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Money creation within the macroeconomy: An integrated model of banking

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ABSTRACT

We develop a monetary framework to describe a macroeconomic system consisting of households, firms, the government, the central bank, and banks. The framework is based on the balance sheets of all sectors, in which the monetary flows between them govern the dynamics of the items. The whole system evolves over time and eventually attains a stationary state. Using this integrated model, we find that all flows coming from banks, including issuing loans, purchasing bonds, paying dividends, and paying interest on deposits, create money. On the contrary, all flows going to banks, including receiving repayments, selling bonds, issuing equities, and receiving interest on loans and bonds, destroy money. These flows associated with the behaviors of money creation and destruction are core factors that determine stationary states. We show the relationships between these flows and stationary stocks, especially the quantity of money. We also present the dependence of final output on these flows. We analyze the effects of monetary policies, such as changing the rate on loans and the amount of bank reserves. We find that an increase in the rate may yield higher output, while injecting more reserves may result in lower output.

1. Introduction

Ignoring the roles of banking systems and credit is a fatal drawback of macroeconomic models (Stiglitz & Greenwald, 2003; Werner, 1997, 2005, 2012). It also contributes to their inability to predict and interpret the 2008 financial crisis. This drawback challenges the validity of current macroeconomic modeling (Borio, 2011; Morley, 2016; Rogoff, 2011). Before the crisis, the original standard dynamic stochastic general equilibrium (DSGE) models were notably successful in modeling and analyzing the real economy, and thus became dominant in macroeconomic researches. It seems natural and justified to continue fixing and improving the original variants of DSGE models to respond to the challenge. We have thus seen many attempts to integrate credit and banks into current DSGE models in the last decade (Brunnermeier & Sannikov, 2014; Christiano et al., 2010; Gertler & Karadi, 2011; Gertler & Kiyotaki, 2010). Without a doubt, they shed significant light on the interaction between the real economy and the financial sector and explain some stylized facts of the crisis.

Almost without exception, these DSGE models consider banks as financial intermediaries. The models mainly concern the real economy in which money plays no significant role. The key assumption in these models is that banks transfer real resources from depositors to borrowers (Angeles, 2019; Jakab & Kumhof, 2018). This view is called the financial intermediation theory of banking. Actually, as the credit creation theory of banking argues, banks do not transfer real resources, but rather create money and purchasing power (Werner, 2014a, 2016).

The credit creation theory of banking was earlier proposed by several highly respected and influential economists, such as Irving Fisher (Fisher, 1922), John Maynard Keynes (Keynes, 1923), and Joseph A. Schumpeter (Schumpeter, 1934). However, this perspective was discarded and instead the financial intermediation theory of banking dominated in the mainstream literature after the 1960s (Werner, 2014a). Since the 2008 financial crisis, a considerable number of works aim to rethink the role of banking in the macroeconomy. To date, there is a profound change in the understanding of the macroeconomic function of banks. The credit creation theory of banking was rediscovered and increasingly accepted as the proper description of the function of banks in an economy (Benes & Kumhof, 2012; Godley, 1999; Godley & Lavoie, 2007; McLeay et al., 2014a, 2014b; Moore, 1988; Rochon, 2006; Ryan-Collins et al., 2012; Werner, 1997, 2012, 2014a, 2014b, 2014c, 2016).

The credit creation theory of banking describes how banks create or destroy money. McLeay et al. (2014a); Werner (2014b) renew this theory, and show that lending creates money and loan repayment destroys money. In addition, McLeay et al. (2014a) argue that banks buying (selling) securities creates (destroys) money. Furthermore,

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banks issuing long-term liabilities and equity shares destroy money. The method they use to analyze money creation is a one-sector model built on the balance sheet of banks. Using the balance sheet approach, Li et al. (2017) obtain the values of the money multiplier with the liquidity coverage ratio requirement. Xiong and Wang (2018); Xiong et al. (2020) show the different impacts on money supply with liquidity coverage ratio, capital adequacy, and leverage ratio requirements. Xing et al. (2019) further explore the money supply with multiple regulations when considering a heterogeneous banking system with diverse balance sheets. These works shed significant light on money creation and the money supply. According to the credit creation theory, lending creates deposits, or money; newly created money is then the result of lending behavior. Conversely, as the financial intermediation theory argues, lending transforms deposits to loans; newly created loans are the result of lending behavior. Accordingly, these works switch attention from how many loans banks provide to how much money banks create. They show the determinants of the money stock and money multiplier with bank regulations. They also help explain the dramatic drop in the money multiplier in the wake of the 2008 financial crisis (Carpenter & Demiralp, 2012; Disyatat, 2011), which contradicts the traditional theory of the money multiplier (Brunner, 1961; Brunner & Meltzer, 1964).

Essentially, the credit creation theory can be integrated into macroeconomic models such as stock-flow consistent (SFC) frameworks (Godley & Lavoie, 2007), the theory of the monetary circuit (Graziani, 2003), and the quantity theory of disaggregated credit (Werner, 1997, 2005, 2012). In such models, researchers use the credit creation theory of banking to analyze the final output in the economy. The SFC and monetary circuit models explicitly describe banks and their credit creation (Godley & Lavoie, 2007; Nikiforos & Zezza, 2017). They account for credit and money as the stocks on the balance sheet of banks. The core of the modeling approach is the SFC principle that changes in stocks are determined by flows, and stocks affect flows. Moreover, these models emphasize interactions between sectors and the logical sequence of the interactions, thus the key corresponding flows, including consumption, investment, government spending, and the final output, are the main concern of these models.

In another vein, Werner (1997, 2005, 2012) disaggregates the macro link between money and aggregate demand—the quantity theory of money—to propose a parsimonious flow-of-funds model (Werner, 2014c), called the quantity theory of disaggregated credit. The theory states that credit is directly linked to transactions because newly created credit is purchasing power. Furthermore, credit is disaggregated into two types: one used for real transactions and the other used for financial transactions, while the former contributes GDP rather than the latter. Finally, the link between credit for real transactions and the value of GDP transactions is built by introducing the real velocity of credit. Likewise, the link between credit for financial transactions and the value of non-GDP transactions is formalized by introducing the financial velocity of credit. Owing to its parsimony, it is easy to use in analyses of empirical issues (Lyonnet & Werner, 2012; Werner, 2012).

As seen, these works significantly improve the understanding on money creation and its role in the macroeconomy. In particular, in the works of Werner (2012, 2014c), an integrated model of banking and the macroeconomy is put forward, in which the banking sector is put at the center of the model and explicitly linked to both real and financial sectors through credit flows. In this line, our objective is twofold. First, we want to describe money creation processes as interactions between the banking and non-banking sector. Thus, we propose a principle for identifying interactions that create or destroy money. Second, we attempt to link money creation to the quantity of money and final output. Furthermore, we show the policy implications of the model with an emphasis on banks and money creation.

1.1. Model preview

To address these issues, in line with the quantity theory of disaggregated credit, we put forward a monetary framework centering on the banking sector, and place money creation of banks at the core of the model. The economy consists of multiple sectors, including firms, households, the government, the central bank, and banks. In our framework, the balance sheets of them are connected with each other via various monetary flows. The whole system can be characterized by the balance-sheet matrix and transactions-flow matrix.[1] Actually, the former presents the current state of the economic system, while the latter specifies all the interactions between sectors in terms of monetary flows. The two matrixes formulate the dynamics of the system.

Money creation processes are described by the virtual monetary flows associated with creating or destroying money. In this way, we integrate different transactions (interactions) into our framework. As argued by Werner (2012, 2014c), in the quantity theory of disaggregated credit, the banking sector should be placed in the locus of the economy. Our paper adds to this literature by focusing on how the banking sector is linked to the rest of the economy via the money creation processes. To do so, our model elaborates the interactions between the banking sector and non-banking ones, and explains how they create (destroy) money and affect the quantity of money and final output.

1.2. Results preview

For banks, the model enables us to scrutinize banks' money creation and destruction. We can investigate which monetary flows (interactions) between the banking and non-banking sector create or destroy money. Dividend and interest payments create money; equity issuance and interest receipt destroy money. These results extend the current understanding of money creation via banks' lending and purchasing securities, and money destruction via banks receiving repayment, selling securities, and issuing equity. We propose a principle for identifying money creation and destruction according to the direction of the monetary flows.

After scrutinizing money creation and destruction, we focus on the dynamics and stationary states of the whole economy. It is worth noting that money creation and destruction are the core factors determining stationary states. More exactly, we show how the monetary flows associated with money creation and destruction affect the stationary stocks and flows. We obtain the stationary solutions of the system and study them under the assumption that investment, government spending, and demand for loans, bonds, and bank equity are insufficient and exogenously given. The insufficient demand for loans and bonds determines the stationary volumes of loans and bonds, respectively. The demand for equity, loans, and bonds from banks, as well as the cost to banks of holding reserves, govern the stationary amount of bank equity.

More importantly, we solve for total deposits, the quantity of money in our case. Our results show that money creation and destruction determine the stationary quantity of money, rather than the equilibrium point determined by equating the supply of and demand for money. More exactly, we express the quantity of money in terms of all money creation and destruction processes. The expression of the quantity of money explicitly includes the terms associated with lending and repayment, bond purchase and sale, and equity issuance. In addition, how the quantity of money relies on dividend payment, interest payment, and interest receipt are given by the sensitivity of the money stock with respect to the interest rate on equity, deposits, and loans and bonds, respectively. The sensitivity is positive (negative) if the payment (receipt) of interest creates (destroys) money. Its absolute value with respect to the interest rate on an asset equals the amount of the asset of a

[1] For more details, please see Godley and Lavoie (2007).

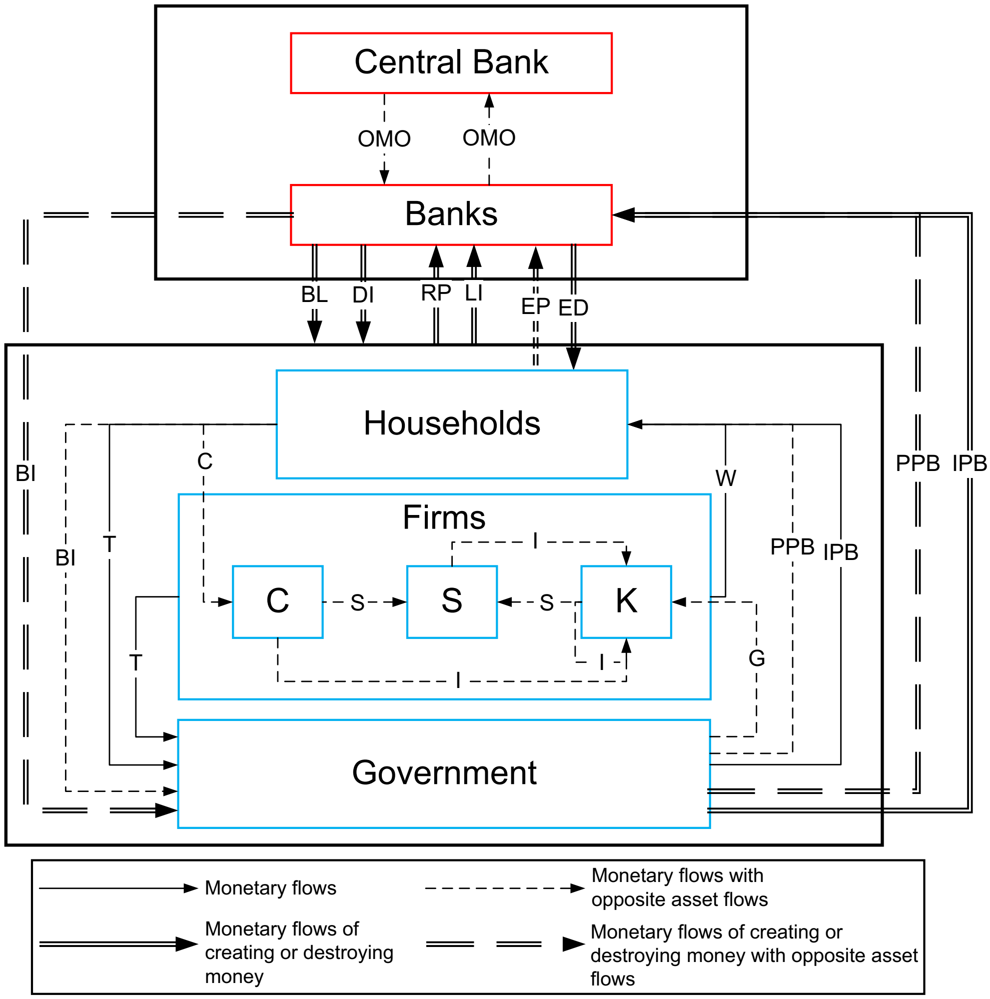

Fig. 1. The building blocks of our model.

unit of the equity-deposit spread. The equity-deposit spread, namely the longest-term interest rate minus the shortest-term interest rate, specifies the level of the interest rate in the economy.

Having the solutions for the stocks, we obtain the stationary endogenous flows, including consumption and final output. We decompose the two flows into investment; government spending; the demand for loans, bonds, and bank equity; and the cost to banks of holding reserves. All the determinants are flows of money instead of flows of physical capital or real goods. For these determinants, we point out the multiplier relationship between investment and the final output and the same multiplier relationship between government spending and the final output. Unlike the basic Keynesian multiplier, the multiplier is decreasing with the marginal propensity to consume (MPC) out of income. The reason is that there is a negative effect of a rise in the MPC out of income on deposits held by households. Due to the decreases in their deposits and interest income on the deposits, despite the rise in the MPC out of income, households have to cut consumption. Importantly, the result presents the relationship between the final output and the flows associated with the processes of money creation and destruction.

1.3. Policy

The model also allows us to examine monetary policy. We focus on two kinds of policy interventions: one aims to change the loan rate, and the other to vary bank reserves. We examine their effects on the stationary quantity of money and the final output. The results show that a rise in the loan rate increases money destruction and thus reduces the quantity of money. Moreover, the increase in the loan rate may increase the final output. The reason is as follows. When the loan rate rises, banks receive more profits and thus have more equity; as their equity rises, both the wealth of households and dividends on the equity increase, which increase autonomous consumption and induced consumption, respectively. There is a higher level of final output. This echoes the findings of Godley (1999); Lyonnet and Werner (2012); Skott (1988).

As for the policy shock to reserves, we find a multiplier effect of a change in reserves on the quantity of money. Notably, the multiple expansions of money can be explained by the endogenous creation of money via interest payments on deposits. And the increase in reserves may decrease the final output. This is because the insufficient demand for credit determines bank lending; thus, the increase in reserves cannot lead to more loans and more profits for banks. At the same time, due to holding unremunerated reserves, banks incur a cost. The increase in reserves decreases the equity of banks and the wealth of households, thereby reducing autonomous consumption and the final output.

As these two results surprisingly suggest, a tighter monetary policy may lead to a higher level of output, and a looser monetary policy may result in a lower one. In particular, for the latter result, because the world's major central banks supplied an extremely large amount of reserves to the banking systems in response to the 2008 financial crisis, banks to date hold a large amount of excess reserves. Nevertheless, it may depress the economy even further if the decline is caused by a lack of demand, especially a lack of credit demand. Martin et al. (2016) also find that holding large excess reserves would generate a negative effect

Table 1
Balance-sheet matrix.

	Households	Consumption-goods firms	Intermediate-goods firms	Capital-goods firms	Government	Central bank	Banks	Σ
Loans	$-L_H$	$-L_C$	$-L_S$	$-L_K$			$+L$	0
Reserves						$-H$	$+H$	0
Deposits	$+D_H$	$+D_C$	$+D_S$	$+D_K$	$+D_G$		$-D$	0
Equity	$+E$						$-E$	0
Government bonds	$+B_H$				$-B$	$+B_{CB}$	$+B_B$	0
Tangible capital		$+K_C$	$+K_S$	$+K_K$				$+K$
Net worth	$-NW_H$	$-NW_C$	$-NW_S$	$-NW_K$	$-NW_G$	$-NW_{CB}$	0	$-K$
Σ	0	0	0	0	0	0	0	0

Notes: A plus sign (+) before a variable denotes an asset, while a minus sign (−) denotes a liability.

on lending and output. Our finding also affirms that central banks should pay interest on reserves to partially offset the cost banks incur due to holding reserves.

1.4. Layout

The structure of our paper is as follows. In Section 2, we present the model. Section 3 illustrates the multiple money creation and destruction mechanisms. Section 4 shows the dynamics of the system and introduces the definition of stationary states. In Section 5, we solve for the stationary state with the premise of insufficient demand in all markets. In Section 6, we discuss the policy implications. Section 7 concludes.

2. The model

Fig. 1 presents the building blocks of our model. The economy consists of five sectors: households, firms, the government, the central bank, and banks. We employ a monetary framework to describe their behaviors and interactions. The economy is characterized by the balance-sheet matrix and the transactions-flow matrix. Table 1 shows the balance-sheet matrix of the economy, which presents the corresponding assets and liabilities of each sector. In Table 1, the sum of each row of financial items is equal to zero, which means that the financial assets of a sector must be the financial liabilities of some other sectors, and vice versa. We define the net worth of each sector as its assets minus its liabilities, which is usually placed on the liability side of the balance sheet with a negative sign. Consequently, the sum of each column in Table 1 is also zero.

The interactions between these sectors via monetary flows can be expressed as a transactions-flow matrix, which is displayed by Table 2. From Table 2, we can see that the sum of each row is zero, where the entries with positive signs are receipts, and the entries with negative signs are payments. Therefore, each monetary flow comes from somewhere and must go somewhere else. Since we present only monetary flows in Table 2, the sum of each column for the non-bank sectors corresponds to the change in their deposits.

2.1. Nonfinancial firms

There are three types of nonfinancial firms: consumption-goods firms (C), intermediate-goods firms (S), and capital-goods firms (K). We show their balance sheets in Table 1. The items on the balance sheets are D_i denoting deposits, K_i tangible capital, L_i bank loans, and NW_i net worth. The subscripts $i = C, S, K$ denote the firm type (C for consumption-goods firms, S for intermediate-goods firms, and K for capital-goods firms). The entries in columns 2, 3, and 4 satisfy the balance sheet identity:

$$D_i + K_i = L_i + NW_i, \tag{1}$$

where $i = C, S, K$.

Within the production sector, consumption-goods firms buy capital and intermediate goods for use in the production of consumption goods and sell them to households. Intermediate-goods firms buy capital goods to produce intermediate goods for sale to consumption- and capital-goods firms. Capital-goods firms buy intermediate goods and their capital goods to produce new capital, which consumption- and intermediate-goods firms will use. Specifically, we denote investment expenditure from consumption-goods firms to capital firms by $I_{C\to K}$, that from intermediate-goods firms by $I_{S\to K}$, and that from capital-goods firms by $I_{K\to K}$. Then we have

$$I = I_{C\to K} + I_{S\to K} + I_{K\to K}, \tag{2}$$

where I is the income of capital-goods firms, representing total

Table 2
Transactions-flow matrix.

	Households	Consumption-goods firms	Intermediate-goods firms	Capital-goods firms	Government	Central bank	Banks	Σ
Consumption	$-C$	$+C$						0
Investment		$-I_{C\to K}$	$-I_{S\to K}$	$-I_{K\to K} + I$				0
Expenditure on intermediate-goods		$-S_{C\to S}$	$+S$	$-S_{K\to S}$				0
Taxes	$-T_{H\to G}$	$-T_{C\to G}$	$-T_{S\to G}$	$-T_{K\to G}$	$+T$			0
Government spending				$+G$	$-G$			0
Wages	$+W$	$-W_{C\to H}$	$-W_{S\to H}$	$-W_{K\to H}$				0
Lending	$+BL_{B\to H}$	$+BL_{B\to C}$	$+BL_{B\to S}$	$+BL_{B\to K}$			$-(+BL)$	0
Principal on loans	$-RP_{H\to B}$	$-RP_{C\to B}$	$-RP_{S\to B}$	$-RP_{K\to B}$			$-(-RP)$	0
Equity purchase	$-EP$						$-(-EP)$	0
Dividends	$+ED$						$-(+ED)$	0
Interest on loans	$-LI_{H\to B}$	$-LI_{C\to B}$	$-LI_{S\to B}$	$-LI_{K\to B}$			$-(-LI)$	0
Interest on deposits	$+DI_{B\to H}$	$+DI_{B\to C}$	$+DI_{B\to S}$	$+DI_{B\to K}$	$+DI_{B\to G}$		$-(+DI)$	0
Bond purchase	$-BI_{H\to G}$				$+BI$		$-(+BI_{B\to G})$	0
Principal on bonds	$+PPB_{G\to H}$				$-PPB$		$-(-PPB_{G\to B})$	0
Interest on bonds	$+IPB_{G\to H}$				$-IPB$		$-(-IPB_{G\to B})$	0
Open market operations						$-OMO$	$+OMO$	0

Notes: A plus sign (+) before a variable denotes a receipt, or a source of funds, while a minus sign (−) denotes a payment, or a use of funds. Note that the minus sign (−) before the parentheses in the bank column denotes the change in deposits (money) as liabilities instead of assets.

investment expenditures in the economy. This monetary flow is accompanied by capital-goods flow in the opposite direction, which is the investment adding to physical capital. Suppose that the price level is set to be one hereafter and the capital K_i of firms i depreciates at a constant rate δ, the dynamics of the capital are then given by respectively

$$\frac{dK_i}{dt} = I_{i\to K} - \delta K_i, \tag{3}$$

where $i = C, S, K$.

Let $S_{C\to S}$ denote the purchase of intermediate goods by consumption-goods firms and $S_{K\to S}$ the purchase of intermediate goods by capital-goods firms. Then, we have

$$S = S_{C\to S} + S_{K\to S}, \tag{4}$$

where S is the income of intermediate-goods firms, representing the total expenditure on intermediate goods in the economy. The reverse intermediate-goods flows accompany these monetary flows.

Between firms and the other sectors, the consumption-goods firms obtain income C from sales to households. Capital-goods firms receive income G from the government. Consumption is the monetary flow accompanied by the consumption-goods flow in the opposite direction, and government spending is the monetary flow accompanied by the capital-goods flow in the opposite direction. In summary, different types of firms receive different incomes; firms overall receive total income Y. Total income consists of consumption, investment, and government spending, that is, $Y = C + I + G$. On the contrary, total income does not include the purchase of intermediate goods, S. This is the main difference between intermediate-goods firms and the other two types of firms in terms of macroeconomic effects.

After receiving income, firms must pay wages W to households. Specifically, $W_{C\to H}$, $W_{S\to H}$, and $W_{K\to H}$ denote the wages paid by consumption-goods firms, intermediate-goods firms, and capital-goods firms, respectively. Additionally, firms must pay lump sum taxes to the government. We denote the tax from consumption-goods firms, intermediate-goods firms, and capital-goods firms by $T_{C\to G}$, $T_{S\to G}$, and $T_{K\to G}$, respectively.

Suppose, furthermore, that firms can raise external finance only by borrowing from banks. Specifically, $BL_{B\to C}$, $BL_{B\to S}$, and $BL_{B\to K}$ denote the borrowing by consumption-goods firms, intermediate-goods firms, and capital-goods firms, respectively. Consequently, firms have a burden of outstanding loans. When the debt matures, the firms must repay the principal and interest of the outstanding loans. We denote the principal payment from consumption-goods firms, intermediate-goods firms, and capital-goods firms by $RP_{C\to B}$, $RP_{S\to B}$, and $RP_{K\to B}$, respectively. We then have the evolution of loans L_i of indebted firms:

$$\frac{dL_i}{dt} = BL_{B\to i} - RP_{i\to B}, \tag{5}$$

where $i = C, S, K$. This equation states that the borrowing increases the debt burden of firms, while the principal repayment reduces it. Additionally, the total repayment includes interest payment $LI_{C\to B}$ from consumption-goods firms, $LI_{S\to B}$ from intermediate-goods firms, and $LI_{K\to B}$ from capital-goods firms. On the other hand, firms receive interest payments on bank deposits. Specifically, we denote the interest receipt of consumption-goods firms, intermediate-goods firms, and capital-goods firms by $DI_{B\to C}$, $DI_{B\to S}$, and $DI_{B\to K}$, respectively.

Note that all monetary inflows increase deposit holdings and all monetary outflows decrease them. Therefore, taking account into all monetary inflows with positive signs and all outflows with negative signs, we obtain the expressions of dynamics of deposits $D_i(i = C, S, K)$, respectively, for.

(i) consumption-goods firms,

$$\begin{aligned}\frac{dD_C}{dt} &= C + BL_{B\to C} + DI_{B\to C}\\ &\quad - W_{C\to H} - I_{C\to K} - S_{C\to S} - RP_{C\to B} - LI_{C\to B} - T_{C\to G};\end{aligned} \tag{6}$$

(ii) intermediate-goods firms,

$$\begin{aligned}\frac{dD_S}{dt} &= S + BL_{B\to S} + DI_{B\to S}\\ &\quad - W_{S\to H} - I_{S\to K} - RP_{S\to B} - LI_{S\to B} - T_{S\to G};\end{aligned} \tag{7}$$

(iii) capital-goods firms,

$$\begin{aligned}\frac{dD_K}{dt} &= I + G + BL_{B\to K} + DI_{B\to K}\\ &\quad - W_{K\to H} - I_{K\to K} - S_{K\to S} - RP_{K\to B} - LI_{K\to B} - T_{K\to G}.\end{aligned} \tag{8}$$

Taking the deposits, loans, and capital as given, we obtain the net worth NW_i of firms i, where $i = C, S, K$. Differentiating the balance sheet identity (Eq. (1)) with respect to time, we can obtain

$$\frac{dD}{dt} + \frac{dK}{dt} = \frac{dL}{dt} + \frac{dNW}{dt}. \tag{9}$$

Combining Eqs. (3) and (5)–(8), from Eq. (9), we have the dynamics of the net worth for each type of firm:

(i) consumption-goods firms,

$$\begin{aligned}\frac{dNW_C}{dt} &= C + DI_{B\to C}\\ &\quad - W_{C\to H} - S_{C\to S} - LI_{C\to B} - T_{C\to G} - \delta K_C;\end{aligned} \tag{10}$$

(ii) intermediate-goods firms,

$$\begin{aligned}\frac{dNW_S}{dt} &= S + DI_{B\to S}\\ &\quad - W_{S\to H} - LI_{S\to B} - T_{S\to G} - \delta K_S;\end{aligned} \tag{11}$$

(iii) capital-goods firms,

$$\begin{aligned}\frac{dNW_K}{dt} &= I + G + DI_{B\to K}\\ &\quad - W_{K\to H} - S_{K\to S} - LI_{K\to B} - T_{K\to G} - \delta K_K.\end{aligned} \tag{12}$$

2.2. Households

We present the balance sheet of households in column 1 in Table 1. The items on the balance sheet are deposits D_H, bank equity E, and government bonds B_H as assets; loans L_H as liabilities; and net worth NW_H. The items of its balance sheet satisfy the balance sheet identity:

$$D_H + E + B_H = L_H + NW_H. \tag{13}$$

Households buy consumption goods by paying C. Here, we assume that households can provide sufficient labor and obtain a wage of $W_{C\to H}$ from consumption-goods firms, $W_{S\to H}$ from intermediate-goods firms, and $W_{K\to H}$ from capital-goods firms. Therefore, the total wages that households receive are $W = W_{C\to H} + W_{S\to H} + W_{K\to H}$. Households must pay lump sum taxes to the government, denoted by $T_{H\to G}$.

Households purchase bank equities, and the purchase, EP, is the monetary flow from households to banks, accompanied by the reverse flow of equity shares. We have

$$\frac{dE}{dt} = EP. \tag{14}$$

By holding equity shares, the households can obtain dividends ED.

Households purchase government bonds to obtain the principal payment $PPB_{G\to H}$ and the interest payment $IPB_{G\to H}$. The purchase of government bonds, $BI_{H\to G}$, is the monetary flow from households to the government, accompanied by the reverse bond flow. The dynamics of government bonds B_H held by households take the following form:

$$\frac{dB_H}{dt} = BI_{H\to G} - PPB_{G\to H}. \tag{15}$$

Like firms, households can borrow from banks. We denote the borrowing flow as $BL_{B\to H}$ and the principal repayment of maturing loans as $RP_{H\to B}$. Then, the dynamics of households' outstanding loan debt L_H are given by

$$\frac{dL_H}{dt} = BL_{B\to H} - RP_{H\to B}. \tag{16}$$

Additionally, households must pay interest on loans, $LI_{H\to B}$, while they obtain interest on deposits, $DI_{B\to H}$.

Likewise, taking account of all money inflows and outflows, we can obtain the dynamics of deposits held by households:

$$\begin{aligned}\frac{dD_H}{dt} &= W + BL_{B\to H} + DI_{B\to H} + ED + PPB_{G\to H} + IPB_{G\to H}\\ &\quad - C - RP_{H\to B} - LI_{H\to B} - EP - BI_{H\to G} - T_{H\to G},\end{aligned} \tag{17}$$

Furthermore, differentiating the balance sheet identity (Eq. (13)) with respect to time, and combining Eqs. (14)–(17), we obtain the dynamics of net worth NW_H:

$$\begin{aligned}\frac{dNW_H}{dt} &= W + DI_{B\to H} + ED + IPB_{G\to H}\\ &\quad - C - LI_{H\to B} - T_{H\to G}.\end{aligned} \tag{18}$$

2.3. The government

Suppose, for simplicity, that the balance sheet items are deposits D_G on the asset side and outstanding bonds B on the liability side. The balance sheet identity requires that

$$D_G = B + NW_G. \tag{19}$$

The government issues bonds to finance its spending and will repurchase them at maturity. Households and banks purchase the bonds. Recall that we denote household purchases of bonds by $BI_{H\to G}$ and bank purchases by $BI_{B\to G}$. As a result, the government issues bonds at the current period,

$$BI = BI_{H\to G} + BI_{B\to G}. \tag{20}$$

At maturity, the government must make the principal payment of $PPB_{G\to H}$ to households and $PPB_{G\to B}$ to banks, so the total principal payment on government bonds is their sum:

$$PPB = PPB_{G\to H} + PPB_{G\to B}. \tag{21}$$

Considering the issuance and redemption of bonds together, we obtain

$$\frac{dB}{dt} = BI - PPB. \tag{22}$$

Moreover, the government must pay interest $IPB_{G\to H}$ to households and $IPB_{G\to B}$ to banks, so that total interest on bonds is

$$IPB = IPB_{G\to H} + IPB_{G\to B}. \tag{23}$$

Meanwhile, the government holds deposits to obtain interest of $DI_{B\to G}$ from banks.

The government spending on capital goods, G, is financed by taxation of firms and households and the issuance of government bonds. Recall that the tax revenue from firms and households is

$$T = T_{C\to G} + T_{S\to G} + T_{K\to G} + T_{H\to G}. \tag{24}$$

We can obtain the dynamics of deposits D_G by considering all money inflows and outflows in the same way as those of firms and households:

$$\frac{dD_G}{dt} = T + BI + DI_{B\to G} - G - PPB - IPB. \tag{25}$$

Substituting Eqs. (22) and (25) into the derivative of the balance sheet identity (Eq. (19)) with respect to time, we obtain the dynamics of net worth NW_G:

$$\frac{dNW_G}{dt} = T + DI_{B\to G} - G - IPB. \tag{26}$$

2.4. The central bank

For simplicity, we assume that the balance sheet of the central bank includes only government bonds B_{CB} as assets, reserves H as liabilities, and net worth NW_{CB}. We can write the balance sheet identity as

$$B_{CB} = H + NW_{CB}. \tag{27}$$

The central bank injects reserves into banks by conducting open market operations (OMOs). OMOs replace government bonds held by the banks with reserves via purchasing government bonds. The purchase of the government bonds from banks leads to a decrease in the government bonds held by banks:

$$\frac{dB_B}{dt} = -OMO, \tag{28}$$

Simultaneously, we can see an addition to the asset side of the central bank balance sheet as a flow:

$$\frac{dB_{CB}}{dt} = OMO. \tag{29}$$

It also adds reserves on the liability side, that is,

$$\frac{dH}{dt} = OMO. \tag{30}$$

This means a simultaneous increase in the reserve account of banks.

The two expressions above, together with Eq. (27), imply that OMOs do not change the net worth of the central bank, that is,

$$\frac{dNW_{CB}}{dt} = 0. \tag{31}$$

2.5. Banks

We now discuss banks, which is the core of the model. Column 7 in Table 1 shows their balance sheets. There are loans L, reserves H, and government bonds B_B as assets; deposits D as liabilities; and equity E. These items satisfy the following identity:

$$L + H + B_B = D + E. \tag{32}$$

Banks receive the total interest revenue of LI on outstanding loans, which is the sum of those from all three types of firms and households,

$$LI = LI_{C\to B} + LI_{S\to B} + LI_{K\to B} + LI_{H\to B}. \tag{33}$$

Loans are the only external funds that firms and households can raise. Recall that we can express the total loans firms and households owe to banks as

$$L = L_C + L_S + L_K + L_H. \tag{34}$$

Following the dynamics of all these outstanding loans, the change in total loans is

$$\frac{dL}{dt} = BL - RP, \tag{35}$$

where $BL = BL_{B\to C} + BL_{B\to S} + BL_{B\to K} + BL_{B\to H}$ and $RP = RP_{C\to B} + RP_{S\to B} + RP_{K\to B} + RP_{H\to B}$. Banks also invest in government bonds, denoted as $BI_{B\to G}$; holding the government bonds, they would receive the principal payment $PPB_{G\to B}$ and the interest payment $IPB_{G\to B}$ at maturity date. Combining banks' bond purchases and the changes in government bonds by OMOs given by Eq. (28) yields

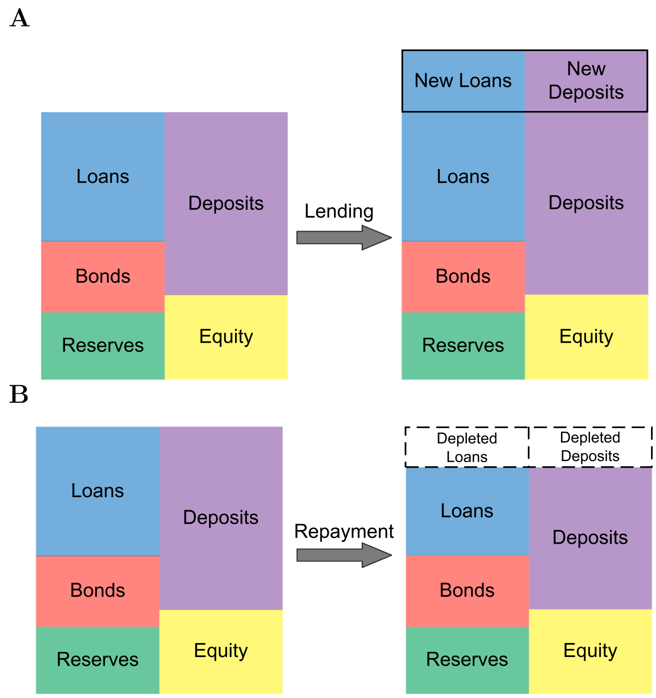

Fig. 2. In Panel A, lending creates loans and deposits simultaneously, while, in Panel B, repayment destroys both at the same time.

$$\frac{dB_B}{dt} = BI_{B\to G} - PPB_{G\to B} - OMO. \tag{36}$$

Deposits are liabilities for banks, but assets of the other sectors, recognized as money in the economy. Aggregating the deposits across all the non-bank sectors, we obtain

$$D = D_C + D_S + D_K + D_H + D_G. \tag{37}$$

The total interest payment DI on deposits is

$$DI = DI_{B\to C} + DI_{B\to S} + DI_{B\to K} + DI_{B\to H} + DI_{B\to G}. \tag{38}$$

Taking account of all money inflows and outflows given by the entries of the non-bank sectors in Table 2, we obtain the dynamics of deposits:

$$\begin{aligned}\frac{dD}{dt} &= BL + BI_{B\to G} + DI + ED \\ &\quad - RP - LI - EP - PPB_{G\to B} - IPB_{G\to B}.\end{aligned} \tag{39}$$

The last item on the balance sheet is equity E, which banks issue to households and for which banks must pay dividends to households, ED. Substituting Eqs. (30), (35), (36) and (39) into the derivative of Eq. (32) with respect to time, we have

$$\frac{dE}{dt} = LI + IPB_{G\to B} - DI + EP - ED. \tag{40}$$

3. Money creation and destruction

Money creation and destruction are the crucial function of banks in the economy. This perspective is called the credit creation theory of banking (Werner, 2014a, 2016). It is contrary to the mainstream understanding of the role of banks, called the financial intermediation theory of banking, in which banks just channel funds from savers to borrowers. Money creation results in an increase in money supply, or total deposits in our model. On the other hand, money destruction is a reverse process that leads to a decrease in money supply. Both actions together are deemed to make money endogenous.

The monetary flows both coming from and going to non-bank sectors do not create or destroy money because such monetary flows are only the transfers of money among them. We present these monetary flows in Table 2 in the first six rows. On the contrary, the interactions involving both the banking and non-banking sector are associated with money creation or destruction processes. We present the corresponding monetary flows in rows 7–15 in Table 2. Specifically, all monetary flows from banks create money and those to banks destroy money. Note that OMOs are the transactions between the central bank and banks that create or destroy monetary base instead of broad money. Money creation is realized by banks via lending to firms and households, bond purchases from the government, dividend payments to households, and interest payments to them all. On the other hand, money destruction is realized via repayments by firms and households, sales of bonds, redemption by the government, equity issuance to households, and interest receipts from them all.

Accordingly, we see that the dynamics of total deposits given by Eq. (39) include all monetary flows associated with creating or destroying money. To make this clearer, we rearrange Eq. (39) to present the four pairs, each of which corresponds to one creation process with a positive sign and the opposite destruction process with a negative sign:

$$\begin{aligned}\frac{dD}{dt} &= BL - RP + BI_{B\to G} - PPB_{G\to B} \\ &\quad + ED - EP + DI - LI - IPB_{G\to B}.\end{aligned} \tag{41}$$

The first pair refers to the interactions between banks and borrowers (firms and households), which we specify by lending and repayment. The second pair indicates the interaction between banks and the government, which we denote by bond purchase and bond sale (or redemption). The third pair states that banks pay households dividends and issue them equity. The last pair concerns the interest that banks pay depositors and charge debtors (borrowers of loans and the government). We will elaborate on and illustrate each of these pairs in the following.

3.1. Lending and repayment

When the bank approves a loan application from a borrower, it records the loan as an asset on the balance sheet. Simultaneously, the bank credits the borrower's bank account with a deposit of the size of the loan. Then, we can see both the loans appearing on the asset side and an equal amount of the deposits appearing on the liability side. Thus, as Panel A of Fig. 2 shows, bank lending simultaneously creates a loan and a matching deposit, thereby creating new money instead of transferring the deposits or the reserves issued by the central bank.

Principal repayment is the money destruction process opposite to bank lending. When a debtor repays an existing loan, he or she must use the deposits in his/her bank account to repay the debt owed to the bank. As the repayment occurs, the bank reduces both the deposits and the loans by the amount equal to the repayment. Thus the repayment destroys money, which is illustrated by the change in the balance sheet of banks in Panel B of Fig. 2.

3.2. Bond purchase and sale

There are two types of bond purchases. The first is banks purchasing bonds directly from the issuer, as in the case of our model. When buying such bonds, the bank first obtains them from the issuer as an asset, thus appearing on the asset side of the balance sheet. Simultaneously, the bank creates deposits with an equal amount of the bonds credited to the bank account of the issuer. Then, we have both the bonds appearing on the asset side and the deposits on the liability side. The bond purchase creates money. The other type is banks purchasing bonds from a third-party institution, which is not the issuer. The purchase from the third-party institution differs from a direct purchase from the issuer in that the latter creates bonds by the issuer and then transfers them to the bank, while the former just transfers the bonds from the institution to

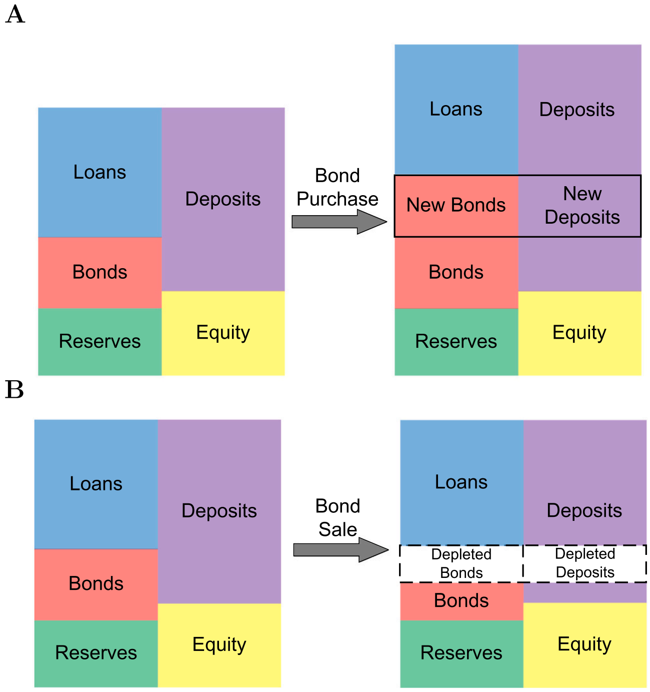

Fig. 3. In Panel A, bond purchase creates loans and deposits simultaneously, while, in Panel B, bond sale destroys both.

the bank. Nevertheless, both create new money instead of transferring existing deposits or cash.

Banks selling bonds is the money destruction process opposite to bond purchase. If a bank sells bonds to a buyer, then the buyer must use the deposits in his/her bank account to buy the bonds. The bonds sold and the deposits used are simultaneously removed from the balance sheet of the bank. The deposits thereby decrease by the same amount as the value of the sold bonds, and thus bond sale destroys money. Bond redemption is a type of bond sale that also destroys money. Fig. 3 shows how bond purchase creates money and bond sale destroys it.

3.3. Dividend payment and equity issuance

A dividend payment must be financed by deposits. When the bank pays a dividend to a shareholder, actually it is transforming a part of equity to the deposits. This means that the bank reduces the equity and adds the deposits as a dividend payment. Thus, dividend payments create money.

Equity issuance is a money destruction process opposite to the dividend payment. The household holds one more equity share to replace the corresponding amount of deposits. That is to say, the bank transforms its liabilities from deposits to equity. Although both are liabilities of the bank, only deposits are regarded as the means of payment. The net effect of the transformation is a decrease in deposits, indicating that equity issuance destroys money.

Unlike the above two money creation and destruction processes that change the asset holdings, dividend payment and equity issuance are just transformations between the bank's equity and deposits on the liability side. That is to say, the transformations do not alter the size of the balance sheet. Fig. 4 presents the outcomes of dividend payments and equity issuance.

3.4. Interest payment and receipt

Banks pay interest on deposits to firms, households, and the government by using a portion of their equities. When paying the interest on deposits, the bank transforms its equity into the deposits. Through

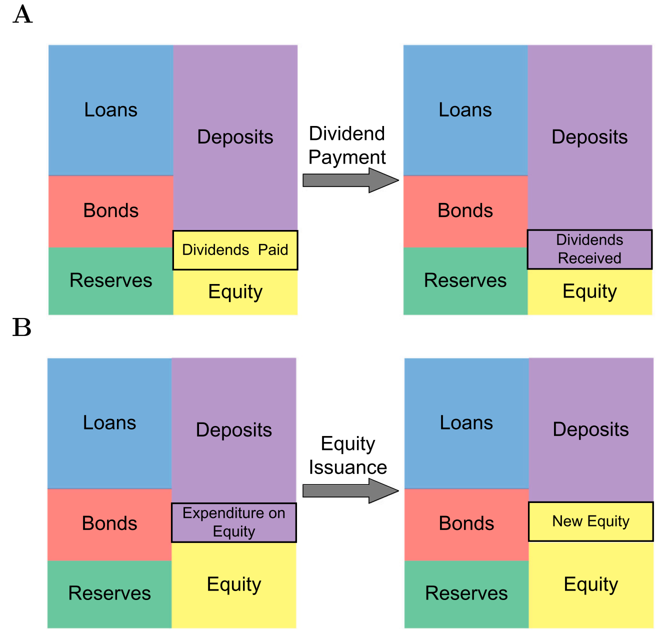

Fig. 4. Panel A shows that equity is transformed into deposits as banks pay dividends to the shareholders; Panel B shows that new equity is created by crowding deposits out.

the payment, the bank reduces the equity and increases the deposits by the amount of the interest payment. Thus, money is created at that moment.

Interest receipts on loans and bonds are money destruction processes opposite to the interest payment. Firms, households, and the government pay the interest by using their deposits. As the interest expense, the deposits that banks take in turn become income of the bank and thus increase equity. The increase in bank equity has the same amount as the decrease in deposits does; thereby, interest receipts destroy money.

Like the outcomes of dividend payments and equity issues shown in

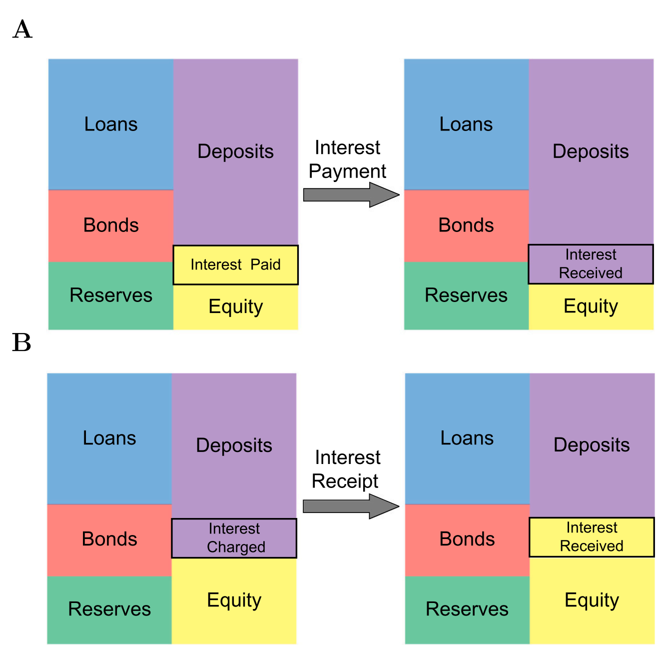

Fig. 5. Panel A shows that interest paid by banks increase deposits, but decrease equity. Panel B shows interest charged by banks reduce deposits, but increase equity.

Table 3
Types of money creation and destruction processes.

Money creation	Money destruction
Lending BL	Principal repayment RP
Bond purchase $BI_{B\to G}$	Bond sale (redemption) $PPB_{G\to B}$
Dividend payment ED	Equity purchase EP
Interest expense DI	Interest receipts from loans and bonds $LI + PB_{G\to B}$

Fig. 4, interest payments and receipts are also types of transformation between the bank's equity and deposits, keeping the size of assets unchanged. Fig. 5 illustrates how interest payments and receipts make such transformations.

Table 3 summarizes the four pairs of money creation and destruction processes mentioned above. We can divide these different money creation and destruction processes into two groups. The first group consists of two pairs: (a) bank lending and principal repayment, and (b) bond purchase and bond sale. They suggest that money creation and destruction are caused by increasing and decreasing the bank's asset holdings, respectively. The second group comprises two pairs: (a) dividend payments and equity purchase, and (b) interest payments on deposits and interest receipts from loans and bonds. They, unlike the first group, are not related to the changes in assets, but the transformations between equity and deposits on the liability side.

A consensus has come to being that banks making loans and purchasing securities create money. However, whether interest payments and dividends can create money is still a controversy. Note that borrowers pay interest to banks. After that, banks would either pay interest to depositors or pay dividends to shareholders. As Ryan-Collins et al. (2012) interpret, banks only transfer existing money from borrowers to depositors and shareholders, thus not changing the money supply.

From our perspective, banks receiving interest, paying interest, and paying dividends are considered as separate processes. When borrowers pay interest to banks, interest payment yields a reduction in the deposits of the borrowers, without changing the deposits of other agents. On the other hand, when banks pay interest to depositors, the depositor's account is credited with money equal to the interest payment withdrawn from the bank's equity account. Thus, banks receiving interest destroys money, while paying interest creates money. Now let us discuss the processes of banks receiving and paying interest together. The difference between the receipt and payment is the profit of the bank, which is retained and added to the equity. This indicates that a part of deposits as money liabilities turns into equity as non-money liabilities. Furthermore, we take dividend payments into account. The retained earnings are given by subtracting dividends from the profits and not equal to zero in general. This means the sum of money created by interest payments and by dividend payments is not equal to money destroyed by interest revenues. As a result, there must be a change in money supply. In summary, if these different processes are examined separately, which one creating money or destroying money can be explicitly clarified.

We use different arrows to depict the different monetary flows in Fig. 1. The direction of the arrow indicates the monetary flow from the use to the source of funds. Single-line arrows represent solely money transfers. Double-line arrows pointing to non-bank sectors represent the virtual monetary flows associated with money creation, and those pointing to banks represent the virtual monetary flows associated with money destruction. In addition, the dotted-line arrows represent the monetary flows with reverse asset flows.

4. Dynamics and stationary states of the economic system

In Section 2, we described all sectors in the system. The evolution of the system is governed by the dynamics of the stock variables in the balance-sheet matrix of Table 1. The changes in the stock variables, according to the stock-flow consistency, are governed by the related monetary flows presented in Table 2. Every monetary flow specifying a transaction between two sectors causes a change in the corresponding deposit holdings. Thus, the dynamics of money (deposits in this model) lie in the locus of those of the system. Additionally, along with the dynamics of money, we present both the dynamics of financial assets and tangible capital. Finally, we define the stationary state of the economy.

4.1. Dynamics of the stock variables

First, we present the dynamics of the deposit holdings of each sector. We write the dynamic equations for the deposits of the three types of firms (Eqs. (6)–(8)), respectively, as

$$\frac{dD_C}{dt} = C + BL_{B\to C} + DI_{B\to C} - W_{C\to H} - I_{C\to K} - S_{C\to S} - RP_{C\to B} - LI_{C\to B} - T_{C\to G}, \tag{42}$$

$$\frac{dD_S}{dt} = S + BL_{B\to S} + DI_{B\to S} - W_{S\to H} - I_{S\to K} - RP_{S\to B} - LI_{S\to B} - T_{S\to G}, \tag{43}$$

$$\frac{dD_K}{dt} = I + G + BL_{B\to K} + DI_{B\to K} - W_{K\to H} - I_{K\to K} - S_{K\to S} - RP_{K\to B} - LI_{K\to B} - T_{K\to G}. \tag{44}$$

We express the dynamics of the deposits of households (Eq. (17)) as

$$\frac{dD_H}{dt} = W + BL_{B\to H} + DI_{B\to H} + ED + PPB_{G\to H} + IPB_{G\to H} - C - RP_{H\to B} - LI_{H\to B} - EP - BI_{H\to G} - T_{H\to G}. \tag{45}$$

Additionally, we denote the evolution of the government's deposits (Eq. (25)) by

$$\frac{dD_G}{dt} = T + BI + DI_{B\to G} - G - PPB - IPB. \tag{46}$$

Aggregating the deposits across all sectors, we obtain the dynamics of total deposits:

$$\frac{dD}{dt} = BL + BI_{B\to G} + DI + ED - RP - LI - EP - PPB_{G\to B} - IPB_{G\to B}, \tag{47}$$

which is the same as that of the deposits on the balance sheet of banks given by Eq. (39).

Second, we show the dynamics of loans and bonds in parallel with that of money. The evolution of firms' outstanding loans (Eq. (5)) is

$$\frac{dL_i}{dt} = BL_{B\to i} - RP_{i\to B}, \tag{48}$$

where the subscript $i = C, S, K$ denotes the type of firm. Likewise, the dynamics of households' outstanding loans (Eq. (16)) are

$$\frac{dL_H}{dt} = BL_{B\to H} - RP_{H\to B}. \tag{49}$$

By aggregating the two equations above, we can obtain the dynamics of total outstanding loans:

$$\frac{dL}{dt} = BL - RP, \tag{50}$$

which are the same as those given by Eq. (35).

Households and banks purchase bonds, which the government will redeem as they mature. The quantity of bonds held by households evolves according to Eq. (15) as

$$\frac{dB_H}{dt} = BI_{H\to G} - PPB_{G\to H}. \tag{51}$$

On the other side, both the purchase and redemption of bonds, as well as the OMOs, determine the bond holdings of banks. According to

Eq. (36), their evolution is

$$\frac{dB_B}{dt} = BI_{B\to G} - PPB_{G\to B} - OMO. \tag{52}$$

Combining Eq. (29), the dynamics of total bonds take the following form:

$$\frac{dB}{dt} = BI - PPB. \tag{53}$$

Third, we can write the evolution of bank equity as

$$\frac{dE}{dt} = LI + IPB_{G\to B} - DI + EP - ED. \tag{54}$$

Finally, to complete the description of the dynamics of the whole system, we need to include the evolution of tangible capital (Eq. (3)), which we write as

$$\frac{dK}{dt} = I - \delta K. \tag{55}$$

4.2. Stationary states

The stationary state is characterized by constant stocks and flows, in contrast to the state of traditional equilibrium featured by market clearing. As clarified by Kornai (1971); Muellbauer and Portes (1978); Werner (2005), even at a stationary state the market does not clear. More importantly, in disequilibrium, the market is rationed and determined by quantities rather than prices via the short side principle. Consistent with Werner (2005), we incorporate the disequilibrium markets with insufficient and exogenously given demand, of which the state is determined by the quantity of demand by the short side principle. Then, under these assumptions, the stock and flow variables are endogenously governed by behavior of agents and interactions between these sectors. Thus, the left-hand sides of the dynamic equations in this section, changes in stocks, are exactly equal to zero. Specifically, changes in deposits, loans, bonds, bank equity, and physical capital are given by Eqs. (42)–(46), Eqs. (48) and (49), Eqs. (51) and (52), Eq. (54), and Eq. (3), respectively. They are all equal to zero.

5. Solving for stationary states

We present the two major steps to solving for the stationary state. First, we must describe the behavior of agents: household consumption, wage payment, and taxation. The reason for the choice of only these behaviors that we need a formulation that makes the model as simple as possible. Second, we need to derive the stationary state in which we can assume that the demand in all markets is insufficient. That is, investment; government spending; and demand for loans, bonds, and equity are all insufficient. Then the short side principle applies. Consequently, insufficient demand determines the quantities of transactions in all markets.

5.1. Behavior of agents

As we mentioned above, there are three types of behavior: household consumption, wage payment, and taxation.

Disposable income and wealth determine households' consumption. Denoting the MPC out of income by *mpc* and the MPC out of wealth by α, we can express the consumption function as

$$\begin{aligned} C &= mpc\cdot(W + DI_{B\to H} + ED + IPB_{G\to H} - LI_{H\to B} - T_{H\to G}) \\ &\quad + \alpha\cdot(D_H + E + B_H - L_H), \end{aligned} \tag{56}$$

where the first term of the right-hand side is induced consumption, which comes from disposable income, and the second term is autonomous consumption, which is generated by net wealth.

Firms pay wages to households. Suppose that the labor share is a fraction of final output accruing to households as wages, denoted by s_L. Then the wage that households receive is

$$W = s_L\cdot Y. \tag{57}$$

The government taxes households, $T_{H\to G}$, and firms, $T_{F\to G}$. We specify taxes on households and firms as in Caiani et al. (2016). We assume that the marginal tax rates on labor income, deposit interest income, bond interest income, and dividends are the same and equal to τ. The taxes on households are proportional to their gross income:

$$T_{H\to G} = \tau(W + DI_{B\to H} + ED + IPB_{G\to H}). \tag{58}$$

Assuming that the taxes on firms are proportional to their profits and setting the marginal tax rate to be τ, we then have

$$T_{F\to G} = \tau(Y + DI_{B\to F} - W - LI_{F\to B}). \tag{59}$$

5.2. Stationary conditions and solutions

We introduce some new notations to present the stationary state well. In stationary states, firms are integrated. Let $BL_{B\to F}$ denote firms' borrowing, $DI_{B\to F}$ the interest income, $RP_{F\to B}$ the principal payment, $LI_{F\to B}$ the interest payment, $T_{F\to G}$ the tax payment, L_F the outstanding loans, and D_F the deposits. Moreover, we introduce the interest rate on loans, deposits, bonds, and equity to explicitly describe the relationships between the payments and their associated stocks. Let r_D denote the deposit rate, r_L the loan rate, r_B the rate of return on bonds, and r_E the rate of return on equity. In stationary states, the banks' reserves H are constant, implying $OMO = 0$. Firms' capital is also constant.

Here, we presume an economy with insufficient demand, which we characterize in terms of insufficient investment, government spending, and demand for loans, bonds, and equity. They are exogenously given and treated as constants (denoted by a bar on head). First, the insufficient investment $\bar{I}$ and government spending $\bar{G}$ determine the final purchase of capital goods. Second, the insufficient demand $\overline{BL_{B\to H}}$ for loans from households and $\overline{BL_{B\to F}}$ for loans from firms comprise the final borrowing. Similarly, the insufficient demand $\overline{BI_{H\to G}}$ for bonds from households and $\overline{BI_{B\to G}}$ from banks constitute the final purchase of bonds. Third, the insufficient demand for equity determines the final purchase of equity, which we denote by $\overline{EP}$.

Having these given insufficient levels of demand, we solve for the equilibria based on the corresponding stationary conditions. On the one hand, we have the stationary quantities of loans and bonds. From the stationary conditions for loans (Eqs. (48) and (49)), we have

$$\overline{BL_{B\to H}} = \frac{L_H}{\omega}, \tag{60}$$

$$\overline{BL_{B\to F}} = \frac{L_F}{\omega}, \tag{61}$$

where ω denotes the loan maturity. Consequently, repayment is a fraction $1/\omega$ of the outstanding loans. By rearranging the equations above, we express the stationary quantities of loans, respectively, as follows:

$$L_H = \omega\cdot\overline{BL_{B\to H}}, \tag{62}$$

$$L_F = \omega\cdot\overline{BL_{B\to F}}. \tag{63}$$

Similarly, from the stationary conditions for bonds (Eqs. (51) and (52)), we have

$$\overline{BI_{H\to G}} = \frac{B_H}{\rho}, \tag{64}$$

$$\overline{BI_{B\to G}} = \frac{B_B}{\rho}, \tag{65}$$

where ρ denotes the bond maturity. The redemption of government bonds is a fraction $1/\rho$ of bonds. Likewise, we derive the stationary quantities of bonds:

$$B_H = \rho \cdot \overline{BI_{H\to G}}, \tag{66}$$

$$B_B = \rho \cdot \overline{BI_{B\to G}}. \tag{67}$$

On the other hand, we can state the SFC budget constraint of each sector and the consumption function of households as follows. From the evolutions of deposits (Eqs. (42)–(46)) and the tax functions (Eqs. (58) and (59)), we have the budget constraints of households, firms, and the government, respectively:

$$\begin{aligned} C &= (1-\tau)(s_L \cdot (C + \overline{I} + \overline{G}) + r_D D_H + r_E E + r_B \rho \cdot \overline{BI_{H\to G}}) \\ &\quad - r_L \omega \cdot \overline{BL_{B\to H}} - \overline{EP}, \end{aligned} \tag{68}$$

$$\overline{I} = (1-\tau)((1-s_L)(C + \overline{I} + \overline{G}) + r_D D_F - r_L \omega \cdot \overline{BL_{B\to F}}), \tag{69}$$

$$\begin{aligned} \overline{G} &= \tau(Y + r_D(D_F + D_H) + r_E E + r_B \rho \cdot \overline{BI_{H\to G}} - r_L \omega \cdot \overline{BL_{B\to F}}) \\ &\quad + r_D D_G - r_B(\rho \cdot \overline{BI_{H\to G}} + \rho \cdot \overline{BI_{B\to G}}). \end{aligned} \tag{70}$$

From the evolution of equity given by Eq. (54), we have the budget constraint of banks:

$$\begin{aligned} \overline{EP} &= -r_L(\omega \cdot \overline{BL_{B\to H}} + \omega \cdot \overline{BL_{B\to F}}) - r_B \rho \cdot \overline{BI_{B\to G}} \\ &\quad + r_D(D_H + D_F + D_G) + r_E E. \end{aligned} \tag{71}$$

In stationary states, the consumption function (Eq. (56)) takes the following form:

$$\begin{aligned} C &= mpc((1-\tau)(s_L \cdot (C + \overline{I} + \overline{G}) + r_D D_H + r_E E + r_B \rho \cdot \overline{BI_{H\to G}}) \\ &\quad - r_L \omega \cdot \overline{BL_{B\to H}}) \\ &\quad + \alpha \cdot (D_H + E + \rho \cdot \overline{BI_{H\to G}} - \omega \cdot \overline{BL_{B\to H}}). \end{aligned} \tag{72}$$

All the above relationships in Eqs. (68)–(72), together with the balance sheet identity of the bank (Eq. (32)), constitute all stationary conditions for the economy. Solving these conditions, we have the expression of bank equity:

$$\begin{aligned} E &= \frac{1}{r_E - r_D} \cdot \left(\overline{EP} + \left(r_L - r_D \right) \left(\omega \cdot \overline{BL_{B\to F}} + \omega \cdot \overline{BL_{B\to H}} \right) \right. \\ &\quad \left. + (r_B - r_D)\rho \cdot \overline{BI_{B\to G}} - r_D H \right). \end{aligned} \tag{73}$$

This expression implies that banks' equity is increased through equity purchases and net interest income from loans and bonds, while it is decreased through the cost of holding unremunerated reserves.

At the same time, the total deposits, or the quantity of money is obtained as follows:

$$\begin{aligned} M &= w \cdot \overline{BL_{B\to F}} + w \cdot \overline{BL_{B\to H}} + \rho \cdot \overline{BI_{B\to G}} + \frac{1}{r_E - r_D} \cdot [r_E H - \overline{EP} \\ &\quad + r_D(w \cdot \overline{BL_{B\to F}} + w \cdot \overline{BL_{B\to H}} + \rho \cdot \overline{BI_{B\to G}}) \\ &\quad - r_L(w \cdot \overline{BL_{B\to F}} + w \cdot \overline{BL_{B\to H}}) - r_B \rho \cdot \overline{BI_{B\to G}}], \end{aligned} \tag{74}$$

which shows that the quantity of money depends on lending and repayment, $\overline{BL_{B\to F}} + \overline{BL_{B\to H}}$, bond purchase and sale by banks, $\overline{BI_{B\to G}}$; and equity issuance, $\frac{1}{r_E - r_D} \cdot \overline{EP}$. In addition, the quantity of money depends on dividend payments and the payment and receipt of interest. We can see the dependence can be charaterized by the sensitivity of M with respect to the interest rate on equity, deposits, loans, and bonds. By differentiating M with respect to the interest rate on equity, deposits, loans, and bonds, we obtain

$$\begin{aligned} \frac{\partial M}{\partial r_E} &= \frac{1}{(r_E - r_D)^2} \cdot (\overline{EP} + (r_L - r_D)(w \cdot \overline{BL_{B\to F}} + w \cdot \overline{BL_{B\to H}}) + (r_B - r_D)\rho \cdot \overline{BI_{B\to G}} - r_D H) \\ &= \frac{E}{r_E - r_D}, \end{aligned} \tag{75}$$

$$\frac{\partial M}{\partial r_D} = \frac{M}{r_E - r_D}, \tag{76}$$

$$\frac{\partial M}{\partial r_L} = -\frac{w \cdot \overline{BL_{B\to F}} + w \cdot \overline{BL_{B\to H}}}{r_E - r_D}, \tag{77}$$

$$\frac{\partial M}{\partial r_B} = -\frac{\rho \cdot \overline{BI_{B\to G}}}{r_E - r_D}, \tag{78}$$

where $\frac{\partial M}{\partial r_E}$ and $\frac{\partial M}{\partial r_D}$ being positive indicates money creation through payments of interest on equity and deposits, while $\frac{\partial M}{\partial r_L}$ and $\frac{\partial M}{\partial r_B}$ being negative indicates money destruction through the receipt of interest on loans and bonds. The denominator of all sensitivities above is the equity-deposit spread $r_E - r_D$, that is, the spread between the longest-term interest rate and the shortest-term interest rate, which reflects the scale of the interest rate in the economy. Thus the sensitivity to the interest rate on an asset takes the form of the stock of the asset per unit of the spread.

In what follows, we solve for the two key flows: consumption and final output. Likewise, we can obtain the stationary consumption from the above stationary conditions,

$$\begin{aligned} C &= \varphi \times [s_L \alpha(1-\tau)(\overline{I} + \overline{G}) \\ &\quad + \alpha((r_L - r_D)(1-\tau)\omega\overline{BL_{B\to F}} - r_L \tau\omega\overline{BL_{B\to H}}) \\ &\quad + (r_B - r_D)\alpha(1-\tau)\rho(\overline{BI_{H\to G}} + \overline{BI_{B\to G}}) \\ &\quad - (r_D mpc(1-\tau) + \alpha\tau)\overline{EP} - r_D \alpha(1-\tau)H], \end{aligned} \tag{79}$$

where

$$\varphi = \frac{1}{\alpha(1 - s_L(1-\tau)) - r_D(1-mpc)(1-\tau)}. \tag{80}$$

Therefore, the final output, $Y = C + \overline{I} + \overline{G}$, becomes

$$\begin{aligned} Y &= \frac{\alpha - r_D(1-mpc)(1-\tau)}{\alpha(1 - s_L(1-\tau)) - r_D(1-mpc)(1-\tau)} \cdot (\overline{I} + \overline{G}) \\ &\quad + \varphi \times [\alpha((r_L - r_D)(1-\tau)\omega\overline{BL_{B\to F}} - r_L \tau\omega\overline{BL_{B\to H}}) \\ &\quad + (r_B - r_D)\alpha(1-\tau)\rho(\overline{BI_{H\to G}} + \overline{BI_{B\to G}}) \\ &\quad - (r_D mpc(1-\tau) + \alpha\tau)\overline{EP} - r_D \alpha(1-\tau)H]. \end{aligned} \tag{81}$$

The above expression has the following implications. Since $(\alpha - r_D(1-mpc)(1-\tau))/(\alpha(1 - s_L(1-\tau)) - r_D(1-mpc)(1-\tau)) > 1$, the first term corresponds to the multiplier effect of investment, $\overline{I}$, and government spending, $\overline{G}$. The value of the multiplier, unlike the basic Keynesian multiplier, is decreasing in *mpc*. This is because here the rise in *mpc* decreasing the deposits of households is taken into account, due to consumption relying on the deposits and interest income on deposits, the drop in deposits reduces consumption and the final output.[2] The second term is the borrowing by firms and households. Borrowing by firms, $\overline{BL_{B\to F}}$, generates a positive effect, while borrowing by households, $\overline{BL_{B\to H}}$, generates a negative effect. This shows the pros and cons of private borrowing in terms of the impact on the final output. By contrast, the third shows the positive impact of government borrowing by issuing bonds, $\overline{BI_{H\to G}}$ and $\overline{BI_{B\to G}}$, on the final output. The fourth indicates the effect of equity purchases, $\overline{EP}$, which reduces the final output. The reason is simple: in each period, the rise in the purchase of equity reduces consumption, however, the former is not included in the final output directly. The last term concerns reserves, H. These are unremunerated and lead to a cost for banks. The cost reduces the equity capital of banks and thus the wealth of households, which reduces consumption.

We can also explain the final output (Eq. (81)) from the money creation perspective. The final output is increased through money creation via borrowing by firms, $\overline{BL_{B\to F}}$, and money creation via banks purchasing bonds, $\overline{BI_{B\to G}}$, and it is decreased by money creation via borrowing by households, $\overline{BL_{B\to H}}$.

In Appendix A, we show the results of the deposit holdings of households, D_H, firms, D_F, and the government, D_G. We also derive these endogenous stocks from the stationary conditions.

[2] We indicate that the rise in *mpc* reduces household deposits in the expression of the stationary amount of deposits held by households in Eq. (A.1).

6. Policy analysis

Now we move to the policy analysis and focus on two exogenous policy shocks: the change in loan rates and the change in reserves. According to the solutions to the steady state obtained above, we focus on the impacts of the shocks on the quantity of money and the final output, respectively.

6.1. Changes in loan rates

We first consider the change in the loan rate. In order to examine its impact, we differentiate the quantity of money (Eq. (74)) and the final output (Eq. (81)) with respect to the loan rate. The derivative of the quantity of money with respect to the loan rate is written as

$$\frac{\partial M}{\partial r_L} = -\frac{w \cdot \overline{BL_{B\to F}} + w \cdot \overline{BL_{B\to H}}}{r_E - r_D}, \tag{82}$$

which is also given by Eq. (77). This implies that a rise in the loan rate increases the income from interest on loans, resulting in the destruction of more money. It therefore reduces the stationary stock of money.

Second, we have the derivative of the final output with respect to the loan rate:

$$\frac{\partial Y}{\partial r_L} = \frac{\alpha(\omega \cdot \overline{BL_{B\to F}})}{\alpha(1 - s_L(1-\tau)) - r_D(1 - mpc)(1-\tau)} - \frac{\alpha\tau(\omega \cdot \overline{BL_{B\to F}} + \omega \cdot \overline{BL_{B\to H}})}{\alpha(1 - s_L(1-\tau)) - r_D(1 - mpc)(1-\tau)}. \tag{83}$$

The above equation shows that there are two opposite effects on the final output in response to the shock to the loan rate. The first term on the right-hand side of the above equation generates a positive effect caused by the borrowing of firms and the consumption of households. Firms' borrowing generates interest income to banks, which accrues to banks' equity; the rise in the borrowing rate leads to the increase in households' wealth and dividends on equity. Thus, firms' borrowing causes both autonomous consumption and induced consumption to rise.[3] So the first term generates a positive effect on the final output.

On the other hand, the second term on the right-hand side generates a negative effect. A rise in the loan rate increases the burden of debt and raises the repayments by firms and households. Firms, according to the SFC budget constraint, must reduce the level of wages. As the wage declines and the loan repayment rises, households must cut their consumption. In addition, the fall in deposits held by households causes a drop in consumption. As we pointed out, banks receiving an interest payment on loans destroy money; the rise in the repayment of interest increases the rate of money destruction. Consequently, the rise in the repayments by households and the drop in wages, leads to a lower quantity of deposits held by households and a fall in interest payments on the deposits households receive. The former decreases autonomous consumption and the latter decreases induced consumption.

These two processes associated with the two terms in Eq. (83) reflect that debt as a driving force of economic growth can be a double-edged sword. Therefore, we need to derive the threshold between the region in which a higher loan rate results in a higher level of output and in which a higher loan rate results in a lower level of output:

$$\overline{BL_{B\to F}} = \frac{\tau}{1-\tau} \cdot \overline{BL_{B\to H}} \tag{84}$$

if $\overline{BL_{B\to F}} > (\tau/(1-\tau))\overline{BL_{B\to H}}$, then a rise in the loan rate stimulates the economy; otherwise, it depresses the economy. This states that if borrowing by firms is sufficiently large, then the positive effect related to firms' borrowing is larger than the negative one related to households' borrowing.

6.2. Changes in reserves

In this subsection, we examine the impact of the policy shock to reserves. This problem received a lot of attention in recent years because it challenges the textbook model on the money supply and the effectiveness of monetary policy by expanding bank reserves. In response to the 2008 financial crisis, the world's major central banks injected massive amounts of reserves into the banking systems. This action resulted in banks holding a large amount of excess reserves. In particular, the quantity of reserves the U.S. banking system held dramatically grew from 45.8 billion in August 2008 to 1.5 trillion in September 2019. Additionally, the Federal Reserve will maintain the ample supply of reserves.[4] Accordingly, it is necessary to examine the impact of the increase in reserves.

First, we present the quantity of money in response to the shock, which can be described by the derivative of the quantity of money with respect to reserves, that is,

$$\frac{\partial M}{\partial H} = \frac{r_E}{r_E - r_D}, \tag{85}$$

showing that the increase in reserves will lead to the expansion of loans and money. In addition, because $r_E/(r_E - r_D) > 1$, the above formula implies that an increase in reserves results in a multiple increase in deposits: the money multiplier effect. To investigate the implication of the multiplier, we rearrange the above formula,

$$\frac{\partial M}{\partial H} = 1 + \frac{r_D}{r_E - r_D}, \tag{86}$$

which implies $\Delta M = \Delta H + (r_D/(r_E - r_D))\Delta H$. This means that we can decompose the increase in the quantity of money into two terms. The first term suggests that part of the increase in the quantity of money is due to the injection of reserves. The second term implies an additional endogenous expansion of money that is driven by interest payments on deposits. The interest payments on deposits increase deposits themselves; thus, it generates a multiple expansion of interest payments and newly created deposits. Consequently, a one-unit increase in reserves leads to an increase in money equal to the multiplier.

Second, to see the response of the final output to the shock, we consider the derivative of the final output with respect to reserves,

$$\frac{\partial Y}{\partial H} = -\frac{\alpha r_D(1-\tau)}{\alpha(1 - s_L(1-\tau)) - r_D(1 - mpc)(1-\tau)}, \tag{87}$$

which gives the surprising result that the rise in bank reserves may generate a negative effect on output. The reason is as follows. Banks incur a cost to hold unremunerated reserves. At the same time, since the insufficient demand determines bank lending, the rise in reserves cannot increase loans. Therefore, the only effect is the cost leading to a decrease in banks' equity and in the wealth of households. Consequently, autonomous consumption and output fall. Our result may support the policy of paying interest on reserves by central banks because these interest payments can partially offset the cost of holding reserves and thereby mitigate the reduction in equity.

7. Conclusion

The 2008 financial crisis and the aftermath of the great recession reignited research interest in the mechanisms of money creation and circulation within the macroeconomy. For this purpose, we put forward a monetary framework to formulate these mechanisms by highlighting

[3] By contrast, households paying interest on loans decreases their deposits and increases their equity holdings simultaneously; it does not change their wealth. Therefore, households paying interest on loans does not change consumption.

[4] See the statement of the Federal Open Market Committee at https://www.federalreserve.gov/newsevents/pressreleases/monetary20190130c.htm.

the role of banks. Our model consists of nonfinancial firms, households, the government, the central bank, and banks. Our framework places the banking system at the center of the system. We characterize their conditions by the balance-sheet matrix, and describe the interactions between them by monetary flows presented in the transactions-flow matrix. Both the balance-sheet matrix and transactions-flow matrix characterize the evolution of the economy. Our study can be divided into two parts: one concerns money creation and destruction, and the other considers the dynamics and stationary state of the whole economic system.

In the first part, we focus on banks creating and destroying money through interactions with firms, households, and the government. All interactions between any two sectors characterized by monetary flows are categorized into two sorts: one associated with money creation or destruction, and the other unrelated to them. All money creation and destruction processes result from the interactions between the banking and non-banking sectors. We find that money creation is realized via banks lending, purchasing bonds, paying dividends, and paying interest on deposits. On the other hand, money destruction is realized via banks receiving repayments, selling bonds, issuing equity, and receiving interest on loans and bonds. In one word, money flowing out of banks creates money, while money flowing back to banks destroys money.

We then turn to the second part. After creation and before destruction, money can circulate in the macroeconomic system. We formulate the dynamics of the system using a set of dynamic equations. As the economy runs, monetary flows change corresponding balance sheet quantities, including money, loans, bonds, and bank equity, which in turn affect the flows themselves. The whole system will eventually reach a stationary state, where no stocks and flows change.

We particularly consider the stationary state under the premise of insufficient demand in each market. That is, investment, government spending, and demand for loans, bonds, and bank equity are insufficient and exogenously given. We solve for the stationary stock and flow variables, especially the money stock and final output. Notably, we show that the monetary flows associated with money creation and destruction are key determinants of the money stock and final output.

Our model also has implications for monetary policy. First, we explore the impacts of policy shocks to the loan rate on the money stock and final output. A rise in the loan rate strengthens money destruction, thus decreasing the quantity of money. However, it may raise the final output because it causes banks' equity and dividends on the equity to rise, thus increasing households' consumption. Second, central banks supplying more reserves leads to the multiple expansion of money stock. The multiplier effect is caused by interest payments on deposits creating money and expanding money stock. Moreover, despite the increase in money stock, the injection of reserves to stimulate the economy may surprisingly decrease the final output. This occurs due to the cost of holding reserves, which reduces the equity held and dividends received by households. As a result, households' consumption decreases.

The integrated framework proposed in this work helps us to understand money creation and circulation in the macroeconomic system and to examine monetary policy interventions. Furthermore, this framework is applicable to many other issues. First, it can be used to examine financial frictions and their following amplification effects as responses to various shocks. Second, it is suitable to investigate banks leveraging and deleveraging, which shape the business cycles. Finally, policymakers can employ the framework to assess the impact and effectiveness of bank regulations on credit markets and macroeconomic performance.

Credit author statement

Boyao Li: Methodology, Visualization, Writing-Revised draft preparation.

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Appendix A. Stationary deposit holdings

Here, we solve the stationary conditions (Eqs. (68)–(72)). A straightforward calculation shows the stationary amounts of deposits, D_H, D_F, and D_G, as follows:

$$\begin{aligned} D_H \;=\; & \chi 1_{D_H}\cdot(\alpha(r_E - r_L)(1 - s_L(1-\tau)) \\ & + (1 - mpc)(r_D(r_L - r_E(1-\tau)) - r_E r_L \tau))\omega\cdot\overline{BL_{B\to H}} \\ & + \chi 2_{D_H}\cdot(r_B(1 - mpc)(1-\tau) - \alpha(1 - s_L(1-\tau)))\rho\cdot\overline{BI_{H\to G}} \\ & + \chi 1_{D_H}\cdot(r_D(1 - s_L mpc(1-\tau)) - \alpha(1 - s_L(1-\tau)) \\ & - r_E(\tau + mpc(1 - s_L)(1-\tau)))\overline{EP} \\ & + \chi 1_{D_H}\cdot(r_L - r_D)(r_E(1 - mpc)(1-\tau) - \alpha(1 - s_L(1-\tau)))\omega\cdot\overline{BL_{B\to F}} \\ & + \chi 1_{D_H}\cdot((r_B - r_D)(\alpha(1 + s_L(1-\tau)) + r_E(1 - mpc)(1-\tau)))\rho\cdot\overline{BI_{B\to G}} \\ & + \chi 2_{D_H}\cdot s_L(1 - mpc)(1-\tau)(\overline{I} + \overline{G}) \\ & + \chi 1_{D_H}\cdot r_D(\alpha(1 - s_L(1-\tau)) - r_E(1 - mpc)(1-\tau))H, \end{aligned} \tag{A.1}$$

where the parameters $\chi 1_{DH}$ and $\chi 2_{DH}$ are given by

$$\begin{aligned} \chi 1_{D_H} &= \frac{1}{(r_D - r_E)(r_D(1 - mpc)(1-\tau)) - \alpha(1 - s_L(1-\tau))}, \\ \chi 2_{D_H} &= \frac{1}{\alpha(1 - s_L(1-\tau)) - r_D(1 - mpc)(1-\tau)}. \end{aligned}$$

$$\begin{aligned} D_F = & \, x^1{}_{D_F}\cdot(\alpha\tau - r_D)((1 - mpc)(1-\tau)(s_L(1-r) + r))\overline{I} + x^2{}_{D_F}\cdot(r_D r_L(1 - mpc)(1-\tau) - \alpha(r_D(1 - s_L)(1-\tau) + r_L\tau))w\cdot\overline{BL_{B\to F}} - x^2{}_{D_F}\cdot\alpha r_L(1 - s_L)\tau w \\ & \cdot\overline{BL_{B\to H}} + x^2{}_{D_F}\cdot\alpha(r_B - r_D)(1 - s_L)(1-\tau)\rho\cdot\overline{BI_{H\to G}} + x^2{}_{D_F}\cdot\alpha(r_B - r_D)(1 - s_L)(1-\tau)\rho\cdot\overline{BI_{B\to G}} - x^2{}_{D_F}\cdot(1 - s_L)(r_D(1 - mpc)(1-\tau) - \alpha)\overline{G} - x^2{}_{D_F} \\ & \cdot(1 - s_L)(r_D mpc(1-\tau) - \alpha\tau)\overline{EP} + x^3{}_{D_F}\cdot\alpha(1 - s_L)(1-\tau)H; \end{aligned} \tag{A.2}$$

where the parameters $\chi 1_{DF}$, $\chi 2_{DF}$, and $\chi 3_{DF}$ are expressed as

$$
\begin{aligned}
\chi 1_{D_F} &= \frac{1}{r_D(1-\tau)(\alpha(1-s_L(1-\tau))-r_D(1-mpc)(1-\tau))},\\
\chi 2_{D_F} &= \frac{1}{r_D(r_D(1-mpc)(1-\tau)-\alpha(1-s_L(1-\tau)))},\\
\chi 3_{D_F} &= \frac{1}{\alpha(1-s_L(1-\tau))-r_D(1-mpc)(1-\tau)}.
\end{aligned}
$$

$$
\begin{aligned}
D_G = {} & x^1{}_{DG}\cdot(r_D(1-mpc)(1-\tau)-\alpha(1-s_L))\overline{G} + x^1{}_{DG}\cdot(r_Br_D(1-mpc)(1-\tau)-\alpha(r_B(1-s_L)(1-\tau)+r_D\tau))\rho\cdot\overline{BI_{H\to G}} + x^1{}_{DG}\\
& \cdot(r_Br_D(1-mpc)(1-\tau)-\alpha(r_B(1-s_L)(1-\tau)+r_D\tau))\rho\cdot\overline{BI_{B\to G}} + x^1{}_{DG}\cdot r_L\tau(\alpha(1-s_L)-r_D(1-mpc))w\cdot\overline{BL_{B\to H}} + x^1{}_{DG}\cdot\alpha\tau(r_L-r_D)w\\
& \cdot\overline{BL_{B\to F}} + x^3{}_{DG}\cdot\tau(r_D(1-\tau)(1-mpc)-\alpha)\overline{I} - x^1{}_{DG}\cdot(r_D-\alpha\tau(1-s_L))\overline{EP} + x^2{}_{DG}\cdot\alpha\tau H; \qquad \text{(A.3)}
\end{aligned}
$$

where the parameters $\chi 1_{DG}$ and $\chi 2_{DG}$ are given by

$$
\begin{aligned}
\chi 1_{D_G} &= \frac{1}{r_D(r_D(1-mpc)(1-\tau)-\alpha(1-s_L(1-\tau)))},\\
\chi 2_{D_G} &= \frac{1}{\alpha(1-s_L(1-\tau))-r_D(1-mpc)(1-\tau)},\\
\chi 3_{D_G} &= \frac{1}{r_D(1-\tau)(\alpha(1-s_L(1-\tau))-r_D(1-mpc)(1-\tau))}.
\end{aligned}
$$

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