An Agent-Based Model of Business Cycle with Gestation Period

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Abstract

To elucidate the essential mechanisms of the business cycle, we constructed a completely closed small macroeconomic model based on Keynes's principle of effective demand. In this model, the gestation period needed to produce capital stock plays a decisive role in generating the business cycle. Further, output price, wage rate, interest rate, and money supply are endogenously determined. Without any outside shocks, our agent-based macroeconomy generates persistent business cycles that are fairly consistent with observations. For example, money supply and new orders for capital stock lead output. Our model is an integrated model in which a seller's market (Walrasian regime) and a buyer's market (Keynesian regime) emerge alternately.

1 Introduction

Major macroeconomic variables, namely consumption, employment, and investment, fluctuate in accordance with the booms and busts of a market economy[1]. The aim of the work presented here was to establish a completely closed agent-based macroeconomic model that provides a unified explanation

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[1]Stock and Watson (1999) observed a high degree of positive association between the series of activities in different sectors and real GDP: fixed investment was about three

of self-generating and persistent business cycles on the basis of the Keynesian principle of effective demand (Keynes (1936)).

The purpose of the work reported here is to construct an agent-based model of the macroeconomy with investment as “the active, driving force” (Minsky (2008), p. 91). To enable us to focus on the essential mechanisms of the business cycle, we excluded random shocks except during the initialization period and restricted the heterogeneity of the agents and their direct interactions. We built an artificial economy consisting of a household, a commercial bank, a central bank, a factory construction company, a finite number of manufacturers, and workers. There are four markets: goods, capital stock, labor, and bonds. The manufacturers are demand constrained (a la Negishi (1979)), bounded rationally, and form expectations adaptively. In addition, it takes time for the builder to construct factories. The output price and wage rate change slowly in response to the respective market conditions. Money is endogenously supplied, and the interest rate reflects the central bank’s monetary rule. The model is small and completely closed, without any outside shocks.

The main results of our simulation are that, in the intermediate run, the model persistently reproduces business cycles, in which the simulated behaviors are fairly consistent with the observed ones, as characterized by Cooley (1995, p.32). For example, consumption fluctuates much less than output while investment fluctuates more than output. Moreover, money supply and new orders for capital stock lead output. Furthermore, the model generates endogenous switching in the demand-deficient and demand-sufficient regimes.

The structure of the paper is as follows. Section 2 presents and explains the model. Section 3 presents the results and discusses their implications. Section 4 summarizes the key points and gives future extensions.

2 Model

2.1 Model overview

Time in our model is discrete with the unit defined as a period. We have three levels of time: month, year, and generation. One month corresponds

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times more volatile than output; nondurable consumption was about half as volatile as output; total employment was strongly procyclical with a lag of about three months; and capital stock was fairly constant.

Assets	Liabilities
book value of factories ($=L^F$)	L^F
M^F	E^F

Table 1: Balance Sheet of Consolidated Firms

to one production period, to which we assign unit length. One year, which encompasses T_m months, corresponds to a gestation period, that is, the period of time needed to build a factory (Kydland and Prescott, 1982). The capital stock lasts for one generation.

The economy consists of a household, a commercial bank, a central bank, a factory construction company (hereafter referred to as a 'builder'), and a finite number J of manufacturers (hereafter referred to as 'firms'), and workers. Firms behave actively whereas all other agents behave passively. There is only one product, two types of labor (workers and managers), capital stock (factories), bonds, and money (deposits in checking accounts).

The firms routinely undertake a sequence of activities each month and repeat the cycle until they go bankrupt. The output of firm j in period t, Q_{jt}, is given by a Cobb-Douglas production function:

$$Q_{jt} = AK_{jt}^{\alpha} N_{jt}^{1-\alpha} \text{ for all } j = 1, 2, \ldots J,$$

where K_{jt} and N_{jt} respectively denote firm j's beginning-of-period productive capital (i.e., total number of factories owned) and total hours of labor. Parameters, A represents the efficiency of the production process while parameter α represents the capital share in the production function.

For simplicity, all types of debt are assumed to have a maturity of one period. Firm j's loan balance at the end of period t is denoted by L_t^j. Its checking account balance, denoted by M_t^j, bears no interest. In each period, the firm repays a portion of the loan principal equivalent to the amount of depreciation cost on its factory. As a result, the book value of the remaining capital stock always equals the outstanding loan balance. Thus, the-end-of-period net equity of the firm, E_t^j, is always equal to M_t^j, as shown in Table 1, where superscript F for a variable indicates the sum over all firms, e.g., $\sum_{j=1}^{J} L^j = L^F$.

The household represents employees (workers and managers), consumers, and shareholders of the firms and the commercial bank. It receives wage and salary incomes from the firms, dividend payments from the bank and firms, and interest incomes on bonds from the bank. The household first decides its consumption level (C), and thus savings, on the basis of its income (Y) and wealth (W^H). It then decides on how to allocate its savings between bonds (B) and money (M^H).

The builder starts building factory in response to an order from a firm. When construction is completed after a gestation period of one year, the builder delivers the factory to the firm in exchange for a sum of money equivalent to the construction cost (i.e., it does not earn a profit or incur a loss). To build a factory, the builder puts ϕ units of product each month for one year. It does not use either factory or labor.

The commercial bank provides investment funds to the firms and builder. It also accepts deposits into checking accounts from firms and the household, the sum of which, namely money supply, is denoted by M, i.e., $M_t = M_t^H + M_t^F$. The bank issues interest-bearing bonds and sells them to the household. The bank incurs no operational costs and returns all profits to the household as dividends. Only the commercial bank holds cash (base money), G, as reserves; hence, all agent transactions are settled by updating the balances of their checking accounts. The commercial bank is required to hold a certain proportion of the total checking account balance in reserve, i.e., γM, where γ is the required reserve ratio (Table 2). The central bank reduces base money by issuing bills and selling them (ΔL^C) to the commercial bank whereas injecting it by funds-supplying operation against pooled-collateral (ΔB^C). For simplicity, the interest rate on the bill and funds-supplying operation are assumed to be the same as the lending and bond interest rates, r_t.

2.2 Flow in each period

Following initialization, our macroeconomic model was repeatedly run with the following 11 steps in each period.

2.2.1 Update interest rate

The excess demand for base money is given by $\gamma M_{t-1} - G_{t-1}$, and the interest rate is updated to restore the balance of base money.

Assets	Liabilities
$R(=G_0+B^C-L^C)$	$M(=M^H+M^F)$
L^C	B^C
$L(=L^F+L^B)$	B
	E_0^b

Table 2: Balance Sheet of Commercial Bank

2.2.2 Make interest and dividend payments

The whole sale interest rate (in interbank market) and the interest rates on loans and bonds are all the same. The interest that accrues on the builder's loan balance is added to the loan principle. Each firm pays interest on its loan principle and repays a fraction of the principle. These payments are made by deducting the amount from the firm's checking account.

The households monthly interest income on bonds and the dividens it receives from the bank and from the firms are added to its checking account. The commercial bank pays its shareholder (the household) all its profits. As a consequence, the net equity (capital) of the bank remains at the initial level.

Each firm has a desired level of money holding (checking account balance), an amount equivalent to the expected sales over θ_M months, i.e., $\bar{M}_t^j \equiv \theta_M P_t \hat{X}_t^j$. If the checking balance exceeds the target level, the difference is distributed to the household the next month. Otherwise, no dividend payment is made.

2.2.3 Deliver completed factories

Firm mod(t, T_m) undertakes new investment at the beginning of period t. Hence, the total sum of input and interest costs between periods $t-T_m+1$ and t gives the end-of-month total loan balance of the builder, which corresponds to the book value of factories under construction (Table 3).

2.2.4 Make investment decision (once a year)

Let $s_m^j(t)$ be the number of firm j's factories m periods from completion for $m = 1, \ldots, T_m$, in period t. When the builder delivers a completed factory, the firm assumes the builder's corresponding loans. We assume that

Assets	Liabilities
book value of factories in progress	L^B

Table 3: Balance Sheet of Builder

the depreciation pattern is the "one-hoss shay," in which factory retains its productive capacity during its operational life[2]. Thus, firm j's stock of capital (i.e., number of factories) evolves in accordance with

$$K_{j,t+1} = K_{jt} - s_1^j(t - T_m T_n) + s_1^j(t), \tag{1}$$

and

$$s_m^j(t+1) = s_{m+1}^j(t) \quad (m = 1, \ldots, T_m - 1). \tag{2}$$

Notice that $s_{T_m}^j(t) = 0$ whenever $j \neq \mathrm{mod}(t-1, T_m)+1$. A completed factory continues to operate for T_y years with a constant production capability. After T_y years, it is shut down and disposed of with zero disposal value. Each firm's history of factory delivery up to period t is given by

$$\{s_1^j(\tau)\}_{\tau=-T_m(T_y-1)+j-1}^{t-1}. \tag{3}$$

The number of currently operating factories, K_{jt}, is the total number of factories completed in the most recent T_y years. The profitability condition for a new investment requires that the quasi-rents expected from the new investment exceed the cost of investment. This condition is equivalent to the requirement that the current output price P_t exceed the expected average cost AC_t:

$$\frac{AC_t}{P_t} = \frac{1}{A}\left[\frac{\phi(1+r_t)}{\alpha\psi(R_t)}\right]^{\alpha}\left[\frac{W_t}{(1-\alpha)P_t}\right]^{1-\alpha} \leq 1. \tag{4}$$

where $\psi(R) \equiv \sum_{\tau=1}^{T_y}\left(1/(1+R)^{T_m}\right)^{\tau}$ is decreasing in R.

If the profitability condition is met, the firm checks whether the demand criterion is satisfied. The amount of new investment is given by the excess of the desired amount of capital stock over the amount in one year. The former is given by $\hat{X}_t^j k_t^{*(1-\alpha)}/A$ while the latter is given by $K_{jt} - s_{T_m}^j(t - T_m T_y)$, where

[2] Hulten and Wykoff (1996) remarked that "when viewed from this intuitive standpoint, the most plausible pattern may well seem to be the 'one-hoss shay,'[...]" (p. 17).

$\hat{X}_t^j = X_t^j$ due to adaptive expectations. We assume that the adjustment cost involved in fast growth is prohibitively large if the volume of new investment is greater than $\theta_I K_{jt}$ with $0 < \theta_I < 1$. This upperbound on investment reduces the dispersion of firm size. Consequently, we can summarize the demand condition as

$$s_{T_m}^j(t) = \min\left[\max\left(\frac{\hat{X}_t^j}{A}k_t^{*(1-\alpha)} + s_{T_m}^j(t - T_m T_y) - K_{jt}, 0\right), \theta_I K_{jt}\right]. \quad (5)$$

Equation (5) says that, the larger the expected demand relative to existing production capacity, the more likely our firm is to undertake a new project. To accmomodate demand uncertainty, we introduce the allowance for demand uncertainty A_s[3], hence the volume of new investment, $S_{T_m}^j(t)$, is given by

$$S_{T_m}^j(t) = (1 + A_s)s_{T_m}^j(t). \quad (6)$$

2.2.5 Decide employment level

Workers are employed on a monthly contract. The firm computes the employment level needed to meet the expected demand as well as the profit-maximizing employment that equates the output price with the marginal cost. The smaller of these two levels gives labor demand. If the aggregate of these levels is greater than the labor available, workers are allocated to firms in proportion to the demand facing each firm.

The level of employment is formulated as

$$N_{jt} = (1 + A_s)\min\left(K_{jt}\left[\frac{(1-\alpha)AP_t}{W_t}\right]^{1/\alpha}, \left[\frac{\hat{X}_t^j}{AK_{jt}^{\alpha}}\right]^{\frac{1}{1-\alpha}}\right). \quad (7)$$

This equation implies that a change in the real wage rate does not affect the employment decision if a firm is demand-constrained.

[3]The concept of this allowance can be understood by imagining that workers cannot vary the intensity of their work. Since the demand for products involves uncertainty, if a firm makes investment and employment decisions simply on the basis of average demand, it will unable to meet any extra demand exceeding the average. A profit maximizing firm will thus obtain extra productive capacity.

Assets	Liabilities
M^H	W^H
B	
$E^F(= M^F)$	
E_0^b	

Table 4: Balance Sheet of Household

2.2.6 Make wage payments

Firm j pays wages $W_t N_{jt}$ to direct workers and pays a proportional amount $(\bar{H} W_t N_{jt})$ to overhead employees by transferring money from the firm's checking account to the household's checking account. The total sum of these amounts over all firms is

$$(1 + \bar{H}) W_t N_t^F. \tag{8}$$

2.2.7 Pay bill for consumption spending

The total household income is the sum of the overhead payment and management compensation, wage incomes, and interest income and dividend income:

$$\begin{aligned} Y_t &= (1 + \bar{H}) W_t N_t^F + r_t B_{t-1} + D_t^F + \Pi_t^b \\ &= (1 + \bar{H}) W_t N_t^F + D_t^F + r_t (L_{t-1} + L_{t-1}^C - B_{t-1}^C) \end{aligned} \tag{9}$$

where $D_t^F = \sum_{j=1}^J D_t^j$ denotes total dividend income. The end-of-period total household assets W_{t-1}^H is given by

$$W_{t-1}^H = M_{t-1} + B_{t-1} + E_0^b. \tag{10}$$

Following Ando and Modigliani (1963), given aggregate income Y_t and total wealth W_{t-1}^H, we compute real consumption C_t using a linear consumption function:

$$P_t C_t = c_y Y_t + c_w W_{t-1}^H, \tag{11}$$

where $0 < c_y, c_w < 1$. Consumption demand is obtained by dividing it by the price level. Adding investment demand, we determine aggregate demand for output. The aggregate demand is allocated to individual firms in proportion to their capital stock, K_{jt}. If the demand exceeds the capacity, workers increase work intensity to meet the demand up to degree of θ_L without receiving any additional wages, hence allowing the firm to gain windfall profits. The household makes the consumption expenditure payment by transferring funds from its checking account to the firm's.

2.2.8 Update prices and money wage rates

At the beginning of period t, firm $\mathrm{mod}(t - T_m + m - 1, T_m) + 1$ has an investment project to be completed within m periods. The volume of investment, i.e., the total number of factories under construction, is given by $I_t = \phi \sum_{m=1}^{T_m} s_m^{\mathrm{mod}\,(t-T_m+m-1,T_m)+1}(t)$. The output price is revised in proportion to the ratio of aggregate excess demand over aggregate productive capacity a la Fisher (1970, 1972):

$$\frac{\Delta P_{t+1}}{P_t} = \beta_p \frac{X_t - Q_t}{Q_t}, \tag{12}$$

where parameter β_p is for translating excess demand into the inflation rate, and $X_t = C_t + I_t$.

The actual rate of unemployment is given by

$$u_t = \frac{\bar{N} - N_t^F}{\bar{N}},$$

where $\bar{N}$ is labor endowment. Money wage rate W_t is revised so that the real wage rate, $w_t = \frac{W_t}{P_t}$, adjusts to remove the imbalance in the labor market. In other words, the money wage rate minus the inflation rate responds to u_t in excess of the natural unemployment rate, u_*. The wage rate is revised in accordance with

$$\frac{\Delta W_{t+1}}{W_t} = \beta_w (u_* - u_t) + \pi_t, \tag{13}$$

where parameter β_w represent the speed of adjustment.

2.2.9 Adjust balance of household checking account

The demand for money (checking account balances) positively depends on income and inversely depends on the interest rate. The household removes excess demand for money by purchasing bonds issued by the bank. Firm j's demand for money evolves in accordand with

$$M_t^j = M_{t-1}^j + \Pi_t^j - D_t^j. \tag{14}$$

Assets	Liabilities
B^C	L^C
G_0	R

Table 5: Balance Sheet of Central Bank

The households adjusts the balance of its checking account in accordance with

$$\Delta M^H = \beta_m \left(\frac{a_y Y_t}{\exp(a_r r_t)} - M^H_{t-1} \right),$$

where β_m is the speed of adjustment, $a_y > 0$ is income elasticity and $a_r > 0$ is the semi-elasticity of the interest rate.

2.2.10 Inject capital

If a firm has a negative balance in its checking account, the household injects capital (i.e., transfers money from its checking account into that of the firm) until the balance reaches the target level.

2.2.11 Implement monetary rule

The central bank implements the following simple monetary rule:

$$\Delta G = \begin{cases} \bar{G} & \text{if } r_t > r^* \text{ and } I_t < I^* \\ -\bar{G} & \text{if } r_t < r^* \text{ and } I_t > I^* \end{cases} \tag{15}$$

The rule says that the central bank increases (decreases) base money (the reserves of the commercial bank, R) by $\bar{G}$, when the interest rate is higher (lower) than target level r^* and the level of investment is below (above) target level I^*.

2.3 Parameter settings

This macroeconomic model was simulated under the parameter conditions shown in Table 6.

Table 6. Parameter settings.

Name	Value
ϕ	1.0
A	1.25
α	0.3
θ_I	0.2
γ_α	$1e-5$
γ	0.1
β_π	0.5
θ_{re}	0.5
c_y	0.95
c_w	0.0038
A_s	1.05
$\bar{H}$	30
θ_L	1.2
θ_M	2.0
θ_D	0.5
a_Y	0.5
a_r	500.0
β_m	0.5
β_p	0.03
$\bar{N}$	180
β_w	0.5
u_N	0.03
r^*	0.01
I^*	0.01
$\bar{G}$	1000.0
I_0	3.0
M_0^H	$2e5$
G_0	$2e4$
$P(0)$	100.0
$W(0)$	100.0
$l(-1)$	20.0

3 Results and Discussion

This section presents the main results and discusses their implications. The observed simulation behaviors in the intermediate run were fairly consistent

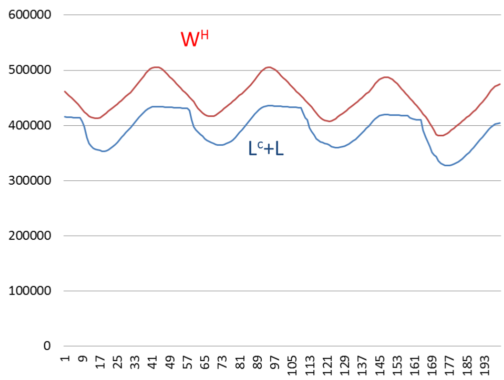

Figure 1: Loan balance of firms and builder and wealth of household in the intermediate run

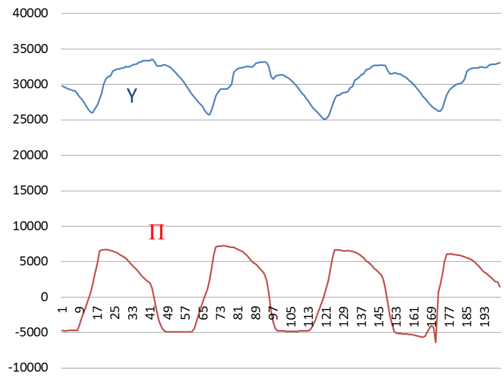

Figure 2: Aggregate nominal income and investment in the intermediate run

with those observed in the business cycle.

In the intermediate run (20 year horizon), several variables exhibited basically smooth cyclical movement while others exhibited compound movements, i.e., large cycles containing smaller cycles, which may reflect the difference in firm size. Included in the first group are the wealth of the household (Figure 1), aggregate nominal income and profits (Figure 2). The variables in the second group are money supply (Figure 3), employment (Figure 4), and real GDP (Figure 5).

The gestation period played a major role in generating cycles. The length of one cycle appears to have been normally distributed with 41 periods on average with a standard deviation of 193 periods. A natural question is

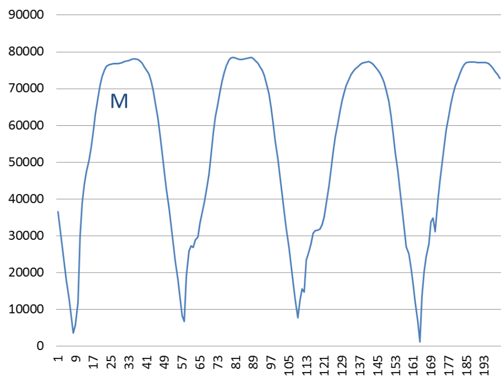

Figure 3: Money supply in the intermediate run

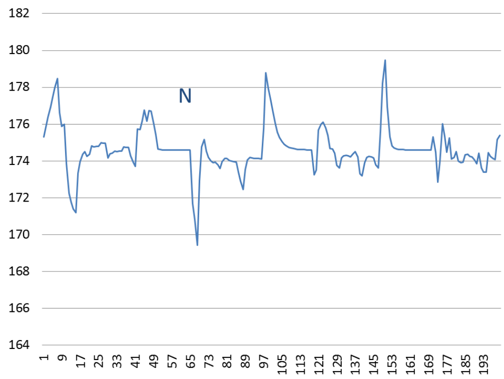

Figure 4: Employment in the intermediate run

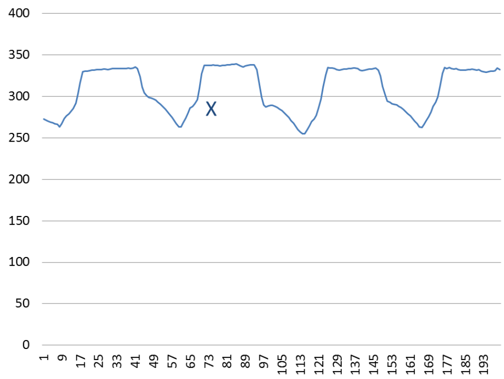

Figure 5: Real GDP (i.e., output demand) in the intermediate run

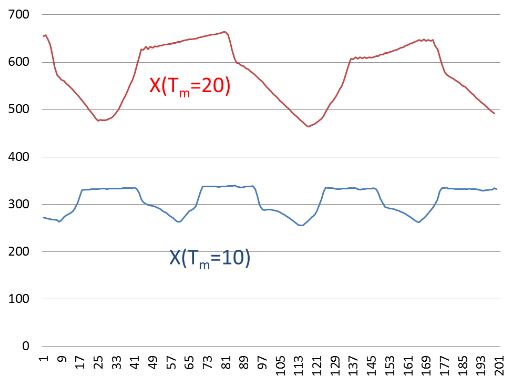

Figure 6: GDP and the lengths of gestation period

what determined the length of a cycle. Figure 6 shows that doubling the length of the gestation period doubled the length of one cycle. This finding is interesting and consistent with insights by Aftalion (1913) and Haberler (1946)[4]

Leading economic indicators can predict peaks and troughs of business cycles several months before they actually occur. Among them are manufacturers' new orders of capital goods and real money supply. New orders for capital goods appear to have moved about seven or eight months ahead of output, as shown in Figure 7, which is fairly consistent with the historical record in the U.S. (Lahiri and Moore (1992). The simulated volume of the money supply (measured by M^H, i.e., balance in household checking account) changed ahead of production by one or two periods (Figure 8).

Equation (7) shows that, when the demand is small relative to productive capacity (i.e., the demand constraint is binding), the level of employment is determined by the volume of aggregate demand. In contrast, when the demand is relatively large (i.e., the demand constraint is not binding), employ-

[4] "My principal thesis is that the chief responsibility for cyclical fluctuations should be assigned to one of the characteristics of modern industrial technique, namely, the long period required for the production of fixed capital (Aftalion, 1913, p.165)." "The idea that the length of the prosperity phase of the cycle depends on the duration of the new productive processes (which is, in the main, the period of construction of new capital equipment) has been widely re-echoed. Professors Pigou and Roberrson attribute to what they call the *gestation period* of capital goods, which is substantially equivalent to the period of construction, an important role in determining the length of the upswing (Haberler, 1946, p.136)."

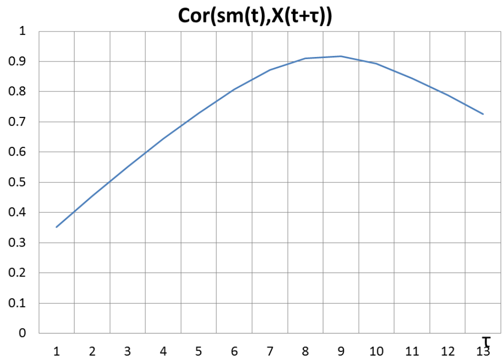

Figure 7: Correlation between new orders for capital goods and lagged GDP

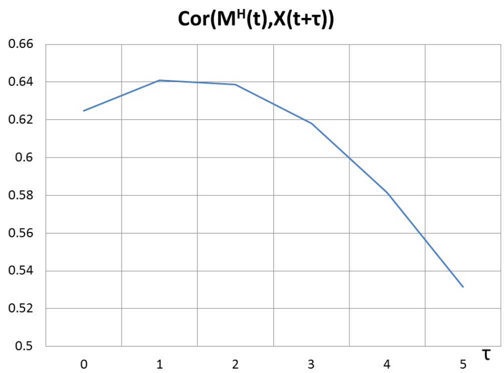

Figure 8: Correlation between money supply and lagged GDP

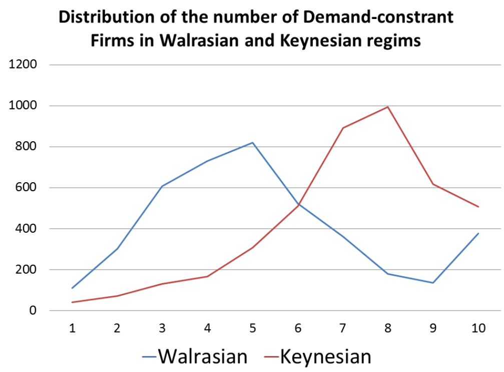

Figure 9: Distributions of number of demand-constrained firms in Keynesian and Walrasian regimes

ment is determined so as to equate the output price and marginal cost (or the real wage rate and marginal productivity of labor). We can expect that, in recession periods, the firms of the former type are dominant whereas in boom periods the firms of the latter type are dominant. To verify this expectation, we classified each period into either a Keynesian or Walrasian regime: as a Keynesian regime if the number of firms that were demand-constrained was larger than a half and as a Walrasian regime otherwise. Figure 9 depicts the distributions of the firms that were demand constrained under the two regimes. As expected, the two distributions are quite different: the average ratio of demand-constrained firms in the Walrasian regime is 0.522 whereas that in the Keynesian regime is 0.723. The P-value, the hypothesis test to determine whether the difference between two mean scores, was less than 0.001. Thus, we can regard the Walrasian regime as a seller's market, and the Keynesian regime as a buyer's market.

The essential elements that cause the business cycle in our model are (1) the gestation period, that is, the time delay between an investment decision and the deliveries of the finished factory, (2) the positive feed-back loop between investment spending on the one hand, and excess aggregate demand and profit on the one other[5], and (3) the factors that affect investment decisions, such as the size of aggregate demand relative to productive capacity, the output price, the real wage rate, and the interest rate. The first and second elements combined create disequilibrating forces that drive the economy

[5]See Chapter 7 of Minsky (1986).

away from the steady state while the third element governs the transition from one phase of a cycle to the next.

There are no stochastic shocks in our model. According to Fisher (1933), there are two sorts of cyclical tendencies: "one is 'forced' or imposed on the economic mechanism from outside. [...] The second sort of cyclical tendency is the 'free' cycle, not forced from outside, but self-generating, operating analogously to a pendulum or wave motion (p. 338)." Our focus is on finding a basic mechanism of the second sort; hence, their works and ours are complementary.

The elementary mechanism of the business cycle in our model is similar to those of Hicks (1950), Kalecki (1935,1937,1939), and Kaldor (1940). However, our model is completely closed, endogenizing prices, i.e., output price, money wage, and interest rate, as well as money supply. Moreover, it incorporates both the multiplier-accelerator principle and the profit principle. Furthermore, the model enables regime switching between Keynesian and Walrasian to emerge naturally.

4 Conclusion

To elucidate the mechanism of the self-generating business cycle, we constructed a completely closed small macroeconomic model based on Keynesian effective demand. The output price, wage rate, interest rate, and money supply are all endogenously determined. With an appropriate parameter tuning, our small artificial economy endogenously reproduced business cycles that are fairly consistent with observed ones. For example, money supply and new orders for capital stock were leading economic indicators. Moreover, the length of the prosperity phase of the cycle depended on the length of the gestation period, which suggests that the gestation period is a decisive cause of cycles. In addition, the complex interactions among the investment activities of the firms led to Keynesian regime and Walrasian regimes emerging endogenously and alternately. The model integrates Keynesian and neoclassical regimes in a unified way.

To facilitate exposition of the model itself, we omitted economic grounds and the detailed derivation of structural equations, which are ready to present in another article. To focus on the essential element that generates the business cycle, we restricted the dispersion of firm size by introducing an adjustment cost for investment.

There are various interesting future avenues for extensions, including allowing for more heterogeneity of the firms, incorporating market psychology, incorporating lender's and borrower's risks, and incorporating credit linkages among banks and their lending rules, to name a few. These extensions will provide an even more realistic picture of the business cycle.

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