variables for 12 periods before and after the shock

	Before crisis	After shock
GDP	3.5%	-9.4%
Inflation	1.5%	-2.2%
Unemployment	8.1%	10.8%
Policy rate	3.0%	0.3%

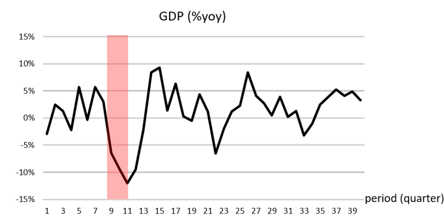


(a) Inflation



(b) policy rate

(c) unemployment rate



(d) GDP (quarterly)

Figure 3: Results for runs with COVID-19-like shock

5.3 Policy simulations in response to COVID-19 shocks

In the previous section, we observe that the interest rate hits the lower bound for quite some time, suggesting that the central bank's ability to stabilize the economy using interest rate may have its limitations. In 2020, many countries including Thailand have turned to fiscal policies to provide the boost necessary for the economy to continue on its previous path before the crisis. This subsection aims to answer two questions: (1) which fiscal policies are more effective and (2) should monetary and fiscal policies be used in coordination?

5.3.1 Different fiscal policies

Three different fiscal policies are considered in our model. First, we assume an unconditional cash transfer to all agents in the economy. This cash transfer acts like a short term universal basic income. This is trying to mimic the "We don't leave anyone behind" policy, which the Thai government made transfers to 15 million people affected from COVID-19. In the model, this increases the agent's actual income, Y, which in turn affects permanent income, Y^p, total wealth, and consumption. In the second policy option, the government is concerned about distribution of income and make cash transfers only to those who are unemployed. Here, we are trying to replicate the effects of the state welfare card program, which make transfers to the poor with a strict income and assets threshold. In our model, the unemployed is likely to be the poorest agents with the least income. In the third policy option, the government subsidizes half of consumption up to a certain point. This is to mimic the "Let's Go Halves" scheme which subsidizes up to 150 Baht of daily consumption, up to a total of 3000 Baht. In the model, we increase the consumption expenditure budget and subsidize cash to the agent during the transaction. There will be some cases that the agent might not actually use up all the subsidy if his initial planned consumption is less than the subsidy and if he is unable to find goods to buy from his shops.

In our model, we make the fiscal policy cost roughly 1% of annual GDP in all three cases to make them comparable. We make the unconditional transfer amount the same as the subsidy amount. Since the unemployment rate is roughly 10% during the crisis, we make the conditional transfer amount to be 10 times higher.

The results are shown in two dimensions in Table 3 and Table 4. Table 3 shows the economy-wide aggregate values similar to Table 2. All of the policies help reduce unemployment rate and lift GDP and inflation rates. At the aggregate level, unconditional transfers and conditional transfers have similar effects. (Note: since we used a crude approximation with the assumption that the unemployment is constant at 10%, the cost to the government is 0.1% of GDP higher in the UCT case and thus slightly more effective) This is due to the homogeneity of our agents, the cash transfer translates to expenditures very similarly across the population. The subsidy to consumption is best for the economy. In the model, this is mainly due to the permanent income adjustment parameter (λ) that the increase in current income does not translate to permanent income right away. On the other hand, the subsidy provides an immediate boost to consumption. This boost also has knock-on effects on future employment as the shops hire more after getting higher sales.

Table 4 shows the average consumption of consumers before and after the crisis with all the different fiscal policy options. If the government is concerned with distributional effects on different segment of the population, the conditional cash transfer represents the best outcome for the 10^{th} percentile of the consumers. This is despite the fact that overall GDP is 2.5% worse than the subsidy option.

With these two dimensions, we can already see that the government needs to weigh

Table 3: Comparing economic aggregates for different fiscal policy options. Numbers are the average for 12 periods before and after the initial shock period

		after crisis			
	before crisis	No policy	UCT	CCT	Subsidy
GDP	3.5%	-9.4%	-6.7%	-7.0%	-4.5%
Inflation	1.5%	-2.2%	-1.4%	-1.6%	-1.5%
Unemployment	8.1%	10.8%	10.1%	10.3%	9.9%
Policy Rate	3.0%	0.3%	0.3%	0.3%	0.4%

their policy options carefully. If they solely care about aggregate values of GDP, they must select the policy options that directly affect consumption, such as a subsidy. Targeting the right group of people to help is a key concern for governments as well. The 75^{th} of the population are less effected by the shock, and helping them may not be the best way to spend money.

Table 4: Comparing distributional effects of different fiscal policy options. Numbers are the average units of consumption goods each period for 12 periods before and after the initial shock period

		after crisis			
	before crisis	No policy	UCT	CCT	Subsidy
10^{th} Percentile	0.17	0.02	0.04	0.11	0.03
25^{th} Percentile	0.43	0.33	0.34	0.33	0.34
50^{th} Percentile	0.65	0.62	0.62	0.62	0.64
75^{th} Percentile	0.80	0.78	0.79	0.79	0.81

5.3.2 Stand-alone vs coordinated policy

In this last section, we look at whether the policies are complementary in getting the economy out of a crisis. We look at four different scenarios; (1) the no policy case where we freeze the policy rate at the latest level before the shock, (2) the regular case where the monetary policy is allowed to go to zero percent, (3) monetary policy rate is again held constant and only the fiscal policy is implemented, and (4) regular monetary policy case with the implementation of fiscal policy. In this section, we look at aggregates so we decide to use the subsidy option for fiscal policy as it is shown to be the most effective in affecting aggregates.

The results are shown in Table 5. The key takeaway here may be that the fiscal policy is more effective than monetary policy. This may be in part because monetary policy is bounded at zero percent and can no longer boost consumption beyond that point. Monetary policy is able to improve GDP by approximately 0.2%, and fiscal policy by roughly 2.5%. The combined impact is roughly the sum of the two, at 2.8%. Due to model randomness, it is very hard to say whether the combined impact is more than the sum of its parts. However, in a bad crisis, we may wish to get all the help we can. Even in the case where both monetary and fiscal policies are activated, the unemployment rate still hovers close to 10%.

Table 5: Different combinations of policies. Average of 18 periods (1.5 years) after initial shock

	No Policy	Monetary Policy	Fiscal Policy	Monetary&Fiscal
GDP	-2.6%	-2.4%	-0.1%	0.2%
Inflation	0.1%	0.0%	0.5%	0.3%
Unemployment	11.2%	10.9%	10.4%	9.6%

6 Conclusions

There are at least three major caveats to note when using agent-based models to analyze policies. One, the level of detail required to calibrate behaviors of all agents correctly is enormous. The calibration to Thai data is done only at the aggregate level; with the means and standard deviations of inflation rate, GDP growth, and unemployment rate adjusted to historical data. To get all the behavioral equations and their parameters correctly calibrated is a daunting endeavor that would require further work. Two, while the built-in randomness and frictions are inherently part of what makes agent-based modeling capable of creating extreme 'tailed' events, they pose a challenge to the robustness and stability of the model. Even with the initial calibration in placed, we had to ignore runs where the economic aggregates vary drastically from historical norms. Lastly, there are many aspects that we have simplified but are key elements in the Thai economy. These include the agricultural and export sectors. In addition, the household sector has accumulated more debt in recent years and is an important topic in the policy circles. None of these elements are taken into account in this model.

The main contribution of this paper is the analysis of fiscal policies and their interactions with monetary policy in an agent-based model framework. A simulated economy can be impacted by an expectation shock that can lead to a crisis at the aggregate level. We simulate different fiscal responses to the crisis. The results show that GDP growth can be best supported via fiscal measures related to consumption boosting, such as a consumption subsidy scheme. However, the government can instead target inequality reduction, and use targeted policies to achieve their goals. An unconditional cash transfer are less effective than the other options, but it is easiest to implement. This alone can make it very attractive, as setting up new infrastructure to filter qualified individuals for a targeted policy can have its drawbacks.

We are not able to confirm whether using both monetary and fiscal policies at the same time has more impact than executing them separately. Coordination, however, is likely to be a necessary component of any economy trying to climb back out of the crisis. The central bank's monetary policy alone can only do so much, given the lack of policy space.

The analysis can be extended in many directions. An interesting path to go down is analyzing the short term versus long term trade-off for the government. In our model, we have yet to impose cost on the government for conducting fiscal transfers. We expect the government to tax back the cost after the economy is back on a normal path. In addition, adding key elements of the Thai economy to the model to make it more specific to our needs is something we wish to explore further.

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A Constants

Parameter	Description	Value
Consumer Parameters		
n	number of goods	50
M	number of banks	24
σ	job search probability	0.5
λ	permanent income adjustment	0.4
v	marginal propensity to consume out of wealth	0.002
ϵ	demand parameter	1
Shop parameters		
θ	supply of entrepreneurship	100
S	setup costs	2
F	fixed costs	2
Δ	wage contract length	12
$\bar{\mu}$	average markup	0.2
f	fire-sale ratio	0.5
β	wage adjustment coefficient	0.3
α	weights on target inflation	0.8
IS	inventories-to-sales threshold	3.0
γ_p	size of price increase	1.017
δ	quit rate	0.00075
Bank parameters		
ξ	reserve requirement	0.03
ϱ	debt-to-equity ratio	0.5
κ	quick ratio threshold	0.5
ψ	return on asset threshold	0.1
l	loan approval rate	9
h	haircut ratio	0.5
C_b	foreclosure cost	0.2
s_d	deposit spread	0.005

s_l	loan spread	0.0175
Central bank parameters		
π^*	target inflation rate	0.02
LCR	liquidity coverage ratio	1
CAR	minimum capital adequancy ratio	0.08
γ_π	inflation coefficient	1.5
γ_y	output gap coefficient	0.5
LB	lower bound of policy rate	0