

The Credit Spread and U.S. Business Cycles*

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In this paper, we constructed a dynamic stochastic general equilibrium model with credit spread, government expenditure, productivity, investment specific technology and preference shocks in order to quantitatively account for the U.S. business cycle fluctuations through 1985-2014. We find that fluctuations in productivity and preference shocks are important in accounting for the fluctuations in output while investment specific technology shocks are important in accounting for the fluctuations in the investment rate. Moreover, credit spread shocks play a significant role in the decline in output and investment rate during the recent financial crisis. Therefore, in our environment, unlike Chari, Kehoe and McGrattan (2007), the intertemporal distortions caused by financial frictions do matter.

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1. INTRODUCTION

The business cycle literature has been considered technology shocks as the main contributor of economic fluctuations over time. As pointed out by Justiniano *et al.* (2010a), previous studies with general equilibrium models tend to attribute a dominant role in business cycles to technology shocks. However, the recent severe economic downturn due to the collapse of credit bubbles has provoked a re-evaluation of such conventional view on aggregate fluctuations. Justiniano *et al.* (2010b) demonstrate empirically that a shock to the marginal efficiency of investment, which is first proposed by Greenwood *et al.* (1988), is the main driving force of fluctuations in investment and hence output in U.S. and that this shock reflects corporate financial conditions for investment spending.

This paper is closely related to the business cycle accounting literature first introduced by Chari, Kehoe, and McGrattan (2007, hereafter CKM) which decomposes business cycle fluctuations into contributions from productivity, government expenditure, intra-temporal distortions and inter-temporal distortions. Brinca, Chari, Kehoe, and McGrattan (2016) use the method to investigate the Great Recession in the U.S., among others, and find that while the main contributor was labor market distortions, the intertemporal distortions also had a considerable impact.

The key difference between our setting and theirs is that while a standard business cycle accounting model defines the intertemporal wedge as distortionary taxes on investment carried out by the household, we decompose the intertemporal distortion into the credit spread that affects the cost of investment and investment specific technology that affects the benefit from investment. This allows us to re-investigate the quantitative importance of intertemporal distortions stemming from financial frictions within their business cycle accounting framework. Hence, our model contains total factor productivity, government expenditure, consumption-leisure preference weight shocks, credit spread and investment specific technology. Total factor productivity, government expenditure and consumption-leisure preference

weight shocks correspond to the productivity, government, intratemporal distortions (wedges) in CKM respectively. Both credit spread and investment specific technology shocks corresponds to the intertemporal distortion (wedge) in CKM.

The business cycle accounting in CKM finds that the productivity and intratemporal wedges together account for essentially all of the fluctuation; the intertemporal wedge explains a relatively small portion of aggregate fluctuations. We find that fluctuations in productivity and preference shocks are important in accounting for the fluctuations in output while investment specific technology shocks are important in accounting for the fluctuations in the investment rate. Moreover, credit spread shocks play a significant role in the decline in output and investment rate during the recent financial crisis. Therefore, in our environment, unlike Chari, Kehoe and McGrattan (2007), the intertemporal distortions caused by financial frictions do matter.

In our analysis, we estimate the model using the quarterly data of output, consumption, investment, labor and credit spreads over the 1985Q1-2007Q4 period. We then back out the shocks using the equilibrium conditions and data of output, consumption, investment, labor and credit spreads over the 1985Q1-2014Q4 period. Finally, we decompose the quantitative impacts of each shock on output over the entire period. We find that productivity and preference shocks are the main sources of the U.S. output fluctuation. On the other hand, investment specific technology shocks are the main sources of the fluctuation in the investment rate. Moreover, credit spread shocks have a significant negative impact on output and the investment rate during the recent financial crisis.

The credit spread in the U.S. fluctuates counter-cyclically and increased dramatically during the recent financial crisis. In this paper, we construct a dynamic stochastic general equilibrium model in order to investigate the impact of credit spread shocks on the U.S. business cycle over the 1985-2014 period. The model is based on a standard real business cycle model with a balance sheet constraint where capital stock must be purchased with credit. Therefore, shocks to credit spreads directly affect the cost of capital.

Our work is related to the literature on the financial frictions and macroeconomic fluctuations. Previous research on this literature focuses on the friction that accounts for endogenous fluctuations in aggregate variables, through which macroeconomic cycles is created and amplified. Kiyotaki and Moore (1997) assumes a simple collateral constraint arising from financial frictions by which drops (increases) in asset values lead to tighter (more relaxed) credit conditions. This leads to amplify the aggregate investment and creates economic fluctuations. Bernanke and Gertler (1989) show how costly state verification as an informational friction amplifies productivity shocks through investment. Calstrom and Fuerst (1997) and Bernanke, Gertler, and Gilchrist (1999) introduce agency cost and financial accelerator in credit markets, which amplify and propagate monetary and productivity shocks to the macroeconomy.

The recent financial crisis led to a number of studies investigating the role of credit shocks on the business cycle. Gilchrist, Yankov, and Zakrajsek (2009) constructs a credit spread portfolio from senior unsecured corporate debt traded in the secondary market over the 1990-2008 period. Their factor-augmented vector auto-regression shows that disturbances in the credit market explain a substantial fraction of the volatility in the U.S. economic activity during 1990-2010. Credit shocks have also been studied in the context of dynamic stochastic general equilibrium models. Jermann and Quadrini (2012) constructs a model with exogenous borrowing constraints on intra-period loans and show that the tightening of financial conditions are important in accounting for the U.S. output declines in 1990-1991, 2001, and 2008-2009. Gourio (2013) constructs a model in which firms choose defaultable debt based on taxes and bankruptcy cost they face and shows that exogenous changes in the probability of disaster can generate countercyclical and volatile credit spreads. Khan and Thomas (2013) and Buera and Moll (2015) construct models with heterogeneous firms facing endogenous borrowing constraints and show that credit shocks can generate a long-lived recession by disturbing the distribution of capital and hence reducing aggregate productivity. Gomes and Schmid (2010) constructs a model with endogenous default and firm entry

and shows that credit market tightening leads to lower output due to higher default and lower firm entry. We define credit shocks as exogenous shocks to the credit spread which affect firm borrowing and hence investment on production capacity.

Kaihatsu and Kurozumi (2014) incorporate a financial accelerator mechanism into a DSGE model with stochastic trends in neutral and investment-specific technological changes, and conduct historical decompositions of U.S output growth rate and investment growth rate in order to empirically show that technology shock is still a main contributor of output fluctuation and the financial shocks are as important for investment fluctuation as the productivity shock.

The remainder of the paper is organized as follows. In section 2, we present the quarterly business cycle features of the U.S. economy. In section 3, we describe the dynamic stochastic general equilibrium model we use to account for these features. In section 4, we explain the quantitative method we adopt and present the quantitative results. Section 5 concludes the paper.

2. THE U.S. BUSINESS CYCLE AND CREDIT SPREADS

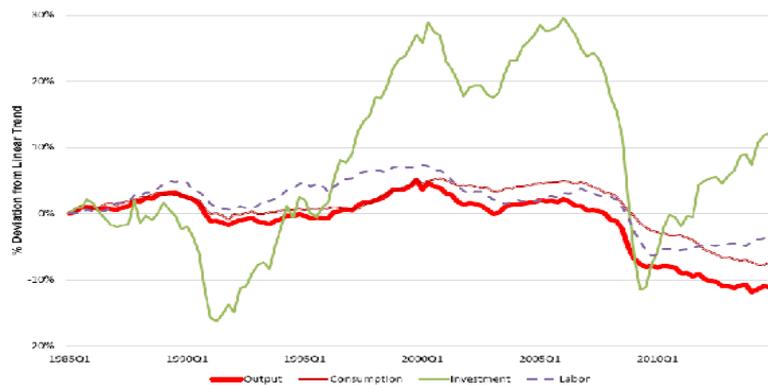
In this section we show the quarterly fluctuations of key macroeconomic variables in the U.S. over the 1985Q1-2014Q4 period. Output is defined as GDP plus the flow service generated from household durable goods stock. The flow service is imputed following Cooley and Prescott (1995).¹⁾ Consumption is defined as expenditures on non-durable goods and services plus the flow service from durable goods stock and government capital stock. Investment is defined as the sum of gross capital formation and expenditures on durable goods. Labor stands for total hours worked defined as the number of employed times hours worked per worker. We normalize the hours worked per worker as a fraction of 14 hours per day which we assume to be the maximum possible

¹⁾ The detailed method for data construction is described in the appendix. We also conduct a sensitivity analysis using GDP as output.

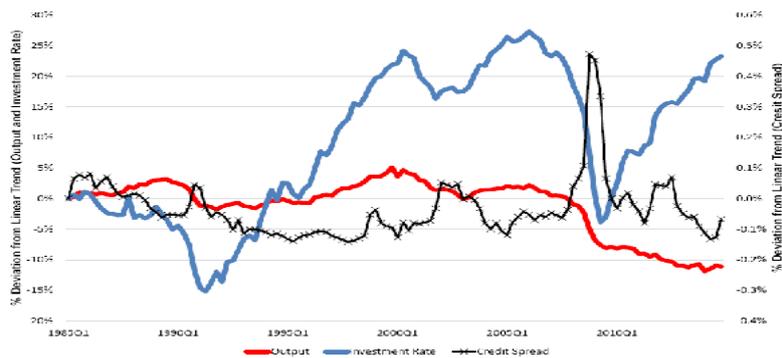
daily working hours. We define the credit spread as the difference between the Baa and Aaa corporate bond rates. The data is obtained from the Federal Reserve Economic Data published by the Federal Reserve Bank of St. Louis.

Figure 1(a) shows the business cycle features of these variables. In order to focus on business cycle features of the economy, we remove long run trends from each variables. First, we divide output, consumption, investment and labor with adult population. Next, we linearly detrend per adult output, consumption and investment with the average per adult growth rate over the

Figure 1 The U.S. Business Cycle and Credit Spreads (1985Q1-2014Q4)



(a) U.S. Linearly detrended business cycles



(b) Investment rate and credit spreads

1985Q1-2007Q4 period which corresponds to the Great Moderate period. For per adult labor, we remove the mean level of the 1985Q1-2007Q4 period as economic growth theory dictates that this variable should be stationary. All lines in figure 1(a) are expressed in terms of the percentage deviation from the long run trend normalizing 1985Q1= 0.

This figure clearly shows that consumption, labor and investment are all procyclical. The correlation coefficient between output is 0.93 for consumption, 0.36 for investment, and 0.91 for labor. If we focus on high frequency fluctuations, the HP filtered correlation coefficients between output and consumption, investment and labor are 0.89, 0.92, and 0.86 respectively. Investment is much more volatile than output, while consumption and labor are less volatile than output. The relative standard deviation relative to that of output is 0.75 for consumption, 2.82 for investment and 0.82 for labor. The fact that consumption is less volatile than output reflects consumption smoothing behavior of the household. The HP filtered relative standard deviations are 0.69 for consumption, 4.42 for investment and 1.17 for labor. Therefore, consumption smoothing holds in the HP filtered data.

Figure 1(b) presents fluctuations of the credit spread and investment rate along the business cycle. Since the credit spread represents the borrowing cost of a credit constrained firm, we conjecture that it will affect the investment rate, which is defined as the ratio of investment to output. For both the investment rate and credit spread we remove the mean level of the 1985Q1-2007Q4 period. The investment rate is highly procyclical, which is obvious given the previous observations of investment and output. The credit spread is countercyclical, with a correlation coefficient of -0.22 with output. This is further pronounced in the HP filtered data, where the correlation coefficient is -0.40 .²⁾ This implies that the main driver of credit spreads was shocks to the supply of credit rather than shocks to the demand for credit. In the following section, we develop a simple model that can quantify this effect.

²⁾ We find similar patterns when we use the spread between Baa bonds and 3-month T-bills: the linearly detrended correlation is -0.52 and the HP-filtered correlation is -0.66 . This is consistent with the findings of Gilchrist, Yankov and Zakrajsek (2009) and Gerba, Caglar and Chadha (2011) that the counter-cyclicity is robust across various measures of credit spreads.

3. MODEL

The model consists of a representative household, firm, financial intermediary and government. The household trades risk free assets with the financial intermediary. The financial intermediary invests in government bonds and lending to the firm. The firm borrows from the financial intermediary in order to purchase capital goods.

3.1. Household

The household maximizes its discounted lifetime utility which depends on consumption, leisure and preference shocks:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t, \Psi_t),$$

where c is consumption, l is normalized labor input, and Ψ_t is the preference shock which is a time varying preference weight on consumption relative to leisure, $1-l$. We define the periodical preference function as

$$u(c_t, l_t, \Psi_t) = \Psi_t \log c_t + (1 - \Psi_t) \log(1 - l_t).$$

The household faces the following budget constraint

$$w_t l_t + a_t + \pi_t + \pi_t^f = c_t + \frac{\Gamma a_{t+1}}{R_t} + \tau_t. \quad (1)$$

That is, it uses the labor income $w_t l_t$, return on the non-state-contingent asset a_t , dividend incomes π_t and π_t^f from firm and financial intermediary respectively, in order to purchase consumption goods and non-state-contingent assets that mature next period with a discount rate of R_t and to pay lump-sum taxes τ_t . All variables are detrended by population growth and labor

augmenting technology growth where Γ adjusts for this growth trend which we assume as a constant.

3.2. Firm

The firm maximizes the discounted present value of profits π_t

$$\max E_0 \sum_{t=0}^{\infty} \prod_{\tau=0}^t \frac{1}{R_{\tau-1}} \pi_t,$$

where $\frac{1}{R_{-1}} = 1$. The profits are defined as output y_t and discounted corporate debt d_{t+1} minus labor, investment and borrowing cost:

$$\pi_t = y_t - w_t l_t - x_t + \frac{\Gamma d_{t+1}}{R_t^L} - d_t, \quad (2)$$

where R_t^L is the discount rate of the corporate debt the firm faces and x_t denotes investment.

Output is defined by a Cobb-Douglas production function

$$y_t = z_t k_t^\theta l_t^{1-\theta}, \quad (3)$$

where z_t is total factor productivity and k_t is the capital stock which accumulates according to the capital law of motion

$$\Gamma k_{t+1} = \phi_t x_t + (1 - \delta) k_t. \quad (4)$$

The investment specific technology shock ϕ_t represents the efficiency in accumulating capital stock as in Greenwood, Hercowitz, and Huffman (1988).³⁾ The growth trend on the left hand side represents the dilution effect

³⁾ Brinca, Chari, Kehoe, and McGrattan (2016) show that a model with investment specific technological progress can be mapped into a prototype business cycle accounting model with investment wedges. In our model, we also have credit spread shocks which also map into

of population and technology growth on capital accumulation.

In this model, the firm resorts to costly borrowing from the financial intermediary due to a balance sheet constraint

$$\Gamma k_{t+1} = \frac{\Gamma d_{t+1}}{R_t^L}. \quad (5)$$

The credit spread plays a key role in our model through this balance sheet constraint (5).⁴⁾ Consider μ_t as the Lagrangian multiplier for this constraint in the firm's maximization problem, which represents the tightness of the balance sheet. For convenience, define $\eta_t = 1 + \mu_t$. Then the first order condition for corporate debt is

$$\Gamma \eta_t = \frac{R_t^L}{R_t}. \quad (6)$$

For simplicity, we assume the credit spread to be exogenous. A high credit spread shock reflects a tight borrowing condition, which limits corporate borrowing and thus investment. Although we do not model the source of the shocks, we consider these as disturbances to the supply of credit such as bank balance sheet shocks or shocks to the monitoring cost for lenders.⁵⁾

3.3. Financial Intermediary

The risk-neutral financial intermediary maximizes the present value of its profits π_t^f

investment wedges.

⁴⁾ The growth trend on both side can be cancelled out but we leave them in equation (5) for mathematical convenience.

⁵⁾ Bernanke, Gertler, and Gilchrist (1999) introduce the financial accelerator effect of endogenous credit spreads based on a costly state verification feature of financial contracts. Kaihatsu and Kurozumi (2014) construct a model with exogenous finance premium shocks in the financial accelerator framework.

$$\max E_0 \sum_{t=0}^{\infty} \prod_{\tau=0}^t \frac{1}{R_{\tau-1}} \pi_t^f,$$

where $\frac{1}{R_{-1}} = 1$. The profits are defined as

$$\pi_t^f = \frac{\Gamma a_{t+1}}{R_t} - \frac{\Gamma b_{t+1}}{R_t} - \frac{\Gamma d_{t+1}}{R_t^L} - (a_t - b_t) + d_t. \quad (7)$$

The financial intermediary earns profits on average as long as $R_t^L > R_t$. For simplicity, we assume that all profits earned by the financial intermediary is rebated to the household. A positive credit spread R_t^L / R_t implies that the financial intermediary is incorporating the firm default risk in their profit maximization problem. For simplicity, we do not model firm default in the equilibrium. Nonetheless, we believe that assuming default in the equilibrium will not affect the main results.

3.4. Government

The government budget constraint

$$g_t = \tau_t + \frac{\Gamma b_{t+1}}{R_t} - b_t, \quad (8)$$

states that additional government spending is paid either by lump-sum taxes from the household, or by additional issuance of government bonds b_{t+1} .

Combining the government budget constraint (8) with the household budget constraint (1), firm's profit (2) and the financial intermediary's profit (7), we get the resource constraint

$$y_t = c_t + x_t + g_t. \quad (9)$$

3.5. Equilibrium

The equilibrium is a set of quantities and prices such that (i) the household optimizes, (ii) the firm optimizes, (iii) the financial intermediary optimizes, (iv) the government budget constraint (8) holds, (v) the resource constraint (9) holds; and (vi) the exogenous state variables follow an AR(1) process

$$\tilde{s}_t = P\tilde{s}_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim N(0, V), \quad (10)$$

where $s_t = \{\eta_t, g_t, z_t, \phi_t, \Psi_t\}'$, $\varepsilon_t = \{\varepsilon_{\eta_t}, \varepsilon_{g_t}, \varepsilon_{z_t}, \varepsilon_{\phi_t}, \varepsilon_{\Psi_t}\}'$, and $\tilde{s}_t = \ln s_t - \ln s$ where s is a steady state value of s_t .

The set of equilibrium conditions are; the consumption-leisure decision equation

$$\frac{1 - \Psi_t}{\Psi_t} \frac{c_t}{1 - l_t} = (1 - \theta) \frac{y_t}{l_t}, \quad (11)$$

the household asset Euler equation

$$\frac{\Psi_t}{c_t} \frac{1}{R_t} = \hat{\beta} E_t \left[\frac{\Psi_{t+1}}{c_{t+1}} \right], \quad (12)$$

where $\hat{\beta} = \beta / \Gamma$, the capital Euler equation

$$\Gamma \left(\eta_t - 1 + \frac{1}{\phi_t} \right) = \frac{1}{R_t} E_t \left[\theta \frac{y_{t+1}}{k_{t+1}} + \frac{1 - \delta}{\phi_{t+1}} \right], \quad (13)$$

the production function (3), the capital law of motion (4), the credit spread (6) and the resource constraint (9).

4. QUANTITATIVE ANALYSIS

4.1. Calibration

Structural parameters are calibrated to match the U.S. data over the 1985Q1-2007Q4 period. We choose this period as it corresponds to the Great Moderation period in which economic fluctuations were modest. The calibrated parameter values are listed in table 1 along with the data targets.

The income share of capital θ is defined as the capital income divided by output. The imputed service flow from durable goods is added to the reported capital income. Output is also adjusted for the imputed service flows as discussed above. We use the quarterly average output growth rate as the growth trend Γ . The capital depreciation rate is calibrated from the capital law of motion equation

$$\delta = 1 - \Gamma + \phi \frac{x}{y} \frac{y}{k},$$

Table 1 Calibration of Parameter Values

Parameters	Names	Values
θ	Capital income share	0.3839
δ	Depreciation rate	0.0131
Ψ	Preference weight	0.2113
η	Credit spread	0.9942
R	Risk-free interest rate	1.0246
$\hat{\beta}$	Subjective discount factor	0.9760
Data Targets	Names	Values
Γ	Output growth trend	1.0081
R^L / R	Credit spread	1.0023
l	Hours worked	0.2110
y / k	Capital-output ratio	0.1043
c / y	Consumption-output ratio	0.6173
x / y	Investment-output ratio	0.2033

given the investment-output ratio and output-capital ratio where we assume that the investment specific technology ϕ is equal to unity in the steady state. The average preference weight Ψ is calibrated from the household intra-temporal first order condition

$$\frac{1-\Psi}{\Psi} = (1-\theta) + \frac{y}{c} \frac{1-l}{l},$$

given the consumption-output ratio and labor. The steady state credit spread shock η is computed from the credit spread equation

$$\eta = \frac{1}{\Gamma} \frac{R^L}{R},$$

given the steady state credit spread. The steady state risk free interest rate is calibrated from the capital Euler equation

$$R = \frac{\theta \frac{y}{k} + \frac{1-\delta}{\phi}}{\Gamma \left(\frac{1}{\phi} + \eta - 1 \right)}.$$

The subjective discount rate $\hat{\beta}$ is calibrated from the household asset Euler equation

$$\hat{\beta} = \frac{1}{R}.$$

4.2. Estimation of the Stochastic Process

The stochastic process of the exogenous state variables is estimated by the Bayesian estimation method using Dynare (Adjemian, Bastani, Juillard, Mihoubi, Perendia, Ratto, and Villemot, 2011). The main reason why we

conduct a structural estimation is because some exogenous state variables are latent variables. For instance, investment specific technology ϕ_t is computed from the capital Euler equation (4) where the right hand side variables are not observable because of the expectation operator. Capital stock is a latent variable as well since the capital law of motion (4) depends on the latent variable ϕ_t . This means that productivity is also a latent variable since it is computed as a residual from the production function (3). Hence, we use the Bayesian method to estimate the lag matrix P and the variance covariance matrix V in the stochastic process (10).

As the model contains 5 exogenous shocks we use the data of 5 observable variables for the estimation so that the model is just identified. We set the estimation period to 1985Q1- 2007Q4 so that the stochastic process estimation period is consistent with the calibration period. The data of per adult output, consumption and investment are all linearly detrended with the average per adult output growth rate while per adult total hours worked and credit spreads are de-meant. We follow Chari *et al.* (2007) and assume that exogenous variables have spillover effects on each other and also have contemporaneous correlation between each other. The estimated values are as follows.⁶⁾

$$P = \begin{pmatrix} 0.842 & -0.002 & 0.026 & 0.000 & -0.002 \\ -0.169 & 0.994 & -0.017 & 0.176 & -0.052 \\ -0.202 & 0.013 & 0.891 & -0.031 & -0.001 \\ 0.212 & -0.044 & 0.065 & 0.833 & -0.033 \\ -0.051 & -0.016 & 0.025 & -0.047 & 0.958 \end{pmatrix},$$

⁶⁾ The initial guess for P is a diagonal matrix with 0.8 as the diagonal terms and zero otherwise and the prior distributions are assumed to be normal with 0.2 standard deviation. The initial guess for the diagonal terms of V is an inverted gamma distribution with 0.1 standard deviation. The off-diagonal terms are obtained by estimating the correlation coefficients among the error terms assuming a normal prior distribution with zero mean and 0.3 standard deviation. We use the posterior mode obtained from the Monte-Carlo based optimization routine in Dynare as the estimates for P and V . We have analyzed the sensitivity of the estimation results to the prior assumptions by increasing the standard errors of the prior distributions of the behavioral parameters by 50%. Overall, the estimation results are very similar.

$$V = \begin{vmatrix} 0.014 & -0.014 & -0.007 & -0.004 & -0.006 \\ -0.014 & 2.965 & 0.078 & -0.111 & -0.160 \\ -0.007 & 0.078 & 0.195 & -0.020 & -0.014 \\ -0.004 & -0.111 & -0.020 & 0.072 & 0.000 \\ -0.006 & -0.160 & -0.014 & 0.000 & 0.189 \end{vmatrix} \times e - 4.$$

4.3. Impulse Responses

In order to understand the channels through which each shocks operate, it is useful to assess the impulse responses of the key endogenous variables to shocks. Given that all structural parameters are calibrated to match the data targets in the U.S. economy, figure 2 show how the endogenous variables response to each of the exogenous shocks in our model. And this response functions are derived from the solutions (policy functions) of the model economy.

In figures 2(a)-(e) we present the impulse responses of output, consumption, investment, and labor to a one percent increase in credit spread, government, productivity, investment specific technology and preference shocks.⁷⁾

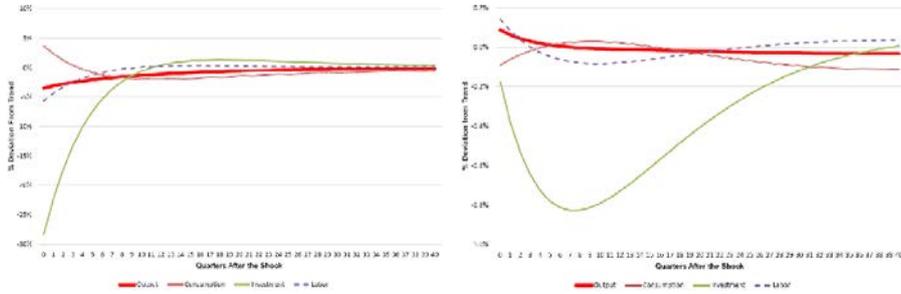
Figure 2(a) shows the impulse response to a 1% increase in credit spread η . An increase in the credit premium increases the cost of investment so investment will fall. As the discount rate declines relative to the lending rate, current consumption and leisure increases due to intertemporal substitution. As a result, current labor supply and thus output will fall.

Figure 2(b) shows the impulse responses to a 1% increase in government expenditure g . The increase in government expenditure reduces the household's disposable income and hence creates a negative income effect which leads to a reduction in consumption and leisure. In addition, the increase in aggregate demand raises the real interest rates, which discourages investment through the typical crowding out channel.

Figure 2(c) shows the impulse response to a 1% increase in productivity z .

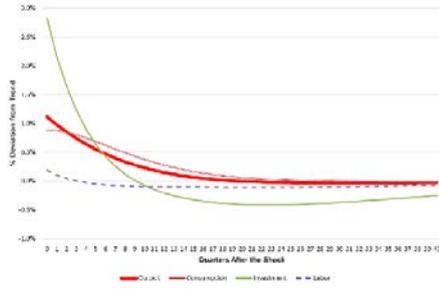
⁷⁾ Since the innovations to the exogenous variables are contemporaneously correlated, we draw the impulse responses to changes in the exogenous variables.

Figure 2 Impulse Responses to a Positive 1% Exogenous Shock⁸⁾

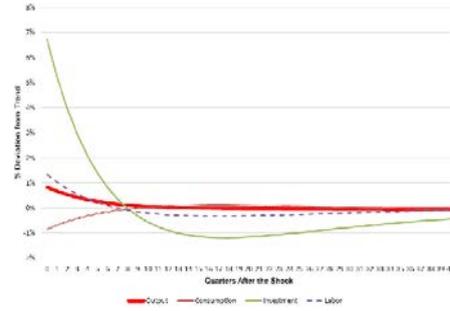


(a) Impulse Response to credit spread shock

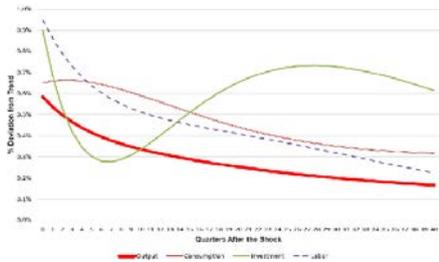
(b) Impulse Response to government shock



(c) Impulse Response to productivity shock



(d) Impulse Response to investment specific shock



(e) Impulse Response to preference shock

The impulses show that this shock clearly boosts all variables, as found in a standard real business cycle literature. Productivity directly increases output.

⁸⁾ The confidence intervals are not shown in figure 2 since the response functions are derived from the solutions (policy functions) of the model economy and are not estimated with data.

In addition, it stimulates labor demand due to the increase in the marginal product of labor. Consumption increases due to the increase in income and the substitution from leisure to consumption. Investment increases as firms anticipate high future marginal product of capital due to the persistence of shocks and households prefer to smooth consumption over time by saving part of the increased income.

Figure 2(d) shows the impulse response to a 1% increase in the investment-specific technology ϕ . This shock reduces the effective price of investment goods relative to consumption goods which leads the firm to increase investment. The increase in the relative price of consumption goods creates a negative income effect on the household, which leads to a decrease in consumption and leisure. This leads to a rise in labor and output.

Figure 2(e) shows the impulse response to a 1% increase in preference weight Ψ . This shock increases the household's subjective value of consumption relative to leisure. Therefore consumption and labor both increases. Output increases as a result of the increases in labor. Investment increases as firms anticipate the high labor supply and thus high marginal product of capital while households prefer to smooth consumption over time by saving part of the increased income.

4.4. Simulation Method

Once all of the parameter values are specified, we can compute the sequence of exogenous shocks and use them for simulation. The simulation method follows the business cycle accounting procedure of Chari *et al.* (2007). First, we solve for the linear decision rules using the Dynare program. Then we use the linear decision rules and data of the observable variables output, consumption, investment, labor and credit spreads in order to compute the exogenous variables. Finally, we plug the exogenous variables one by one into the model in order to decompose the quantitative impact of each shock on the endogenous variables over the entire periods.

The sequence of exogenous variables are computed as follows. First we

solve the linearized model so that the structure is expressed as the system of linear equations in state-space representation:

$$\tilde{k}_{t+1} = A\tilde{k}_t + B\tilde{s}_t, \quad (14)$$

$$\tilde{v}_t = C\tilde{k}_t + D\tilde{s}_t, \quad (15)$$

where $v_t = \{y_t, c_t, x_t, l_t, p_t\}'$ are the observable variables.

We assume that capital stock in the initial period is at the steady state level so that $\tilde{k}_1 = 0$. Then, from the measurement equation (15) we can compute the exogenous variables for the initial period as

$$\tilde{s}_1 = D^{-1}\tilde{v}_1,$$

given that \tilde{v}_1 are observable. Then, from the transition equation (14) we can compute the capital stock level for the second period as

$$\tilde{k}_2 = A\tilde{k}_1 + B\tilde{s}_1.$$

For the next period, we can compute the level of the exogenous variables

$$\tilde{s}_2 = D^{-1}(\tilde{v}_2 - C\tilde{k}_2),$$

given the previous result. Then we can compute the capital stock level for the third period as

$$\tilde{k}_3 = A\tilde{k}_2 + B\tilde{s}_2,$$

and so on so forth to compute the full sequence of $s_t = \{\eta_t, g_t, z_t, \phi_t, \Psi_t\}'$.⁹⁾

⁹⁾ In the original Chari, Kehoe and McGrattan (2007) method, capital stock can be directly inferred from their capital law of motion $k_{t+1} = x_t + (1 - \delta)k_t$. Given the data of investment. We have to back out the level of capital stock each period because of the latent investment specific technology shocks.

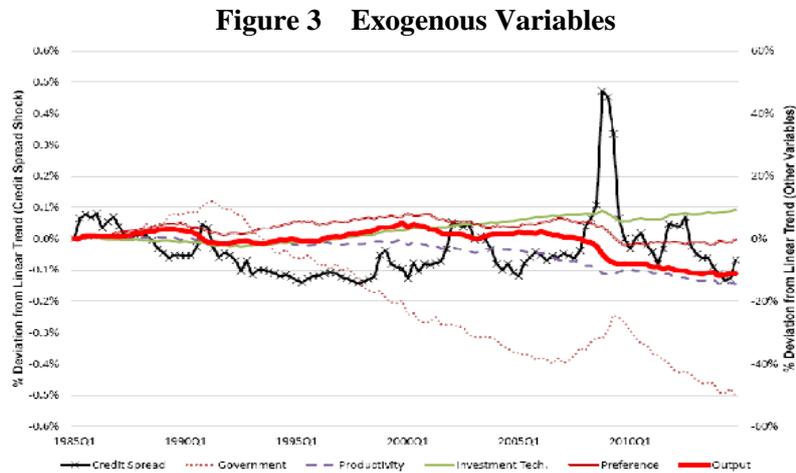
The simulation is based on the full sequence of the exogenous variables. We compute the full sequence of capital stock and endogenous variables with response to each exogenous variable $s_{j,t}$ as

$$\begin{aligned}\tilde{k}_{j,t+1} &= A\tilde{k}_{j,t} + B\tilde{s}_{j,t}, \\ \tilde{v}_{j,t} &= C\tilde{k}_{j,t} + D\tilde{s}_{j,t},\end{aligned}$$

where $j = \eta, g, z, \phi, \Psi$.

4.5. Results

Figure 3 shows the fluctuation of the computed exogenous state variables and output. The credit spread shock is much less volatile than the other variables and hence measured separately on the left axis. Government shock has been trending downwards after the 1990s whereas there is a distinct increase during 2008 and 2009 reflecting the increase in fiscal spending after the onset of the subprime loan crisis.¹⁰ Productivity shock is slightly trending



¹⁰ We included trade balance in government expenditure following Chari, Kehoe, and McGrattan (2007). It turns out that this variable is not important in accounting for the U.S. business cycles so we will not make further adjustment.

Table 2 High Frequency Properties of Exogenous Variables

Exogenous Variable x	Relative St. dev.	Cross-correlation of output with				
		$x(-2)$	$x(-1)$	$x(0)$	$x(+1)$	$x(+2)$
Credit spread	0.068	-0.560	-0.540	-0.399	-0.195	0.031
Government	2.258	-0.538	-0.565	0.500	-0.502	-0.377
Productivity	0.576	0.570	0.591	0.586	0.266	0.014
Investment Tech.	0.441	0.211	0.371	0.561	0.688	0.739
Preference	0.995	0.444	0.588	0.704	0.833	0.849

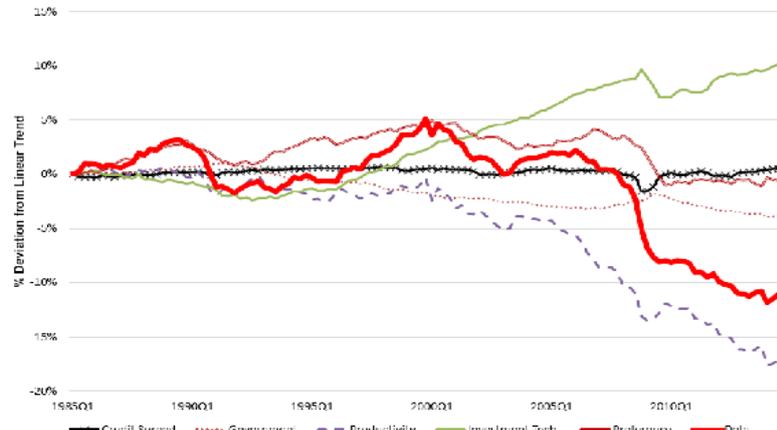
down while investment specific technology and preference shocks are slightly trending upwards until 2007.¹¹⁾

In order to investigate the high frequency properties of the exogenous variables, we detrend the variables with the HP filter and compute moments following Chari *et al.* (2007). Credit spread and government shocks are countercyclical and seem to lead the cycle. Productivity, investment technology and preference shocks are all procyclical. Productivity seems to slightly lead the cycle while investment specific technology and preference shocks lag the cycle. The main reason why our productivity series is less correlated with output than in studies such as Chari *et al.* (2007) is because our capital stock series is affected by the investment specific technology shocks that is not present in their model.¹²⁾ The key question is, how much do these shocks affect the endogenous variables.

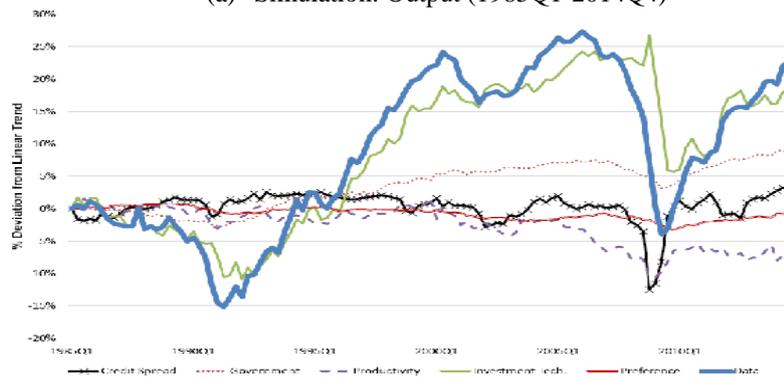
Figure 4(a) shows the simulated outputs as a result of plugging each series of shocks one by one into the decision rule of output. Preference shocks are important in accounting for the overall output fluctuation about the trend. Productivity shocks are important in accounting for the decline in output after 2000. Investment specific technology shocks are important in accounting for the output growth during the 1990s. Credit spread and government expenditure shocks seem less important in accounting for the fluctuation in

¹¹⁾ The upward trend in investment specific technology shocks are consistent with the observation that the relative price of investment goods to consumption goods have been declining over time.

¹²⁾ Capital stock is treated as a latent variable in both models. In our model, a procyclical investment specific technology shock will cause a procyclical fluctuation in capital stock. This reduces the procyclicality of the measured productivity shocks.

Figure 4 Simulation Results

(a) Simulation: Output (1985Q1-2014Q4)



(b) Simulation: Investment rate (1985Q1-2014Q4)

output. However, credit spread shocks do explain 1.8% of the drop in output out of the 5.0% drop during the 2007Q4 to 2008Q4 period.

Figure 4(b) shows the simulation results for the investment rate defined as the ratio of investment to output. This shows that investment specific technology shocks are most important in accounting for the fluctuation in the investment rate through the entire period. Credit spread shocks contribute significantly to the sharp investment collapse during the recent financial crisis. Government, productivity and preference shocks also contribute to the drop in the investment rate during the financial crisis but to a lesser extent.

In order to investigate the high frequency properties of the simulated

Table 3 Cyclical Behavior of Simulated Output

Exogenous Variable x	Relative St. dev.	Cross-correlation of output with					Cont. Index
		$s_j (-2)$	$s_j (-1)$	$s_j (0)$	$s_j (+1)$	$s_j (+2)$	
Credit spread	0.068	-0.560	-0.540	-0.399	-0.195	0.031	0.104
Government	2.258	-0.538	-0.565	0.500	-0.502	-0.377	-0.096
Productivity	0.576	0.570	0.591	0.586	0.266	0.014	0.385
Investment Tech.	0.441	0.211	0.371	0.561	0.688	0.739	0.200
Preference	0.995	0.444	0.588	0.704	0.833	0.849	0.407

variables, we decompose the HP filtered fluctuations of data variable into the contributions of each exogenous shock as in Otsu (2010). The contribution indexes are defined as

$$\text{cont}(\tilde{v}, \tilde{s}_j) = \text{corr}(\tilde{v}, \tilde{v}_j) \times \frac{\text{std}(\tilde{v}_j)}{\text{std}(\tilde{v})} \equiv \frac{\text{cov}(\tilde{v}, \tilde{v}_j)}{\text{var}(\tilde{v})},$$

where \tilde{v} corresponds to the fluctuation of variable v in the data and \tilde{v}_j is the simulated fluctuation of variable v in the model with only one exogenous variable s_j .

Table 3 reports the moments computed from HP filtered output simulation results in order to investigate high frequency properties of the model. Productivity and preference shocks generate more high frequency output fluctuation than the other shocks. The simulated series with credit spread, productivity, investment specific technology and preference shocks are positively correlated with the data. This shows that productivity and preference shocks have the largest contribution while credit spread and investment specific technology shocks also contribute to output fluctuation.

Our result that productivity and preference shocks are important in accounting for the U.S. business cycles is consistent with the result of Chari *et al.* (2007). Preference shocks in our model are observationally equivalent to the labor market distortions in their model that are computed from the intra-temporal first order condition.¹³⁾ Our result that investment specific

¹³⁾ Preference shocks also appear in the household intertemporal first order condition. In order

Table 4 Cyclical Behavior of Simulated Investment Rate

Exogenous Variable x	Relative St. dev.	Cross-correlation of output with					Cont. Index
		$s_j(-2)$	$s_j(-1)$	$s_j(0)$	$s_j(+1)$	$s_j(+2)$	
Credit spread	0.486	0.645	0.608	0.426	0.186	-0.024	0.207
Government	0.167	0.648	0.741	0.775	0.712	0.580	0.129
Productivity	0.283	0.611	0.583	0.471	0.207	-0.047	0.133
Investment Tech.	0.734	0.121	0.346	0.627	0.748	0.783	0.460
Preference	0.092	0.092	0.643	0.765	0.868	0.875	0.070

technology shocks contribute to output fluctuation are consistent with the result of Brinca *et al.* (2016) that investment wedges made significant contribution to the Great Recession in the U.S.. Both investment specific technology shocks in our model and investment market distortions in their model are computed from the capital Euler equation. However, the former also affects the capital law of motion (4) while the later does not. When a positive investment specific technology shock hits the economy, this increases future capital stock given the observed level of investment. Therefore, it directly affects future output, which is a channel not present in Chari *et al.* (2007). Moreover, our finding that credit spreads contribute to high frequency output fluctuation is important because this implies that financial frictions can drive business cycles to some extent.

Table 4 reports the moments computed from the HP filtered investment rate simulation results. While all exogenous variables contribute to the fluctuation of the investment rate, nearly half of the high frequency fluctuation of the investment rate is accounted for by investment specific technology shocks.

Our result that investment specific technology shocks are important in accounting for the fluctuation in U.S. investment is consistent with the finding of Justiniano *et al.* (2011). It is also consistent with Brinca *et al.* (2016) which finds that investment wedges are pre-dominantly responsible for the huge drop in investment during the Great Recession. Chen, Imrohorglu and Imrohorglu (2009) finds that the population growth rate, depreciation rate and productivity growth rate are important in accounting for the fluctuation in the

to be completely observationally equivalent, the preference shocks must be permanent.

U.S. investment rate.¹⁴⁾ The time-varying depreciation rate in their model plays a role similar to investment specific technology shocks in our model as the two affect the capital accumulation equation in a similar way.

4.6. Sensitivity Analysis

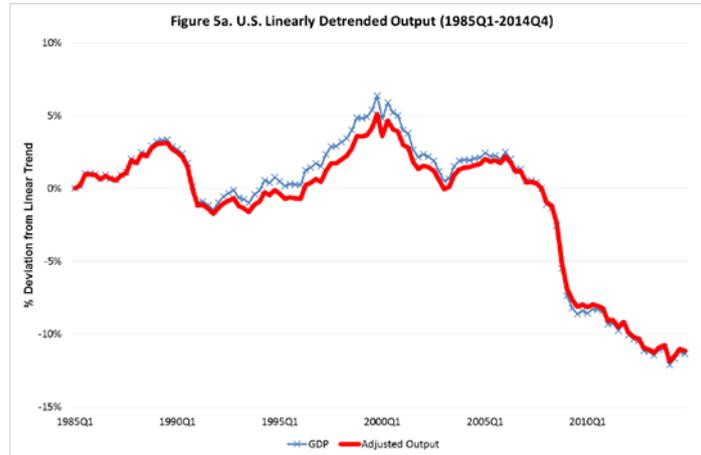
In this section, we conduct sensitivity analysis in order to investigate the robustness of our results. First, we compare the results using standard SNA data without adjustments to the imputed service flow from durable goods. Next, we introduce investment adjustment cost to the model. We find that our results are robust to these alternative settings.

Figure 5(a) plots the linearly detrended non-adjusted GDP series and our output series adjusted for the service flow from durable goods. The linear trend growth rate is computed as the average growth rate of each series over the 1985Q1-2007Q4 period. The overall pattern is very similar where our adjusted series is slightly less volatile than the non-adjusted GDP series. This is because the service flow from durable goods is less volatile than GDP. Figure 5(b) plots the linearly detrended series of non-adjusted household consumption expenditure on goods and services and the consumption series adjusted for the service flow from durable goods. The non-adjusted series is more volatile than the adjusted series implying that the imputed service flow is less volatile than the non-adjusted consumption series. Therefore, without the adjustment for durable services, we will understate the consumption smoothing of the household.

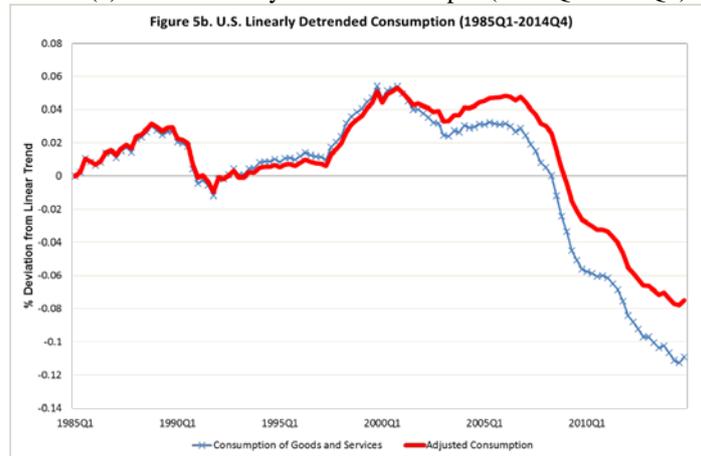
Christiano and Davis (2006) showed that investment adjustment costs increase the importance of the intertemporal wedge in an otherwise standard business cycle accounting model. Following their setting, we introduce a standard quadratic adjustment cost function to the capital law of motion so that (4) is now

¹⁴⁾ Chen, Imrohoroğlu and Imrohoroğlu (2009) define the investment rate as the net investment to net national product ratio $\frac{x_t - \delta_t k_t}{y_t - \delta_t k_t}$, rather than the investment to output ratio.

Figure 5 Sensitivity Analysis



(a) U.S. Linearly Detrended Output (1985Q1-2014Q4)



(b) U.S. Linearly Detrended Consumption (1985Q1-2014Q4)

$$\Gamma k_{t+1} = \phi_i x_t + (1 - \delta) k_t - \frac{\mu}{2} \left(\frac{i_t}{k_t} - \frac{\bar{i}}{\bar{k}} \right)^2 k_t,$$

where $\frac{\bar{i}}{\bar{k}}$ is the steady state investment to capital ratio. The adjustment cost parameter μ is set so that the marginal Tobin's q is equal to 1.

For each sensitivity analysis, we calibrate and estimate the model

Table 5 Sensitivity Analysis: Contribution Index

Exogenous Variable s	Output			Investment rate		
	Benchmark	SNA	Adj. cost	Benchmark	SNA	Adj. cost
Credit Spread	0.104	0.133	0.072	0.207	0.242	0.144
Government	-0.096	-0.155	-0.056	0.129	0.014	0.230
Productivity	0.385	0.321	0.429	0.133	0.044	0.209
Investment Tech.	0.200	0.178	0.117	0.460	0.401	0.288
Preference	0.407	0.522	0.438	0.070	0.299	0.129

parameters and simulate the model based on these alternative parameters. Table 5 reports the simulation results from this exercise. With the SNA data for both output and investment rate simulations, the contribution of preference shocks are greater than the benchmark results. This is because consumption is more volatile in the non-adjusted data and the computed preference shock is more volatile, which we believe is misleading. For the investment adjustment cost, the contribution of productivity increases while that of credit spread and investment specific technology shocks decrease. This is because the adjustment cost reduces the movement of investment and capital stock so that the measured productivity shock becomes more pro-cyclical. Therefore, unlike Chari *et al.* (2007), introducing investment adjustment costs do not increase the importance of the intertemporal disturbances.

5. CONCLUSION

In this paper, we constructed a dynamic stochastic general equilibrium model with credit spread, government expenditure, productivity, investment specific technology and preference shocks in order to quantitatively account for the U.S. business cycle fluctuations through 1985-2014. We find that fluctuations in productivity and preference shocks are important in accounting for the fluctuations in output while investment specific technology shocks are important in accounting for the fluctuations in the investment rate. Moreover, credit spread shocks play a significant role in the decline in U.S. output and investment rate during the recent financial crisis. Therefore, in our environment, intertemporal distortions caused by financial frictions do matter.

There are several remaining issues that we have not discussed in this paper. Investment specific technology shocks can also be modelled in a two sector model with consumption and investment goods producers. Productivity in the investment sector should operate in a similar fashion as the investment specific technology in our model. The robustness of our results should be checked across these different settings such as Justiniano, Primiceri and Tambalotti (2011). In addition, studies such as Fisher (2006) identify the fluctuations of investment specific technology using the data of the relative price of investment goods to consumption goods. While investment specific technology is treated as a latent variable in our model, we could potentially utilize the data of its empirical counterpart. Furthermore, by assuming exogenous credit spread, we are ignoring the feedback channel of the shocks through endogenous reactions of the financial market. We can alternatively introduce financial shocks in a model with endogenous credit spreads as in Kaihatsu and Kurozumi (2014). We believe that this will not change the main result of the paper. Since these issues are beyond the scope of this paper, they are left for future research.

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