News Shocks under Financial Frictions*

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Abstract

This paper examines the dynamic effects and empirical role of aggregate and sectoral TFP news shocks in the context of frictions in financial markets. Financial frictions result in credit spreads that contain important information about expectations of future economic activity. A TFP news shock identified from the VAR model generates a significant decline in the corporate bond spread and a broad based expansion in activity in anticipation of a future TFP improvement. A DSGE model enriched with a financial sector of the Gertler-Kiyotaki type generates very similar quantitative dynamics and shows that strong linkages between leveraged equity and capital prices are critical for the amplification of TFP news shocks. The consistent assessment from both methodologies provides support for the traditional 'news view' of aggregate fluctuations. The analysis sheds light on important differences in the propagation of sectoral TFP news shocks.

Keywords: News shocks, Business cycles, DSGE, VAR, Bayesian estimation.

JEL Classification: E2, E3.

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1 Introduction

The news driven business cycle hypothesis formalized in Beaudry and Portier (2004) and restated in Jaimovich and Rebelo (2009) posits that changes in expectations of future fundamentals are an important source of business cycle fluctuations. Movements in financial markets encapsulate changes in expectations about the future and are a powerful mechanism that triggers changes in economic activity. A vast body of research finds that financial markets are characterized by frictions that lead to credit spreads—differences in yields between private debt instruments and government bonds of comparable maturities—whose movements contain important information on the evolution of the real economy and encompass predictive content for future economic activity.[1]

In this paper we quantify the empirical significance and dynamic effects of aggregate and sectoral news shocks in light of propagation through frictions in financial intermediation. We investigate the issue using two widely-used methods that provide complementary readings on the significance and dynamics of news shocks. First, we use a vector autoregression (VAR) model enriched with credit spreads to study the dynamic effects and empirical relevance of news shocks on economic activity in the presence of financial frictions. We isolate a novel stylized fact. A total factor productivity (TFP) news shock identified from the VAR model generates a broad based increase in real activity and a significant decline of the corporate bond spread in anticipation of the future improvement in TFP. We establish that the response of the corporate bond spread to a news shock is a robust finding that holds across alternative specifications of the VAR model and different identification methods for both aggregate and sectoral TFP news shocks.[2] The VAR model finds that aggregate TFP news shocks account for a sizeable portion of macroeconomic fluctuations.

We further study the issue using a dynamic stochastic general equilibrium (DSGE) model whose microfoundations enable the underpinning of the theoretical mechanisms for the propagation of aggregate and sectoral news shocks. We enrich a standard DSGE model by em-

[1] See Gilchrist and Zakrajsek (2012) and Philippon (2009).

[2] Our identification scheme follows Forni et al. (2014). We show that the alternative schemes in Francis et al. (2014) and Barsky and Sims (2011) produce very similar results.

bedding financial frictions via leveraged lenders similar to Gertler and Karadi (2011) and Gertler and Kiyotaki (2010) into a two-sector model with nominal and real rigidities. To investigate the propagation of sectoral news shocks consumption- and investment-goods-producing sectors are subject to sector-specific TFP technologies, in line with the evidence in Basu et al. (2013).[3] We apply the DSGE model directly to post-1990s U.S. real and financial data, estimating its parameters with Bayesian methods, and produce dynamic responses and business cycle statistics that find TFP news shocks important drivers of business cycle fluctuations. In this way, the model features corporate bond spreads as an important component for the propagation of news shocks.

To assess whether the financial channel conforms the dynamic responses of the variables to TFP news shocks in the DSGE and VAR methods, we perform a Monte Carlo experiment. We compare the impulse responses to an aggregate TFP news shock from the empirical VAR model with those estimated from the same VAR model on artificial data generated using posterior estimates of the DSGE model. We find that responses of key macroeconomic aggregates (including corporate bond spreads) in the data are qualitatively very similar and within the confidence intervals of the VAR responses from artificial model data. The experiment shows that accounting for financial frictions leads the two methodologies independently implemented to reach similar conclusions and therefore the different approaches could potentially result in consistent readings on the empirical relevance of news shocks.

To appraise the quantitative relevance of news shocks between the two methods, we compare shares in the forecast error variance of key macro aggregates. We find those shares quite similar between methods. For example, at business cycle frequencies (6 to 32 quarters), the VAR model establishes that TFP news shocks account for between 29% to 50% of the variance in output and between 29% to 35% of the variance in hours worked. The DSGE model finds the same shocks account for between 26% to 31% of the variance in output and between 26% to 42% of the variance in hours worked. Taken together, these findings suggest

[3]An important motivation for considering a two-sector economy is the recent evidence in Basu et al. (2013), which suggests that sector-specific technological changes have extremely different macroeconomic effects.

that both methodologies find TFP news shocks an important source of business cycles since the 1990s and hence provide support for the traditional 'news view' of aggregate fluctuations.

The DSGE model provides a compelling explanation for the propagation mechanism and the empirical relevance of TFP news shocks. The presence of leveraged financial intermediaries delivers amplification of news shocks due to the feedback loop between leveraged equity and capital prices. These financial intermediaries hold claims to productive capital in their portfolios. When the price of capital increases, their leverage constraint eases, and their balance sheet expands. This dynamic generates a further rise in the demand for capital and a further rise in the price of capital. The demand for capital is thus amplified by leverage, bidding up the capital price relative to a standard New Keynesian (NK) model without financial frictions. The amplification delivers a strong lending and investment phase and a strong economy-wide boom. By contrast, in the standard DSGE model, amplification is weak. For example, the version of the model without financial frictions predicts that TFP news shocks account for a maximum of 12% and 16% of the variance in output and hours worked, respectively, much in line with the existing estimated DSGE literature.

The analysis provides novel insights on the propagation and empirical relevance of sectoral TFP news shocks. Both methodologies suggest consumption-specific TFP news shocks to be important drivers of business cycles. They, however, disagree substantially on the empirical role of investment-specific TFP news shocks. The VAR evidence suggests a strong collinearity of consumption- and investment-specific news shocks. The responses to either type of sectoral news shock closely resemble the responses of the aggregate news shock, indicative of a possible technological spill-over effect across sectors. DSGE models typically studied in the literature, including ours, are silent about technological spillovers and, given the assumed orthogonality between sectoral TFP news shocks, cannot—by construction—account for this collinearity.

Our study is related to the large research agenda on the role of news shocks for macroeconomic fluctuations. The literature shows substantial disagreement over the propagation mechanism and empirical plausibility of TFP news shocks.[4] In the context of the

[4]The review article by Beaudry and Portier (2014) provides an extensive discussion on the literature.

VAR methodology, Beaudry and Portier (2006), Beaudry and Lucke (2010), Beaudry et al. (2012) find that TFP news shocks account for the bulk of macroeconomic fluctuations whereas Barsky and Sims (2011) and Forni et al. (2014) detect a limited role of TFP news shocks to aggregate fluctuations. More recently, Zeev and Khan (2015) identify investment-specific news shocks as a major driver of U.S. business cycles, a finding supportive of the traditional 'news view' of fluctuations. In the context of the DSGE methodology, Schmitt-Grohe and Uribe (2012) estimate a real business cycle model and find that TFP news shocks are unimportant drivers of business cycle fluctuations and suggest that alternative non-structural news shocks, such as wage mark-up news shocks, are important drivers of economics fluctuations. Fujiwara et al. (2011) and Khan and Tsoukalas (2012) reach a similar conclusion in models with nominal rigidities. Görtz and Tsoukalas (2016) and Theodoridis and Zanetti (2015) find some empirical relevance for TFP news shocks. Görtz and Tsoukalas (2016), study how financial frictions, similar to this paper, alter the propagation mechanism of news shocks—relative to standard DSGE models—and can in principle be significant drivers of business cycles. We contribute to this line of research by showing that financial frictions imply similar dynamic effects and comparable empirical relevance of TFP news shocks across different methods and are therefore critical to resolve divergences.

The remainder of the paper is organized as follows. Sections 2 and 3 describe the DSGE and VAR models, respectively. Section 4 describes the data and the estimation methods. Section 5 presents the results for the VAR model. Section 6 reconciles the differences between the DSGE and the VAR findings. Section 7 assesses the role of sectoral news shocks and section 8 concludes.

2 The DSGE model

This section provides a description of the two-sector DSGE model that most closely resembles those developed by Ireland and Schuh (2008) and Görtz and Tsoukalas (2016). The

model extends previous studies by allowing a financial sector similar to Gertler and Karadi (2011), where banks lend capital to consumption- and investment-goods-producing sectors, to interact with sectoral news shocks. Below, we describe the parts of the model related to the goods-producing sectors, the financial sector, the exogenous disturbances, and the arrival of information. Appendix C provides a description of the complete model.

2.1 Overview

The model comprises two sectors that manufacture consumption and investment goods. Investment goods are used as capital input in the production process of each sector, and consumption goods provide utility to the households. Households consume, save in interest-bearing deposits with financial intermediaries, and supply labor input in a monopolistically competitive labor market where wages are set with Calvo contracts. A continuum of sector-specific intermediate goods producers use labor and capital services to manufacture distinct investment and consumption goods subject to sector-specific Calvo contracts. Capital producers use investment goods and existing capital to manufacture new sector-specific capital goods. Leveraged constrained financial intermediaries acquire capital and collect deposits from households. The monetary authority sets the nominal interest rate, according to a Taylor rule.

2.2 Intermediate and final goods production

A monopolist produces consumption and investment-specific intermediate goods according to the production technologies

$$C_t(i) = \max\left[a_{lt}A_t(L_{C,t}(i))^{1-a_c}(K_{C,t}(i))^{a_c} - A_t V_t^{\frac{a_c}{1-a_i}} F_C, 0\right]$$

and

$$I_t(i) = \max\left[v_{lt}V_t(L_{I,t}(i))^{1-a_i}(K_{I,t}(i))^{a_i} - V_t^{\frac{1}{1-a_i}} F_I, 0\right],$$

respectively. The variables $K_{x,t}(i)$ and $L_{x,t}(i)$ denote the amount of capital and labor services rented by firm i in sector $x = C, I$, and the parameters $(a_c, a_i) \in (0, 1)$ denote capital shares

in production.[5] The variables A_t and V_t denote the (non-stationary) level of TFP in the consumption and investment sector, respectively, and the variables $z_t = ln(A_t/A_{t-1})$ and $v_t = ln(V_t/V_{t-1})$ denote (stationary) stochastic growth rates of TFP in the consumption and investment sector, respectively. The variables a_{lt}, v_{lt}, denote the stationary level of TFP in the consumption and investment sector, respectively. To facilitate the exposition, subsection 2.6 describes the processes for the exogenous disturbances. Intermediate goods producers set prices according to Calvo (1983) contracts.

Perfectly competitive firms manufacture final goods, C_t and I_t, in the consumption and investment sector by combining a continuum of intermediate goods in each sector, $C_t(i)$ and $I_t(i)$, respectively, according to the production technologies

$$C_t = \left[\int_0^1 (C_t(i))^{\frac{1}{1+\lambda^C_{p,t}}} di\right]^{1+\lambda^C_{p,t}} \quad \text{and} \quad I_t = \left[\int_0^1 (I_t(i))^{\frac{1}{1+\lambda^I_{p,t}}} di\right]^{1+\lambda^I_{p,t}},$$

where the exogenous elasticities $\lambda^C_{p,t}$ and $\lambda^I_{p,t}$ across intermediate goods in each sector determine the (sectoral) price markup over marginal cost. Similar to the standard NK framework, prices of final goods in each sector ($P_{C,t}$ and $P_{I,t}$) are CES aggregates of intermediate goods prices. Appendix C provides details on price-setting decisions of the intermediate goods producers.

2.3 Households

As in Gertler and Karadi (2011), households comprise two types of members, workers of size $1-f$ and bankers of size f. Each workers j supplies diversified labor in return for a wage while each bankers f manages a financial intermediary. Effectively, households own the intermediaries managed by bankers, but they do not own the deposits held by the financial intermediaries. Perfect risk sharing exists within each household. The proportion of workers and bankers remains constant over time. However, members of the households are allowed to switch occupations to avoid bankers having to fund investments from their own capital

[5] As in Christiano et al. (2005), the presence of fixed costs in production in both sectors (i.e. $F_C > 0$ and $F_I > 0$) leads to zero profits along the non-stochastic balanced growth path thereby the analysis abstracts from entry and exit of intermediate good producers. Fixed costs grow at the same rate of sectoral output to retain relevance for the firms' profit decisions.

without having to access credit. Bankers become workers in the next period with probability $(1-\theta_B)$ and transfer the retained earnings to households. Household supply start-up funds to workers who become bankers. Each household maximizes the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t b_t \left[\ln(C_t - hC_{t-1}) - \varphi \frac{(L_{C,t}(j) + L_{I,t}(j))^{1+\nu}}{1+\nu} \right],$$

where E_0 is the conditional expectation operator at the beginning of period 0, $\beta \in (0,1)$ is the discount factor, and $h \in (0,1)$ is the degree of external habit formation. The inverse Frisch labor supply elasticity is denoted by $\nu > 0$, and the parameter $\varphi > 0$ enables the model to replicate the steady state level of total labor supply in the data.[6] The variable b_t denotes an intertemporal preference shock. Each household faces the following budget constraint expressed in consumption units

$$C_t + \frac{B_t}{P_{C,t}} \leq \frac{W_t(j)}{P_{C,t}}(L_{C,t}(j) + L_{I,t}(j)) + R_{t-1}\frac{B_{t-1}}{P_{C,t}} - \frac{T_t}{P_{C,t}} + \frac{\Psi_t(j)}{P_{C,t}} + \frac{\Pi_t}{P_{C,t}}, \tag{1}$$

where the variable B_t denotes holdings of risk-free bank deposits, Ψ_t is the net cash flow from the household's portfolio of state contingent securities, T_t is lump-sum taxes, R_t, is the (gross) nominal interest rate paid on deposits, and Π_t is the net profit accruing to households from ownership of all firms. The wage rate, W_t, is identical across sectors due to perfect labor mobility. As in Erceg et al. (2000), each household sets the wage according to Calvo contracts. The desired markup of wages over the household's marginal rate of substitution (or wage mark-up), $\lambda_{w,t}$, follows an exogenous stochastic process.

2.4 Production of capital goods

Production of physical capital. We assume that significant reallocation costs between sectors lead to immobile sector-specific capital.[7] Capital producers in each sector $x = C, I$

[6] Note that consumption is not indexed by (j) because perfect risk sharing leads to similar asset holding across members of the household.

[7] Ramey and Shapiro (2001) find strong evidence of large reallocation costs between sectors. Boldrin et al. (2001), Ireland and Schuh (2008), Huffman and Wynne (1999) and Papanikolaou (2011) es-

manufacture capital goods using a fraction of investment goods from final-goods producers and undepreciated capital from capital-services producers, subject to investment adjustment costs (IAC), similar to Christiano et al. (2005). Solving the optimization problem of capital producers yields the standard capital accumulation equation

$$\bar{K}_{x,t} = (1-\delta_x)\bar{K}_{x,t-1} + \mu_t\left(1 - S\Big(\frac{I_{x,t}}{I_{x,t-1}}\Big)\right)I_{x,t}, \tag{2}$$

for $x = C, I$. The parameter δ_x denotes the sectoral depreciation rate, the function $S(I_{x,t}/I_{x,t-1})$ captures IAC and has standard properties—i.e. $S(\cdot)$ satisfies the following conditions: $S(1) = S'(1) = 0$ and $S''(1) = \kappa > 0$. Finally, the variable μ_t denotes the marginal efficiency of investment (MEI) shock, as in Justiniano et al. (2010).

Production of capital services. The producers of physical capital use funds from financial intermediaries to purchase capital from physical capital producers and choose the utilization rate to convert it into capital services. They rent capital services to intermediate-goods producers that operate in a perfectly competitive market for a rental rate equal to $R^K_{x,t}/P_{C,t}$ per unit of capital. At the end of period $t+1$, they sell the undepreciated portion of capital to physical capital producers.[8] The utilization rate, $u_{x,t}$, transforms physical capital into capital services according to

$$K_{x,t} = u_{x,t}\bar{K}_{x,t-1},$$

for $x = C, I$ and subjects to a cost $a_x(u_{x,t})$ per unit of capital. The function $a_x(u_{x,t})$ has standard properties—i.e. in steady state, $u = 1$, $a_x(1) = 0$ and $\chi_x \equiv (a''_x(1)/a'_x(1))$ denotes the cost elasticity. The producers of capital services choose the utilization rate to maximize their profits

$$\max_{u_{x,t+1}}\left[\frac{R^K_{x,t+1}}{P_{C,t+1}}u_{x,t+1}\bar{K}_{x,t} - a_x(u_{x,t+1})\bar{K}_{x,t}A_{t+1}V_{t+1}^{\frac{a_c-1}{1-a_i}}\right],$$

for $x = C, I$. The total income for the producers of capital services in period $t+1$ is equal

tablish that constrained factor mobility improves the performance of theoretical models of the business cycle to replicate movements in aggregate fluctuations.

[8] It is worth noting that the price of capital, equivalent to Tobin's marginal Q, is equal to $Q_{x,t} = \Phi_{x,t}/\Lambda_t$, where Λ_t and $\Phi_{x,t}$ are the Lagrange multipliers on the households' budget constraint (1) and capital accumulation constraint (2), respectively.

to $R^B_{x,t+1}Q_{x,t}\bar{K}_{x,t}$, with

$$R^B_{x,t+1} = \frac{\frac{R^K_{x,t+1}}{P_{x,t+1}}u_{x,t+1} + Q_{x,t+1}(1-\delta_x) - a_x(u_{x,t+1})A_{t+1}V_{t+1}^{\frac{a_c-1}{1-a_i}}}{Q_{x,t}}, \tag{3}$$

where $R^B_{x,t+1}$ denotes the real return from capital. As in Gertler and Karadi (2011), producers of capital services finance the purchase of capital at the end of each period with funds from financial intermediaries, as described in the next subsection. Thus, $R^B_{x,t+1}$ also represents the return earned by financial intermediaries (see Appendix C for details).

2.5 Financial sector

Financial intermediaries fund the acquisitions of physical capital from capital-services producers using their own equity capital and deposits from households. They lend in specific islands (sectors) and cannot switch between them.[9] The financial sector in the model follows closely Gertler and Karadi (2011), and we therefore limit the exposition to the key equations and allow Appendix C to provide the complete set of equations. Three equations encapsulate the key dynamics in the financial sector: the balance sheet identity, the demand for assets that links equity capital with the value of physical capital (i.e. the leverage constraint) and the evolution of equity capital. We describe each of them in turn.

The nominal **balance sheet identity** of a branch that lends to sector $x = C, I$ is,

$$Q_{x,t}P_{C,t}S_{x,t} = N_{x,t}P_{C,t} + B_{x,t}, \tag{4}$$

where the variable $S_{x,t}$ denotes the quantity of financial claims on capital services that the producers held by the intermediary, and $Q_{x,t}$ denotes the price per unit of claim. The variable $N_{x,t}$ denotes equity capital (i.e. wealth) at the end of period t, $B_{x,t}$ are households deposits, and $P_{C,t}$ is the price level in the consumption sector.

Financial intermediaries maximize the discounted sum of future equity capital (i.e. the expected terminal wealth). Bankers may abduct funds and transfer them to the household.

[9] Alternatively we can interpret the financial sector as a single intermediary with two branches, each specializing in providing financing to one sector only, where the probability of lending specialization is equal across sectors and independent across time. Each branch maximizes equity from financing the specific sector. For example, within an intermediary, there are divisions specializing in consumer or corporate finance. The financial sector can be interpreted as a special case of Gertler and Kiyotaki (2010).

This moral hazard/costly enforcement problem limits the capacity of financial intermediaries to borrow funds from the households and generates an endogenous **leverage constraint** that limits the bank's ability to acquire assets. Thus, the equation for the demand of assets is

$$Q_{x,t}S_{x,t} = \varrho_{x,t}N_{x,t}, \tag{5}$$

where the value of assets that the intermediary acquires ($Q_{x,t}S_{x,t}$) depends on equity capital, $N_{x,t}$, and the leverage ratio, $\varrho_{x,t}$.[10] Note that when $\varrho_{x,t} > 1$, the leverage constraint (5) magnifies the changes in equity capital on the demand for assets. For instance, higher demand for capital goods, which raises the price of capital, increases equity capital (through the balance sheet identity), which in turn generates further changes in the demand for assets by intermediaries pushing the price of capital. This amplification turns out to be the critical mechanism to attach an important role to news shocks in the estimated model.

The **evolution of equity capital** is described by the law of motion,

$$N_{x,t+1} = \big(\theta_B[(R^B_{x,t+1}\pi_{C,t} - R_t)\varrho_{x,t} + R_t]\frac{N_{x,t}}{\pi_{C,t+1}} + \varpi Q_{x,t+1}S_{x,t+1}\big), \tag{6}$$

where θ_B is the survival rate of bankers, ϖ denotes the fraction of assets transferred to new bankers, and $\pi_{C,t+1}$ denotes the gross inflation rate in the consumption sector. Equation 6 shows that equity capital is a function of the excess (leveraged) real returns earned on equity capital of surviving bankers and the value of assets owned by news bankers. Banks earn expected (nominal) returns on assets (i.e. the risk premium) equal to

$$R^S_{x,t} = R^B_{x,t+1}\pi_{C,t+1} - R_t, \tag{7}$$

for $x = C, I$. The leverage constraint (5) entails non-negative excess returns that vary over time with movements in the equity capital of intermediaries.

Producers of capital services finance capital acquisition ($Q_{x,t}\bar{K}_{x,t}$) by issuing financial claims against the value of acquired physical capital ($Q_{x,t}S_{x,t}$), such that the following constraint holds

$$Q_{x,t}\bar{K}_{x,t} = Q_{x,t}S_{x,t}. \tag{8}$$

[10] As shown in Appendix C, the leverage ratio (i.e. the bank's intermediated assets-to-equity ratio) is a function of the marginal gains of increasing assets (holding equity constant), increasing equity (holding assets constant), and the gain from diverting assets.

As in Gertler and Karadi (2011), there are no frictions in the process of intermediation between nonfinancial firms, and banks and therefore we can interpret the financial claims as one-period, state-contingent bonds in order to interpret the excess returns in equation (7) as a corporate bond spread.

2.6 Exogenous disturbances and arrival of information

The model embeds the following exogenous disturbances: sectoral shocks to the growth rate of TFP (z_t, v_t), sectoral shocks to the level of TFP (a_{lt}, v_{lt}), sectoral price mark-up shocks ($\lambda^C_{p,t}$, $\lambda^I_{p,t}$), wage mark-up shock ($\lambda_{w,t}$), preference shock (b_t), monetary policy shock ($\eta_{mp,t}$), government spending shock (g_t), and MEI (μ_t) shock. Each exogenous disturbance is expressed in log deviations from the steady state as a first-order autoregressive (AR(1)) process whose stochastic innovation is uncorrelated with other shocks, has a zero-mean, and is normally distributed. For the monetary policy shock ($\eta_{mp,t}$), the first order autoregressive parameter is set equal to zero. Appendix C provides details on the exogenous disturbances.

The model embeds news shocks to sectoral productivity growth. The productivity growth processes in the consumption and investment sector follow the law of motions

$$z_t = (1-\rho_z)g_a + \rho_z z_{t-1} + \varepsilon^z_t, \qquad \text{and} \qquad v_t = (1-\rho_v)g_v + \rho_v v_{t-1} + \varepsilon^v_t, \tag{9}$$

where the parameters g_a and g_v are the steady-state growth rates of the two TFP processes above, and $\rho_z, \rho_v \in (0,1)$ determine their persistence.

The representation of news shocks is standard and follows, for example, Schmitt-Grohe and Uribe (2012), Khan and Tsoukalas (2012) and Theodoridis and Zanetti (2015). The stochastic innovations in the exogenous disturbances in (9) are defined as

$$\varepsilon^z_t = \varepsilon^z_{t,0} + \varepsilon^z_{t-4,4} + \varepsilon^z_{t-8,8} + \varepsilon^z_{t-12,12}, \quad \text{and} \quad \varepsilon^v_t = \varepsilon^v_{t,0} + \varepsilon^v_{t-4,4} + \varepsilon^v_{t-8,8} + + \varepsilon^v_{t-12,12},$$

where the first component, $\varepsilon^x_{t,0}$, is unanticipated (with $x = z, v$) whereas the components $\varepsilon^x_{t-4,4}$, $\varepsilon^x_{t-8,8}$, and $\varepsilon^x_{t-12,12}$ are anticipated and represent news about period t that arrives four, eight and twelve quarters ahead, respectively. As conventional in the literature, the anticipated and unanticipated components for sector $x = C, I$ and horizon $h = 0, 1, \ldots, H$

are *i.i.d.* with distributions $N(0, \sigma^2_{z,t-h})$ and $N(0, \sigma^2_{v,t-h})$ that are uncorrelated across sector, horizon and time.

3 The VAR model

Consider the following reduced form VAR(p) model,

$$y_t = A(L)u_t, \tag{10}$$

where y_t is an $n \times 1$ vector of variables of interest, $A(L) = I + A_1 L + A_2 L^2 + ... + A_p L^p$ is a lag polynomial, $A_1, A_2, ..., A_p$ are $n \times n$ matrices of coefficients and, finally, u_t is an error term with $n \times n$ covariance matrix Σ. Define a linear mapping between reduced form and structural errors, ε_t,

$$u_t = B_0 \varepsilon_t, \tag{11}$$

We can then write the structural moving average representation as

$$y_t = C(L)\varepsilon_t, \tag{12}$$

where $C(L) = A(L)B_0$, $\varepsilon_t = B_0^{-1} u_t$, and the matrix B_0 satisfies $B_0 B_0^{'} = \Sigma$. The B_0 matrix may also be written as $B_0 = \tilde{B}_0 D$, where $\tilde{B}_0$ is any arbitrary orthogonalization of Σ and D is an orthonormal matrix ($DD' = I$).

The h step ahead forecast error is,

$$y_{t+h} - E_{t-1} y_{t+h} = \sum_{\tau=0}^{h} A_\tau \tilde{B}_0 D \varepsilon_{t+h-\tau}. \tag{13}$$

The share of the forecast error variance of variable i attributable to shock j at horizon h is then

$$V_{i,j}(h) = \frac{e_i^{'}\Big(\sum_{\tau=0}^{h} A_\tau \tilde{B}_0 D e_j e_j^{'} D^{'} \tilde{B}_0^{'} A_\tau^{'}\Big) e_i}{e_i^{'}\Big(\sum_{\tau=0}^{h} A_\tau \Sigma A_\tau^{'}\Big) e_i} = \frac{\sum_{\tau=0}^{h} A_{i,\tau} \tilde{B}_0 \gamma\gamma^{'} \tilde{B}_0^{'} A_{i,\tau}^{'}}{\sum_{\tau=0}^{h} A_{i,\tau} \Sigma A_{i,\tau}^{'}}, \tag{14}$$

where e_i denotes selection vectors with one in the i-th position and zeros elsewhere. The e_j vectors pick out the j-th column of D, denoted by γ. $\tilde{B}_0 \gamma$ is an $n \times 1$ vector corresponding to the j-th column of a possible orthogonalization and can be interpreted as an impulse response vector. In the following section, we discuss the estimation and identification methodology

that yields an estimate for the TFP news shock from the VAR model.

4 Data and estimation

We estimate the models using quarterly U.S. data for the period 1990:Q1−2013:Q4.[11]

DSGE estimation. We estimate the DSGE model using the following vector of observables: $[\Delta \log Y_t, \Delta \log C_t, \Delta \log I_t, \Delta \log W_t, \pi_{C,t}, \Delta(\frac{P^I}{P^C}), \log L_t, R_t, R_t^C, R_t^I, \Delta \log N_t]$, which comprises output (Y_t), consumption (C_t), investment (I_t), real wage (W_t), consumption sector inflation ($\pi_{C,t}$), relative price of investment ($\frac{P^I}{P^C}$), hours worked (L_t), nominal interest rate (R_t), consumption sector corporate bond spread (R_t^C), investment sector corporate bond spread (R_t^I), and bank equity, respectively (N_t), and the term Δ denotes the first-difference operator. Variables for aggregate quantities are expressed in real, per-capita terms using civilian noninstitutional population. We demean the data prior to estimation.[12] We use these variables to keep the analysis as close as possible to related studies such as Smets and Wouters (2007), Justiniano et al. (2010) and Khan and Tsoukalas (2012) while incorporating important financial variables. Appendix B provides a detailed description of data sources. The financial variables consist of the sectoral corporate bond spreads and a publicly available measure of intermediaries' equity capital reported by the Federal Financial Institutions Examination Council.[13] The latter refers to total equity of all insured U.S. commercial banks, expressed in real per capita terms. We inform the estimation with the corporate bond spreads that in principle can help to identify news shocks as they are likely to contain advance information

[11] We start the estimation in 1990:Q1 due to the availability of financial data on sectoral corporate bond spreads.

[12] Removing sample means from the data prevents the possibility that counterfactual implications of the model for the low frequencies may distort inference on business cycle dynamics. For example, in the sample, consumption has grown by approximately 0.32% on average per quarter, while output has grown by 0.20% on average per quarter respectively. However, the model predicts that they grow at the same rate. Thus, if we hardwire a counterfactual common trend growth rate in the two series, we may distort inference on business cycle implications that is of interest to us.

[13] A corporate bond spread is defined as the difference between a company's corporate bond yield and the yield of a U.S. Treasury bond with an identical maturity—information provided by Reuters' Datastream. In constructing spreads, we consider only nonfinancial corporations and only bonds traded in the secondary market. Appendix B describes how we map individual companies to the consumption and investment sector using the input-output tables.

about future economic activity. Philippon (2009) argues that corporate bond spreads may contain news about future corporate fundamentals and provides evidence that information extracted from corporate bond markets, in contrast to the stock market, is informative for U.S. business fixed investment. Gilchrist and Zakrajsek (2012) find that corporate bond spreads have predictive power for future GDP.

In the the DSGE model, TFP news shocks compete with other shocks to account for the variation in the data. The cross equation restrictions implied by the equilibrium conditions of the model identify the different shocks. We estimate a subset of parameters using Bayesian methods and calibrate the remaining parameters with the standard values described in Table 5 of Appendix A.4. The prior distributions conform to the assumptions in Justiniano et al. (2010) and Khan and Tsoukalas (2012), as reported in Table 1. We consider four, eight, and twelve quarter ahead sector-specific TFP news. This choice is guided by the desire to limit the size of the state space of the model while being flexible enough to allow the news processes to accommodate revisions in expectations. Similar time horizons are considered by Christiano et al. (2014), Schmitt-Grohe and Uribe (2012), Khan and Tsoukalas (2012) and Theodoridis and Zanetti (2015).[14]

Table 1 reports information on the posterior distribution of parameters. In the interest of space, we do not discuss the posterior means of the estimated parameters in detail. Posterior means are broadly in line with estimates from earlier work: Smets and Wouters (2007), Khan and Tsoukalas (2012), and Justiniano et al. (2010).

VAR estimation. To estimate the VAR model, we consider VAR specifications with seven variables. The VAR specifications are described in section 5. A key input for the VAR analysis is an observable measure of technology. We follow the convention in the empirical literature and use the measure of utilization-adjusted TFP (aggregate and sectoral) provided by John Fernald of the San Francisco Fed (Fernald (2014)). To estimate the VAR model, we use three lags and a Minnesota prior similar to those in Kurmann and Otrok (2013) and

[14]The prior means assumed for the TFP news components are in line with these studies and imply that the sum of the variance of news components is, evaluated at prior means, at most one half of the variance of the corresponding unanticipated component.

Table 1: Prior and Posterior Distributions

Parameter	Description	Prior Distribution			Posterior Distribution		
		Distribution	Mean	Std. dev.	Mean	10%	90%
h	Consumption habit	Beta	0.50	0.10	0.51	0.45	0.58
ν	Inverse labour supply elasticity	Gamma	2.00	0.75	0.20	0.11	0.33
ξ_w	Wage Calvo probability	Beta	0.66	0.10	0.59	0.54	0.63
ξ_C	C-sector price Calvo probability	Beta	0.66	0.10	0.83	0.81	0.85
ξ_I	I-sector price Calvo probability	Beta	0.66	0.10	0.83	0.79	0.87
ι_w	Wage indexation	Beta	0.50	0.15	0.17	0.08	0.27
ι_{pC}	C-sector price indexation	Beta	0.50	0.15	0.07	0.04	0.10
ι_{pI}	I-sector price indexation	Beta	0.50	0.15	0.61	0.43	0.78
χ_I	I-sector utilization	Gamma	5.00	1.00	4.32	3.12	5.62
χ_C	C-sector utilization	Gamma	5.00	1.00	4.52	3.26	5.84
κ	Investment adj. cost	Gamma	4.00	1.00	2.29	1.87	2.74
ϕ_π	Taylor rule inflation	Normal	1.70	0.30	1.57	1.45	1.70
ρ_R	Taylor rule inertia	Beta	0.60	0.20	0.82	0.79	0.85
ϕ_{dX}	Taylor rule output growth	Normal	0.125	0.10	0.74	0.64	0.83
	Shocks: Persistence						
ρ_z	C-sector TFP growth	Beta	0.40	0.20	0.72	0.67	0.77
ρ_v	I-sector TFP growth	Beta	0.40	0.20	0.38	0.27	0.47
ρ_b	Preference	Beta	0.60	0.20	0.90	0.87	0.92
ρ_μ	Marginal efficiency of investment	Beta	0.60	0.20	0.90	0.87	0.93
ρ_g	Government spending	Beta	0.60	0.20	0.97	0.96	0.99
$\rho_{\lambda_p^C}$	C-sector price markup	Beta	0.60	0.20	0.06	0.03	0.10
$\rho_{\lambda_p^I}$	I-sector price markup	Beta	0.60	0.20	0.84	0.78	0.89
ρ_{λ_w}	Wage markup	Beta	0.60	0.20	0.08	0.03	0.13
ρ_{a_l}	C-sector stationary TFP	Beta	0.60	0.20	0.83	0.41	0.98
ρ_{v_l}	I-sector stationary TFP	Beta	0.60	0.20	0.95	0.93	0.96
	Shocks: Volatilities						
σ_z	C-sector TFP	Inv Gamma	0.50	2	0.17	0.14	0.21
σ_{z4}	C-sector TFP. 4Q ahead news	Inv Gamma	$0.5/\sqrt{3}$	2	0.09	0.07	0.11
σ_{z8}	C-sector TFP. 8Q ahead news	Inv Gamma	$0.5/\sqrt{3}$	2	0.14	0.10	0.18
σ_{z12}	C-sector TFP. 12Q ahead news	Inv Gamma	$0.5/\sqrt{3}$	2	0.22	0.18	0.26
σ_v	I-sector TFP	Inv Gamma	0.50	2	0.26	0.19	0.34
σ_{v4}	I-sector TFP. 4Q ahead news	Inv Gamma	$0.5/\sqrt{3}$	2	0.20	0.14	0.26
σ_{v8}	I-sector TFP. 8Q ahead news	Inv Gamma	$0.5/\sqrt{3}$	2	0.13	0.09	0.17
σ_{v12}	I-sector TFP. 12Q ahead news	Inv Gamma	$0.5/\sqrt{3}$	2	0.24	0.17	0.30
σ_b	Preference	Inv Gamma	0.10	2	1.11	0.95	1.28
σ_μ	Marginal efficiency of investment	Inv Gamma	0.50	2	1.62	1.37	1.89
σ_g	Government spending	Inv Gamma	0.50	2	0.46	0.42	0.50
σ_{mp}	Monetary policy	Inv Gamma	0.10	2	0.12	0.11	0.14
$\sigma_{\lambda_p^C}$	C-sector price markup	Inv Gamma	0.10	2	0.50	0.46	0.55
$\sigma_{\lambda_p^I}$	I-sector price markup	Inv Gamma	0.10	2	0.09	0.06	0.11
σ_{λ_w}	Wage markup	Inv Gamma	0.10	2	0.81	0.69	0.93
σ_{a_l}	C-sector stationary TFP	Inv Gamma	0.50	2	0.34	0.25	0.44
σ_{v_l}	I-sector stationary TFP	Inv Gamma	0.50	2	1.57	1.29	1.83

Notes. The posterior distribution of parameters is evaluated numerically using the random walk Metropolis-Hastings algorithm. We simulate the posterior using a sample of 500,000 draws and discard the first 100,000 of the draws.

compute confidence bands by drawing from the posterior. Due to the shrinkage of VAR coefficients achieved by the Minnesota prior, results are robust to using four instead of three lags. The time series included in the VAR enter in levels, consistent with the treatment in the empirical VAR literature (see Barsky and Sims (2011) and Beaudry and Portier (2004, 2006, 2014)). To estimate the VAR model we use three lags and a Minnesota prior similar to those in Kurmann and Otrok (2013) and compute confidence bands by drawing from the posterior—details are given in Appendix A.3. Due to the shrinkage of VAR coefficients achieved by the Minnesota prior, results are robust to using four instead of three lags. The time series included in the VAR enter in levels, consistent with the treatment in the empirical VAR literature (see Barsky and Sims (2011), Beaudry and Portier (2004, 2006, 2014)).

To identify the TFP news shock from the VAR model, we adopt the identification scheme of Forni et al. (2014). Specifically, we assume that the news shock (i) does not move TFP on impact and (ii) has maximal impact on TFP in the long run (at the 40 quarters horizon). The Forni et al. (2014) identification scheme is similar in spirit to the identification scheme in Francis et al. (2014), also referred to as the Max Share, and it allows other shocks to affect TFP in short and medium horizons. Appendix A.2 presents VAR findings using the Max Share method, which recovers the news shock by maximizing the variance of TFP at a specific long but finite horizon (we set the horizon to 40 quarters as well). The appendix also reports findings using the identification scheme in Barsky and Sims (2011) that recovers the news shock by maximizing the variance of TFP over the horizons zero to 40 quarters. The impulse responses recovered from the Max Share and Barsky-Sims methods are virtually indistinguishable from the results based on the Forni et al. (2014) method.[15]

[15]These methods are variants of Uhlig (2003). The agnostic nature of the VAR restrictions is appealing, although the potential non-fundamental nature of structural shocks (an issue likely to arise with news shocks due to the proliferation of state variables) may invalidate inference. Non-fundamentalness implies that the underlying model cannot be inverted and hence lacks a Wold representation in structural shocks that can be recovered from VAR methods. Beaudry et al. (2015) suggest the issue is of a quantitative nature and that a VAR representation "close enough" to the true representation may exist, making VAR methods suitable for the identification of news shocks.

5 Results from the VAR model

In this section, we focus on the aggregate TFP news shock that is studied extensively in the empirical VAR literature.[16] In the interest of examining the response of relevant variables to the identified TFP news shock as well as to ensure robust results, we estimate three alternative VAR specifications, denoted by I, II, and III, each of which comprises seven variables. Each VAR specification features the (utilization-adjusted) aggregate TFP series and six other variables. The methodology used to compute the TFP measures is based on the growth accounting methodology in Basu et al. (2006) and corrects for unobserved capacity utilization, described in Fernald (2014).[17] These six variables are a subset of the variables used in the DSGE analysis. We also use two additional variables in the VAR analysis, relative to the information set in the DSGE model, namely the Michigan consumer confidence indicator (E5Y) and the S&P 500 index.[18] Both have been shown to contain important information for the identification of news shocks (see Barsky and Sims (2011), Forni et al. (2014) and Beaudry and Portier (2004, 2006, 2014)).[19] In addition to the results from the three VAR specifications discussed below, Appendix A.1 (Figure 10) reports results from a larger VAR system that incorporates both sectoral corporate bond spread series, and bank equity. These are key information variables used in the estimation of the DSGE model, since the transmission of the latter emphasizes the interaction between spreads and bank equity.

VAR specification I. Figure 1 displays IRFs from the first VAR specification featuring aggregate TFP, output, hours, consumption, corporate spread, CPI inflation, and consumer

[16] Section 7 discusses results for sectoral TFP news shock.

[17] The data is available from $www.frbsf.org/economic-research/economists/jfernald/quarterly_tfp.xls$. Throughout the paper we use the July 2015 vintage.

[18] For comparison, we have selected variables that are often used in the VAR literature. The consumer confidence survey measure summarizes responses to the following question: "Turning to economic conditions in the country as a whole, do you expect that over the next five years we will have mostly good times, or periods of widespread unemployment and depression, or what?" The variable is constructed as the percentage giving a favorable answer minus the percentage giving an unfavorable answer plus 100.

[19] In the VAR analysis, we use and report results for the popular BAA corporate bond spread. In the DSGE model, we use sectoral corporate bond spreads, which are of similar rating quality as the BAA spread. VAR results with the sectoral bond spreads are similar both qualitatively and quantitatively and are available upon request.

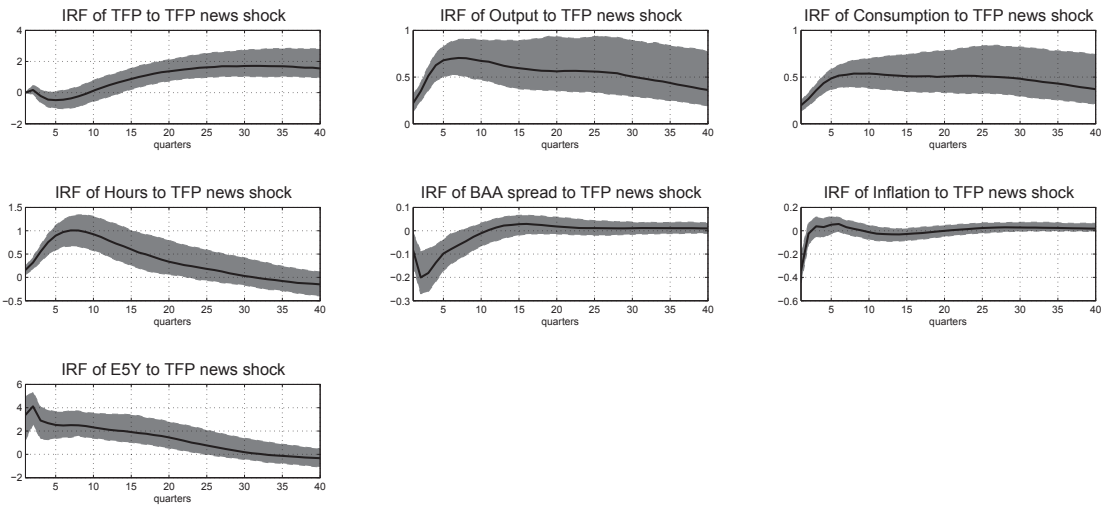


Figure 1: **Aggregate TFP news shocks, specification I.** Sample is 1990Q1-2013Q4. Impulse responses to an aggregate TFP news shock from a seven variable VAR (specification I) featuring aggregate TFP, output, hours, consumption, corporate bond spread (BAA spread), CPI inflation, and consumer confidence (E5Y) estimated with 3 lags. The shaded gray areas are the 16% and 84% posterior bands generated from the posterior distribution of VAR parameters. The units of the vertical axes are percentage deviations.

confidence. Variables are used in this ordering, and results are robust to alternative orderings. The shaded areas represent the 16% and 84% posterior confidence bands. Several interesting findings emerge. First, TFP rises in a delayed fashion, and it becomes significantly different from zero after approximately four years. This pattern shows that the identification scheme produces empirically plausible news shocks, as discussed in Beaudry and Portier (2014). Second, the VAR-identified TFP news shock creates a boom today: output, consumption, and hours increase significantly on impact, and they display hump-shaped dynamics. Third, the BAA corporate bond spread declines significantly, suggesting that corporate bond markets anticipate movements in future TFP, which is consistent with an economic expansion induced by an increase in lending. Qualitatively the VAR responses are consistent with the IRFs from the DSGE model. The behavior of the BAA spread is a novel stylized fact that, to the best of our knowledge, no previous studies have documented, and it motivates our choice for a model of financial frictions that lead to endogenous spreads. Fourth, the confidence indicator (E5Y) also increases in anticipation of the future rise in TFP, consistent with the work by Barsky and Sims (2011, 2012) that finds that the indicator retains a strong

predicting power of future economic outlook. Finally, the news shocks is associated with a short-lived decline in CPI inflation. It is interesting to note that the co-movement pattern displayed in Figure 1 fails to conform to the findings in Barsky and Sims (2011), where good news about future TFP is associated with a short lived recession, not a boom. Sims (2016) evaluates the properties of different TFP vintages and finds in an application to news shocks, using the 2015 vintage, macroeconomic effects in support to our findings.

VAR specification II. Figure 2 displays IRF from a different VAR specification that features TFP, investment, hours, consumption, S&P 500 index, CPI inflation, and consumer confidence (in this ordering). First, note that the IRFs for the variables that are common in specifications I and II are qualitatively and quantitatively similar to each other (compare Figures 1 and 2). The response of investment is consistent with the overall broad-based rise in activity, and it rises significantly in response to good news about future TFP, anticipating the realization of improved technology. The S&P 500 index also rises significantly in anticipation of the future rise in TFP, consistent with the evidence reported in Beaudry and Portier (2006) and Barsky and Sims (2011).

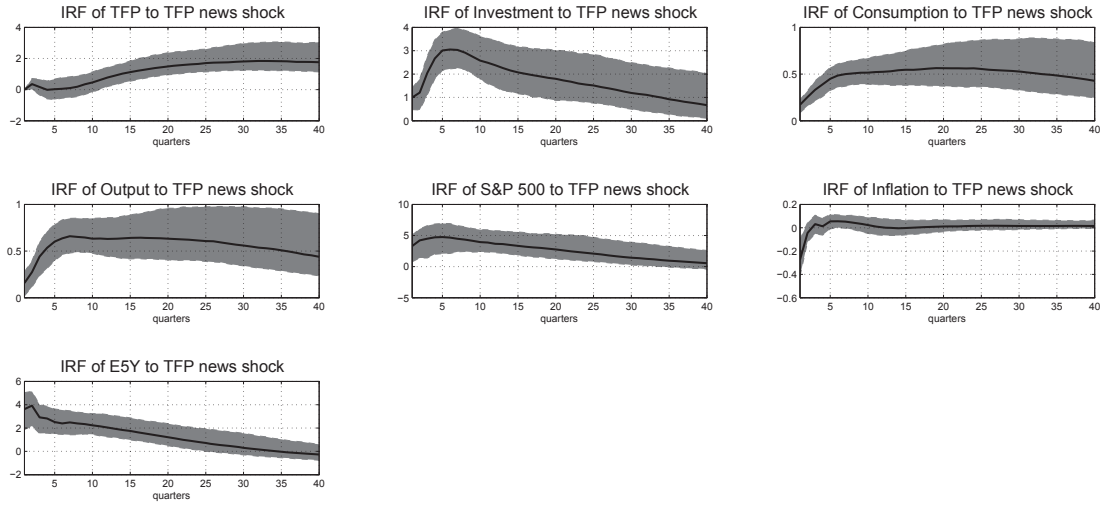


Figure 2: **Aggregate TFP news shocks, specification II.** Sample is 1990Q1-2013Q4. Impulse responses to an aggregate TFP news shock from a seven variable VAR (specification II) featuring aggregate TFP, investment, hours, consumption, S&P 500, CPI inflation, and consumer confidence (E5Y) estimated with 3 lags. The shaded gray areas are the 16% and 84% posterior bands generated from the posterior distribution of VAR parameters. The units of the vertical axes are percentage deviations.

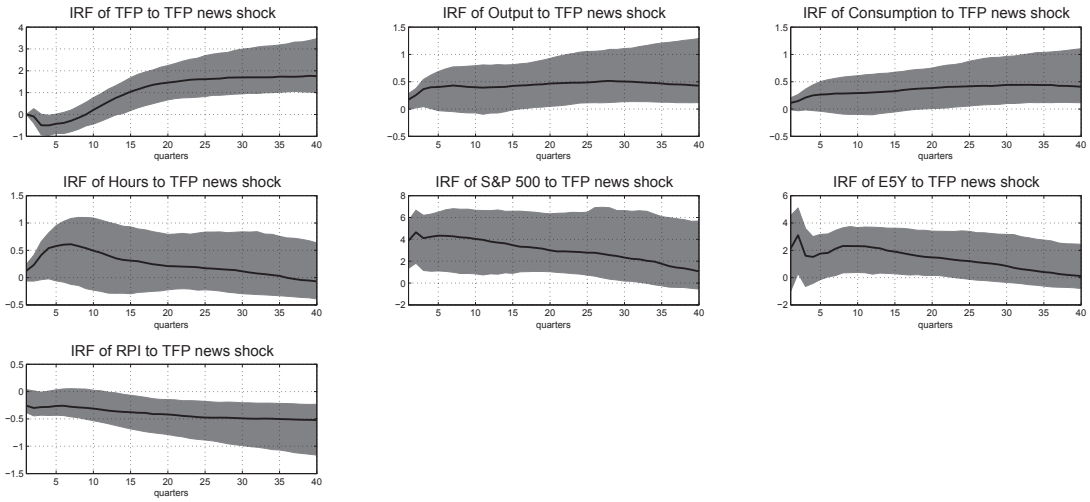


Figure 3: **Aggregate TFP news shocks, specification III.** Sample is 1990Q1-2013Q4. Impulse responses to an aggregate TFP news shock from a seven variable VAR (specification III) featuring aggregate TFP, output, hours, consumption, S&P 500, consumer confidence (E5Y), and relative price of investment (RPI) estimated with 3 lags. The shaded gray areas are the 16% and 84% confidence bands generated from the posterior distribution of VAR parameters. The units on the vertical axes are percentage deviations.

VAR specification III. Figure 3 displays IRF from a VAR specification that features TFP, output, hours, consumption, S&P 500 index, consumer confidence, and the relative price of investment (RPI). Following the innovative work of Fisher (2006), recent research in Zeev and Khan (2015) identifies, using VAR methods, investment-specific news shocks using the RPI as a key indicator variable.[20] The RPI is defined as the investment (chain-weighted aggregate of gross private domestic investment and consumer durables) deflator over the consumption (chain-weighted aggregate of services and nondurables consumption) deflator. Both deflators are computed using the official National Income and Products Accounts (NIPA) data (see Appendix B). Figure 3 suggests that the responses to variables common to specifications I and II are qualitatively very similar to this specification. The interesting feature from this specification is the response of the RPI to a positive TFP news shock. Whereas the response of the RPI is not significantly different from zero in the short run, the RPI nevertheless declines significantly after approximately three years following the TFP news shock. The timing of this decline approximately coincides with the increase

[20]Other related work seeking to identify investment-specific shocks (unanticipated or news) using VAR methods includes, Beaudry and Lucke (2010), Chen and Wemy (2015), and Benati (2016).

in future TFP, suggesting a close covariation between the two in the long run. The stock market booms immediately and significantly, similar to the behavior in Figure 2. We discuss the implications of this interesting finding in more detail in Section 7.

6 Reconciling DSGE and VAR results

6.1 Results from the DSGE model

In this section we discuss the findings from the DSGE model on the empirical significance and the dynamic propagation of news shocks. We also provide a comparison with findings from standard models in the literature that abstract from financial frictions. Our main focus is to quantify the financial amplification of TFP news shocks that results from the presence of leveraged intermediaries. Görtz and Tsoukalas (2016), using common model elements, provides a detailed discussion on the role played by nominal rigidities and the two sector structure for the propagation of TFP news shocks. Their findings emphasize the importance of nominal rigidities for the co-movement properties of news shocks and suggest that the two sector structure plays a very limited role for their propagation.[21] Table 2 reports the variance decomposition of the estimated DSGE model for each news shock and the sum of the unanticipated shocks. The entries show that the estimation assigns significant importance to TFP news shocks as a source of fluctuations. In their totality, TFP news shocks account for 27.6%, 28.6%, 30.4%, 39.5% of the variance in output, consumption, investment and hours worked, respectively, in business cycle frequencies. Consumption-specific news shocks play a major role in this total, accounting for 24.6%, 27.7%, 26.2%, 37.1% of the variance in the same macro aggregates. The estimation finds strong links between financial variables and real aggregates as sectoral news shocks explain a sizable share of the variance in the sectoral bond spreads.

[21] Görtz and Tsoukalas (2016) show that in response to a positive news shock, countercyclical markups move labour demand and supply curves rightwards offsetting the negative wealth effect on labour supply, thereby generating co-movement.

Table 2: Variance decomposition at posterior estimates—business cycle frequencies (6-32 quarters)

	z	z^4	z^8	z^{12}	v	v^4	v^8	v^{12}	a_l	v_l	μ	all other shocks	Sum of TFP shock contribution: unanticipated cols. 1, 5	all news cols. 2-4 , 6-8	z news cols. 2-4	v news cols. 6-8
Output	16.0	3.8	8.7	12.2	1.0	0.6	0.3	2.0	0.8	7.8	18.0	28.8	25.6	27.6	24.6	3.0
Consumption	24.4	5.1	9.0	13.6	0.1	0.1	0.1	0.6	5.5	4.2	5.1	31.8	34.2	28.6	27.7	0.8
Investment	3.7	2.1	8.2	16.0	1.7	1.0	0.5	2.7	0.1	13.9	13.6	36.6	19.4	30.4	26.2	4.2
Total Hours	4.9	3.7	13.2	20.2	0.8	0.5	0.3	1.6	0.2	6.4	12.7	35.4	12.4	39.5	37.1	2.4
Real Wage	20.5	3.8	4.6	4.7	0.1	0.6	0.3	1.5	3.9	2.3	3.3	54.2	26.8	15.4	13.1	2.3
Nominal Interest Rate	3.6	3.3	17.0	40.6	0.4	0.1	0.1	0.4	0.2	4.4	9.5	20.6	8.6	61.6	60.9	0.6
C-Sector Inflation	1.3	1.6	11.6	35.7	0.3	0.1	0.0	0.2	1.7	1.0	2.4	44.2	4.2	49.3	48.9	0.3
C-Sector Spread	8.0	3.8	13.5	24.2	0.3	0.3	0.3	2.0	0.9	6.5	13.9	26.1	15.7	44.2	41.6	2.6
I-Sector Spread	9.7	4.0	13.4	23.5	0.8	0.2	0.0	0.1	0.9	4.2	9.6	33.5	15.6	41.3	40.9	0.4
Equity	16.0	3.1	11.1	29.4	0.4	0.1	0.0	0.5	0.1	6.3	11.0	21.8	22.8	44.2	43.6	0.6
Rel. Price of Investment	15.3	2.8	2.7	1.3	3.2	1.8	0.5	1.8	1.1	22.2	6.8	39.9	41.8	11.0	6.8	4.2

z = TFP growth shock in consumption sector, $z^x = x$ quarters ahead consumption sector TFP growth news shock, v = TFP growth shock in investment sector, $v^x = x$ quarters ahead investment sector TFP growth news shock, a_l and v_l = stationary (level) TFP shocks in the consumption and investment sector, μ = marginal efficiency of investment shock. Business cycle frequencies considered in the decomposition correspond to periodic components with cycles between 6 and 32 quarters. The decomposition is performed using the spectrum of the DSGE model and an inverse first difference filter to reconstruct the levels for output, consumption, total investment, the real wage, equity, and the relative price of investment. The spectral density is computed from the state space representation of the model with 500 bins for frequencies covering the range of periodicities. We report median shares.

The investment- and consumption-specific TFP news shocks account for a share of approximately 41% and 44% of the variance of bond spreads in the investment and consumption sector, respectively. TFP news shocks are also quantitatively important for the variation in the nominal interest rate and consumption inflation rate, accounting for approximately 49% and 61% of their variance, respectively.[22]

These findings are in sharp contrast to the results in DSGE models that abstract from financial frictions. To isolate the contribution of the financial channel in our model, we estimate two restricted versions of the model that abstract from financial frictions: a one-sector model, similar to one described in Fujiwara et al. (2011), Khan and Tsoukalas (2012), and Justiniano et al. (2010) as well as a variant of our two-sector model.[23] Table 3 compares the variance decomposition across the different models and shows that one- and two-sector versions of the model that abstract from financial frictions find a limited empirical role to news shocks. In these constrained versions of the baseline model, the totality of TFP news shocks account for approximately 10% and 11% of the variation in output. This finding is consistent with related results in the DSGE literature that attribute a limited role to aggregate and sectoral news shocks (see, for example, Fujiwara et al. (2011), Khan and Tsoukalas (2012) and Schmitt-Grohe and Uribe (2012), among others).

[22] Our findings regarding the empirical significance of news shocks are robust to excluding the MEI shock, considering a shorter pre-crisis sample that ends in 2007Q4 and shortening the horizons for news shocks (i.e. agents receive signals up to eight quarters in advance).

[23] Both models turn off the financial channel, i.e. the balance sheet identity (4), the leverage constraint (5), the evolution of equity capital (6), and the financial constraint (8) that describe the financial sector. The one-sector model can be written as a special case of the two-sector model. It imposes a perfectly competitive investment sector and perfect capital mobility.

Table 3: Variance decomposition – business cycle frequencies (6-32 quarters)

	Baseline model with financial frictions				Two sector model without financial frictions				One sector model without financial frictions			
	all TFP unanticipated	all TFP news	MEI (μ)	all other shocks	all TFP unanticipated	all TFP news	MEI (μ)	all other shocks	all TFP unanticipated	all TFP news	MEI (μ)	all other shocks
Output	25.6	27.6	18.0	28.8	10.1	8.7	41.5	39.6	11.5	11.2	30.5	46.9
Consumption	34.2	28.6	5.1	31.8	8.2	6.1	5.0	79.5	8.1	5.1	29.0	57.8
Investment	19.4	30.4	13.6	36.6	18.7	11.8	53.4	15.7	9.4	12.8	39.1	38.7
Total Hours	12.4	39.5	12.7	35.4	8.3	13.1	37.1	40.7	2.8	12.4	33.1	51.7
Real Wage	26.8	15.4	3.3	54.2	7.8	13.9	35.8	41.7	21.8	17.6	3.6	57.0
Nominal Interest Rate	8.6	61.6	9.5	20.6	5.1	7.7	32.9	54.4	2.8	6.7	75.4	15.2
C-Sector Inflation	4.2	49.3	2.4	44.2	0.8	0.2	0.0	98.9	6.0	4.7	51.0	38.3
C-Sector Spread	15.7	44.2	13.9	26.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
I-Sector Spread	15.6	41.3	9.6	33.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Equity	22.8	44.2	11.0	21.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Rel. Price of Investment	41.8	11.0	6.8	39.9	27.5	6.6	29.9	35.0	81.0	19.0	0.0	0.0

Business cycle frequencies considered in the decomposition correspond to periodic components with cycles between 6 and 32 quarters. The decomposition is performed using the spectrum of the DSGE model and an inverse first difference filter to reconstruct the levels for output, consumption, total investment, the real wage and the relative price of investment. The spectral density is computed from the state space representation of the model with 500 bins for frequencies covering the range of periodicities. We report median shares.

We plot impulse response functions (IRF) in order to gain intuition on the propagation of TFP news shocks and understand the mechanism that enhances the empirical relevance to news shocks in the baseline model with financial frictions. Figure 4 plots the response of selected variables to a three-year ahead consumption-specific TFP news shock in the two-sector model with financial channel (solid line) together with those for the two-sector model without the financial channel (dashed line). We normalize the shock to be of equal size across simulations. The amplification of the news shock is significantly stronger in the model with the financial channel.

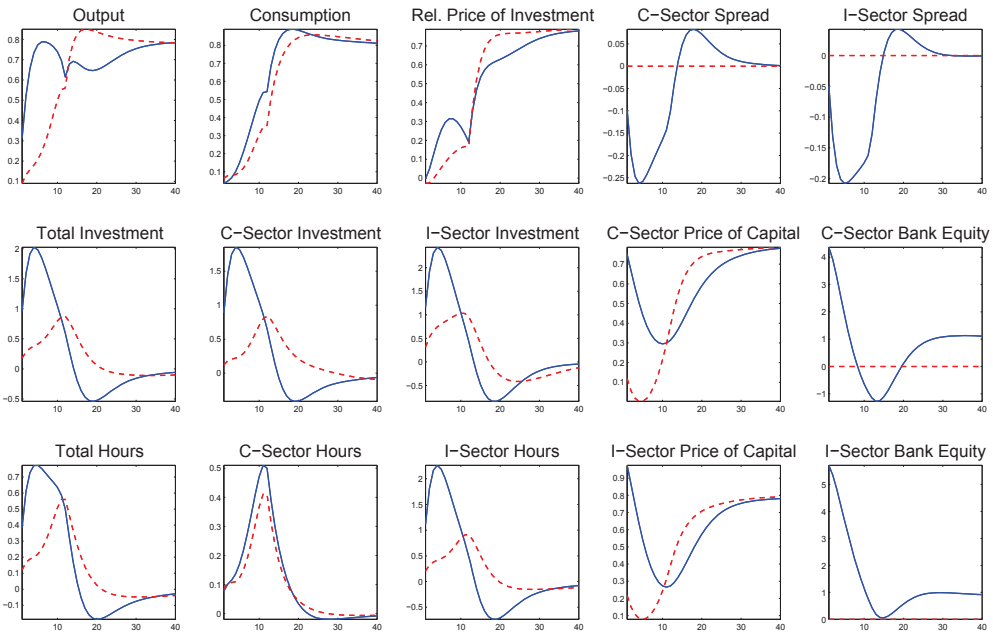


Figure 4: Responses to a one std. deviation TFP news shock (anticipated 12-quarters ahead) in the consumption sector. Baseline model with financial intermediation (blue solid line), and model without financial intermediation (red dashed line) at baseline estimates. The horizontal axes refer to quarters and the units of the vertical axes are percentage deviations.

In the model with financial frictions, the impact of the consumption-specific news shock is amplified by the effect of capital prices on intermediaries' equity. A positive news shock raises capital prices, which in turn boost bank equity. Better capitalized banks expand demand for capital assets, and the process further increases capital prices, leading to a strong investment boom. Figure 4 shows that the responses of capital prices are qualitatively different between the two models. In both models, capital prices increase in anticipation of the future rise

in productivity. However, in the baseline model with financial frictions, capital prices rise sharply (approximately seven times more compared to the model without financial frictions) due to the amplification effect of financial intermediaries on the demand for capital. As the stock of capital increases and accumulates, agents expect capital prices and returns from capital to decline. Other things equal, the surge in capital prices creates a strong incentive to build new capital before the improvement in technology materializes, which in turn stimulates a strong rise in current hours worked and output. By contrast, in the model without financial frictions, capital prices increase moderately on impact and rise further in the future, which suppresses—relative to the baseline—current investment spending in anticipation of future increase in the returns to capital.

The DSGE model provides relevant insights on the significance of the marginal efficiency of investment (MEI) shock, which recent studies with estimated DSGE models with (Khan and Tsoukalas (2012)) and without (Justiniano et al. (2010)) news shocks, find considerably more important than TFP shocks to explain business cycles fluctuations.[24] We corroborate these findings in the estimated versions of the model that abstracts from the financial channel, namely, the one-sector and two-sector model without financial frictions (see Table 3). For instance, in the two-sector model without financial frictions, MEI shocks explain the bulk of movements in the variance of output (41%), investment (53%), and hours worked (37%). By contrast, in the baseline model with the financial sector, MEI shocks account for approximately, 18%, 14%, and 13% in the variance of the same set of macroeconomic aggregates. The key reason for the reduced role of MEI shocks in the presence of financial frictions is related to the fact that an exogenous increase in MEI generates a fall in the price of installed capital by increasing the transformation rate of investment goods to installed capital. The decline in capital prices severs the financial channel that stimulates equity capital gains for the financial intermediaries in response to an increase in investment

[24] We include the MEI shock in the estimation for comparison purposes with the literature. The MEI differs from the investment-specific shock in that the latter is a permanent shock and affects only the productivity of the investment sector. By contrast, the MEI affects the transformation of investment goods to installed capital and affects both sectors.

demand and capital prices. Thus, a decline in capital prices induces a fall in equity and restricts the facilitation of lending and investment spending. The same logic operates in the case of investment-specific shocks of the unanticipated or anticipated type. Section 7 discusses investment-specific news shocks in detail.

6.2 The DSGE as the data generating process

In this section, we compare the dynamics to TFP news shocks across the two methods. We focus on the aggregate TFP news shock since it facilitates comparison with related empirical studies (see, for instance, Beaudry and Portier (2006), Beaudry and Lucke (2010), Barsky and Sims (2011), and Forni et al. (2014)). We perform a Monte Carlo experiment and generate 1,000 samples of artificial data from the DSGE model, drawing parameter values from the posterior distribution. We compare the empirical IRF from the VAR model (specification I) against those estimated with identical VAR specifications (along with posterior bands) on the artificial data samples.[25] Following the methodology in Fernald (2014), we extract a model-based aggregate TFP measure by weighting together the two model-based sectoral TFP growth components weighting them by their GDP shares. Figure 5 compares the IRF from the VAR model in specification I (dashed line) with those from the Monte Carlo experiment (diamond line). Qualitatively, the dynamic responses from the model-based VAR are similar to the responses from the empirical VAR. A noticeable exception is the impact response of inflation, which is positive in the DSGE model but negative in the VAR model. The intuition for this difference is as follows: In the baseline DSGE model with financial frictions, the rise in the price of capital in response to the TFP news shock (see Figure 1) generates a strong increase in the rental rate of capital, which amplifies the increase in the marginal cost of production and therefore leads to an increase in inflation. For most of the variables, the empirical median response in the VAR model is, in the vast

[25] We have simulated the model over 1,096 periods. We construct the level of the resulting time series and discard all but the last 96 periods (the same sample size as the data) to minimize the impact of initial values. We have used a simple average of the sectoral spreads to estimate the VAR on the simulated model samples. The empirical VAR uses the BAA spread as described in specification I.

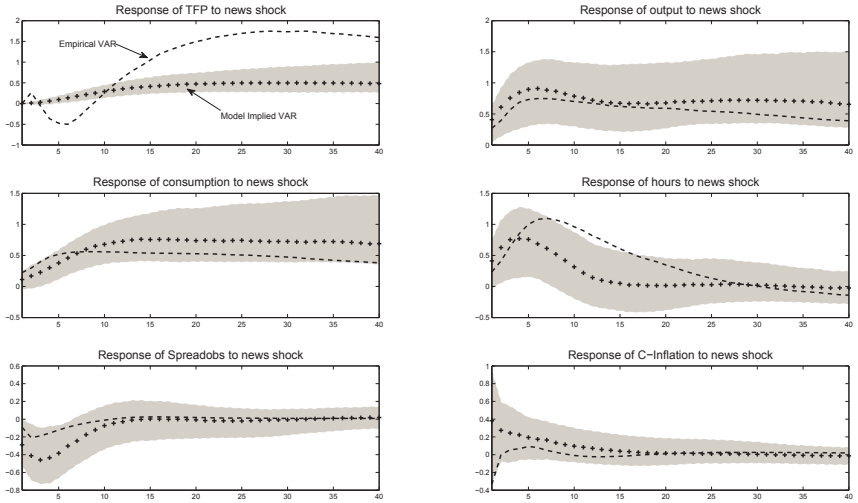


Figure 5: **Aggregate TFP news shock.** Sample is 1984Q1-2013Q4. The thick solid line is the impulse response to TFP news shock from a seven variable VAR featuring aggregate TFP, corporate bond spread (BAA spread), consumption, output, hours, CPI inflation, and consumer confidence (E5Y) estimated with 3 lags. The thin solid line (dotted lines) is the median (16%, 84% confidence bands) impulse response to an aggregate TFP news shock estimated from a VAR on 1,000 samples, generated from the model. The horizontal axes refer to forecast horizons (quarters) and the units of the vertical axes are percentage deviations.

majority of periods, inside the posterior confidence bands of the model-based VAR. Another notable difference is the response of the aggregate TFP, as the long-run increase is much higher in the empirical responses compared to the responses with artificial data. We discuss the intuition for this difference in section 7, which focuses on comparing sector-specific TFP shocks. We note however that the estimation of the DSGE model does not include a measure of TFP among the observables to produce an estimate of the TFP news shock. In this respect, we follow the majority of studies that use DSGE models to infer technology shocks without using TFP as an observable. Moreover, we refrain from using a measure of TFP since it lacks corrections for imperfect competition and potential mark-up variation as well as factor reallocation that are only available with annual data. Thus, movements in quarterly TFP series may potentially reflect non-technology factors and therefore provide a noisy measure of the true underlying technological process. This is problematic since the DSGE estimation forces the model-implied TFP to exactly replicate the noisy measure of

TFP.[26] Recently, and in line with our rationale, Sims (2016) finds significant differences in the various vintages of utilization-adjusted TFP stemming from differences in the estimates of utilization over time, a source of measurement error.

6.3 A quantitative evaluation

To evaluate the quantitative differences between the VAR and DSGE methods, we compare the forecast error variance decompositions (FEVD) for the totality of TFP news shock obtained from the VAR and DSGE models at business cycle frequencies (6-32 quarters). Table 4 shows the FEVD of the common variables in the VAR model (top panel), the DSGE models with financial frictions (center panel), and the DSGE model without financial frictions (bottom panel). Entries report the total variance accounted for by the aggregate TFP news shocks identified from the VAR model and the sum of the variance accounted for by the six TFP news shocks in the DSGE model. Table 4 shows that for most of the variables, the FEVDs in the DSGE model with financial frictions are closer to their counterparts in the VAR model. The model that abstracts from financial frictions predicts instead a considerably smaller role that news shocks play in explaining movements in macroeconomic variables. An obvious shortcoming of the model without financial frictions, relative to the baseline model, is its inability to account for the variance in the bond spread. In general, the median shares of the FEVD accounted for by TFP news shocks in the DSGE model with financial frictions are close and fall within the posterior bands of the median shares predicted by the VAR model. One exception is the RPI. In the DSGE model, TFP news shocks explain approximately 11% of the long-run variance in RPI compared to 60% of the variance in RPI in the VAR model. While useful as an informal test of the model's ability to close the gap with VAR-based estimates, the comparison is meant to be suggestive and qualitative. The DSGE model uses different data moments and identifies many more shocks compared to the VAR. For example, the variance of the TFP news shocks estimated by the

[26] By contrast, the VAR-based identification implies that the TFP news shock is not the only source of uncertainty that explains the variance in TFP in short-run horizons.

Table 4: Share of variance explained by TFP news shocks

	Horizon (quarters)				
	6	12	20	24	32
VAR (medians, 16% and 84% confidence bands in brackets.)					
Output	29	33	40	43	50
	[5 62]	[6 70]	[10 75]	[12 77]	[17 79]
Consumption	21	29	38	44	51
	[3 63]	[4 71]	[8 76]	[11 77]	[15 80]
Investment*	31	36	46	51	57
	[4 67]	[5 73]	[10 78]	[13 80]	[20 81]
Total Hours	29	30	32	33	35
	[5 65]	[5 70]	[7 67]	[9 66]	[11 66]
S&P 500	42	50	51	52	55
	[11 66]	[16 71]	[20 74]	[22 75]	[24 76]
Rel. Price of Investment	39	42	51	55	60
	[7 73]	[8 78]	[17 84]	[22 86]	[31 88]
C-Sector Inflation*	19	19	20	20	21
	[9 32]	[10 30]	[11 31]	[11 32]	[12 33]
Spread*	16	19	20	21	22
	[5 42]	[7 40]	[8 41]	[8 42]	[9 44]
DSGE model with financial frictions (medians)					
Output	31	29	29	28	26
Consumption	14	4	19	28	39
Investment	33	26	32	32	29
Total Hours	26	25	39	42	42
C-Sector Price of Capital	49	49	56	54	45
I-Sector Price of Capital	49	46	50	50	42
Average Price of Capital	49	48	53	52	44
Rel. Price of Investment	26	21	10	10	11
C-Sector Inflation	8	22	51	57	62
C-Sector Spread	17	24	44	47	48
I-Sector Spread	12	21	42	44	45
Average Spread	14	23	43	46	47
DSGE model without financial frictions (medians)					
Output	6	6	6	8	12
Consumption	17	16	6	5	7
Investment	3	4	10	12	16
Total Hours	5	7	12	14	16
C-Sector Price of Capital	7	11	18	18	17
I-Sector Price of Capital	13	13	28	30	30
Average Price of Capital	10	12	23	24	24
Rel. Price of Investment	14	10	5	6	8
C-Sector Inflation	0	0	0	0	0

Sample is 1990Q1-2013Q4. The decomposition results for the VAR are from a VAR with aggregate TFP as described in specification IIII. *The investment decomposition results are from the same specification but where we replace consumption with investment. The spread and inflation decomposition are from VAR specification I.

model is a fraction of the variance estimated by the VAR news shock, putting the model at a disadvantage relative to the VAR in this comparison. This comparison is nevertheless informative on whether in principle the propagation and empirical relevance of news shocks is quantitatively similar across the two methods.

7 New insights from sectoral TFP news shocks

In this section, we provide new evidence on the role of sector-specific TFP news shocks, discussing similarities and differences between VAR and DSGE methods. The sectoral analysis is helpful in that it provides new insights on the propagation mechanism of news shocks. Our focus on aggregate TFP news in the previous sections was motivated by the fact that the bulk of empirical VAR studies employ an aggregate TFP measure to identify news shocks. However, recent evidence in Basu et al. (2013) shows that an aggregate TFP measure masks important differences in the macroeconomic effects of sectoral technologies. To further investigate the issue, it is helpful to consider the equation that links investment- and consumption-specific TFP measures with the aggregate TFP measure. As described in Fernald (2014), the equation is

$$dTFP_{agg,t} = w_{i,t} dTFP_{i,t} + (1 - w_{i,t}) dTFP_{c,t}, \tag{15}$$

where the variables $dTFP_{agg}$, $dTFP_i$, and $dTFP_c$ denote (utilization-adjusted) TFP growth rates in aggregate, investment- and consumption-specific sectors, respectively, and the coefficient w_i denotes the share of the investment sector, expressed in value added. Equation (15) shows that the aggregate TFP growth rate is an expenditure share-weighted average of sectoral TFP growth rates. The correlation between $dTFP_i$ and $dTFP_c$ is equal to 0.31, pointing to a weak co-movement between the two series and therefore suggesting that changes in aggregate TFP cannot be interpreted as a single homogeneous technological indicator. In our sample, average w_i is equal to 0.24. Therefore, by construction, the growth rate of the consumption-specific TFP holds a larger contribution to the growth rate of aggregate TFP. In addition, the aggregate TFP growth rate co-moves more closely with the growth

rate of consumption-specific TFP (correlation coefficient equal to 0.88) than the growth rate of investment-specific TFP (correlation coefficient equal to 0.72), further suggesting that movements in the growth rate of aggregate TFP are largely influenced by the growth rate in consumption-specific TFP.

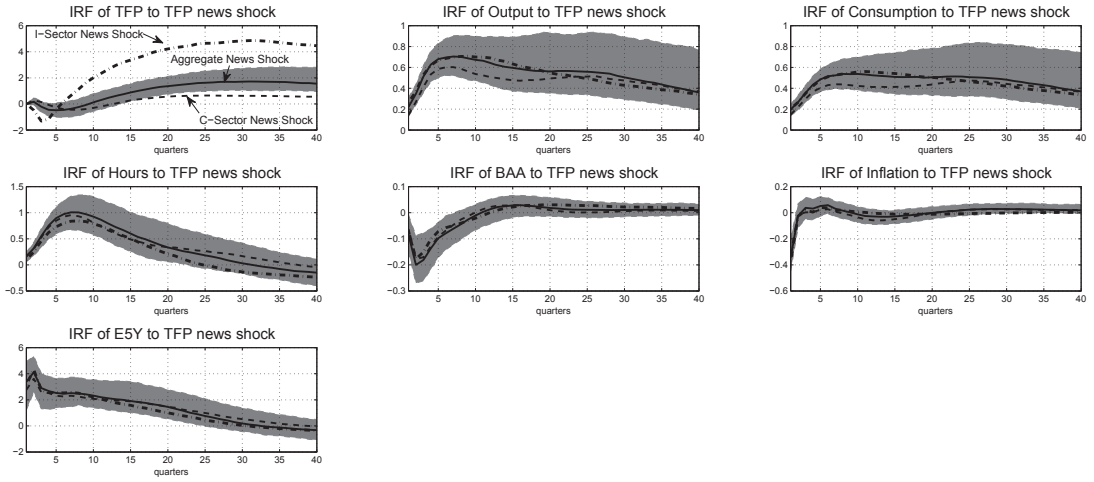


Figure 6: **Aggregate and sector-specific TFP news shocks, specification I.** Sample is 1990Q1-2013Q4. Impulse responses to an aggregate, consumption- and investment-specific TFP news shock from a seven variable VAR (specification I) featuring aggregate/sectoral TFP, output, hours, consumption, corporate bond spread (BAA spread), CPI inflation, and consumer confidence (E5Y) estimated with 3 lags. The shaded gray areas are the 16% and 84% posterior bands generated from the posterior distribution of VAR parameters corresponding to the specification with the aggregate TFP measure. The units of the vertical axes are percentage deviations.

The VAR model isolates interesting patterns in the propagation of sector-specific TFP news shocks, and the DSGE model provides helpful interpretations. We identify the sector-specific TFP news shocks in the VAR model using the identification scheme described in section 4 and series for sectoral (utilization-adjusted) TFP measures by Fernald (2014). Figures 6, 7, and 8 show the IRF to aggregate and sector-specific news shocks estimated across the three specifications of the VAR model described in section 5.[27] Interestingly, the variables' responses to the investment- and consumption-specific news shocks are similar to each other. Figure 16 in the Appendix documents and confirms the strong correlation of

[27]The Appendix reports separate Figures (14 and 15) that display the posterior confidence bands for each sectoral news shock reported in the Figures below.

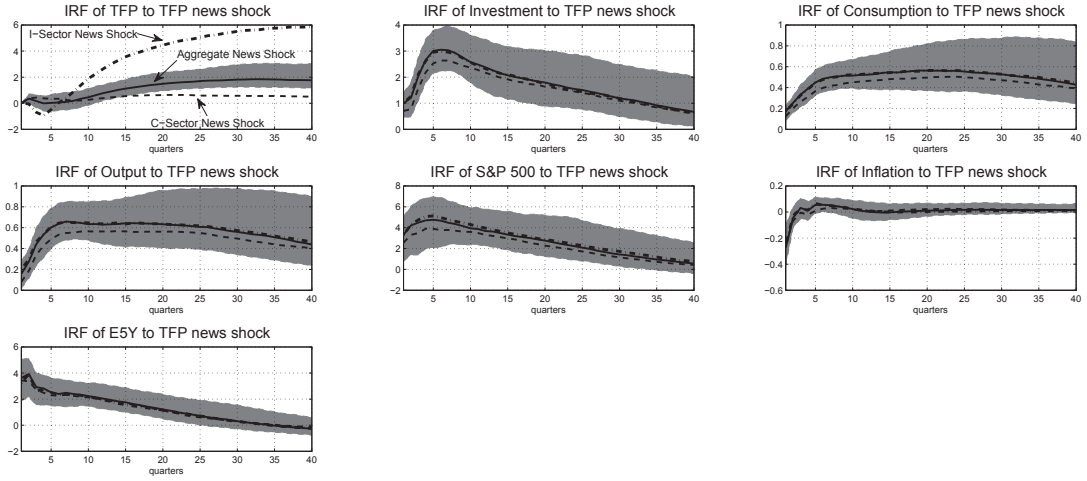


Figure 7: **Aggregate and sector-specific TFP news shocks, specification II.** Sample is 1990Q1-2013Q4. Impulse responses to an aggregate, consumption- and investment-specific TFP news shock from a seven variable VAR (specification II) featuring aggregate/sectoral TFP, investment, hours, consumption, S&P 500, CPI inflation, and consumer confidence (E5Y) estimated with 3 lags. The shaded gray areas are the 16% and 84% posterior bands generated from the posterior distribution of VAR parameters corresponding to the specification with the aggregate TFP measure. The units of the vertical axes are percentage deviations.

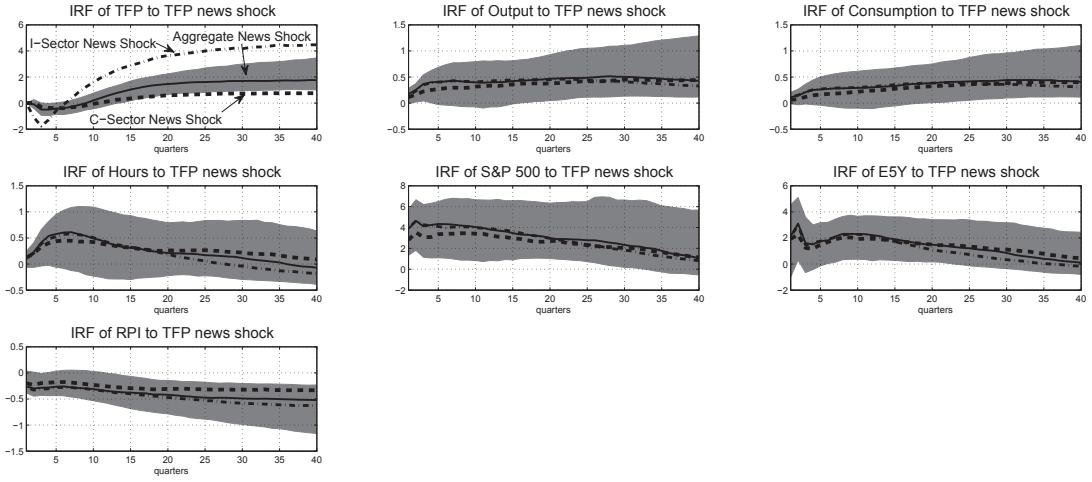


Figure 8: **Aggregate and sector-specific TFP news shocks, specification III.** Sample is 1990Q1-2013Q4. Impulse responses to an aggregate, consumption- and investment-specific TFP news shock from a seven variable VAR featuring aggregate/sectoral TFP, output, hours, consumption, S&P 500, consumer confidence (E5Y), and relative price of investment (RPI) estimated with 3 lags. The shaded gray areas are the 16% and 84% confidence bands generated from the posterior distribution of VAR parameters corresponding to the specification with the aggregate TFP measure. The units of the vertical axes are percentage deviations.

sector-specific news shocks, which is in all cases greater than 0.96.[28] The IRF to either of the sectoral TFP news shocks suggest a broad-based expansion in economic activity, with a slow buildup of sectoral TFP, a rise in the stock market and consumer confidence, and a decline in the RPI. Moreover, the responses to the sectoral TFP news shocks are within the confidence bands of the IRF to the aggregate news shock (except for the series of sectoral TFP). Note also that the decline in the BAA corporate bond spread is a robust stylized fact that continues to hold across sectoral news shocks.

Three additional robust findings across the VAR specifications are worth discussing. First, the long-run response of the investment-specific TFP measure is larger compared to the long-run responses of either aggregate or consumption-specific TFP measures. This pattern can be explained by the fact that (utilization-adjusted) TFP growth in the investment sector is significantly higher on average compared to the corresponding measure in the consumption sector and, by virtue of equation (15), the aggregate measure. Second, in the short run, the expansion of investment-specific TFP is faster and larger in magnitude than the expansion of the consumption-specific TFP. For example, in Figure 6, investment-specific TFP rises above zero after four quarters whereas consumption-specific TFP rises above zero after twelve quarters, indicative of a diffusion of TFP growth from the investment to the consumption sector. At the twelve-quarter horizon, investment-specific TFP is already three percentage points higher compared to consumption-specific TFP. Third, the long-run decline in RPI is concomitant with the increase in aggregate and consumption-specific TFP. The response of the RPI either to the consumption-specific or the aggregate news shock is significant after three years (see Figure 8), and this timing roughly coincides with the timing of the statistically significant increase in aggregate and consumption-specific TFP. The long run co-movement between the RPI and consumption-specific and aggregate TFP is consis-

[28]Interestingly, the correlation between the surprise sectoral TFP shocks ranges between 0.35 to 0.41, which is close to the correlation between sectoral TFP growth rates in the data. The surprise TFP shock is the reduced form innovation from the TFP equation in the VAR, which is orthogonal to the corresponding TFP news shock. The weak correlation between sectoral surprise TFP shocks is consistent with the evidence in Basu et al. (2013) and validates our approach of a two-sector DSGE model with separate sector-specific technologies.

tent with the evidence of co-integration between aggregate TFP and the RPI reported in Schmitt-Grohe and Uribe (2011).[29]

The strong collinearity between sector-specific news shocks strongly indicates we are identifying a common news shock with similar macroeconomic effects. In combination with the three findings described above it suggests the presence of technological spillovers. A spillover may take the form of innovations in new capital equipment produced by the investment sector that are adopted on a large scale basis by the consumption sector. This spillover is consistent with the long-run decline in the RPI, and the increase in TFP in the investment sector, leading to an increase in TFP in the consumption sector. Basu et al. (2003) have documented on detailed industry data that this type of spillover typically characterizes general purpose technologies. These authors establish that innovations in information and communication technologies (ICT) in a set of equipment-producing industries, coincided with a decline in the price of ICT, and were associated with a strong TFP acceleration in industries that used ICT technologies in the 1990s. The majority of the ICT using industries were service-oriented, comprising a large fraction of the consumption sector.

The VAR evidence therefore suggests that consumption-specific news shocks retain a prominent role for the determination of aggregate TFP news shocks. This implication is evident from the similar dynamic patterns between the level of the consumption-specific TFP and the level of aggregate TFP. In addition, consumption-specific news shocks generate responses in a large set of macroeconomic aggregates, asset prices, inflation, survey expectations, and the RPI that are quantitatively similar to those produced by investment-specific news shocks, despite having a significantly lower long-run increase in the level of

[29] The decline in the RPI displayed in Figure 8 is significantly different from zero at all horizons, conditional on the investment-specific TFP news shock. That the RPI can jump immediately to a news shock is consistent with the RPI expression in the model given by

$$\frac{P_{I,t}}{P_{C,t}} = \frac{\text{mark up}_{I,t}}{\text{mark up}_{C,t}} \frac{1-a_c}{1-a_i} \frac{A_t}{V_t} \left(\frac{K_{I,t}}{L_{I,t}}\right)^{-a_i} \left(\frac{K_{C,t}}{L_{C,t}}\right)^{a_c}$$

where a_c and a_i are capital shares in consumption and investment sector, respectively; V_t and A_t, are TFP in the investment and consumption sector, respectively; and $\frac{K_{x,t}}{L_{x,t}}, x = I, C$ is the capital-labor ratio in sector x. mark up$_{x,t}$ is the price mark-up, or inverse of the real marginal cost, in sector x. The equation clearly shows that the relative price of investment responds to a sector-specific TFP news shock that causes a change in the capital labor ratio across sectors.

consumption-specific TFP.[30]

A critical discrepancy between the VAR and DSGE models occur in the propagation of investment-specific TFP news shocks. Figure 9 shows the IRF to an investment-specific TFP news shock identified in the DSGE model with financial frictions. The figure shows

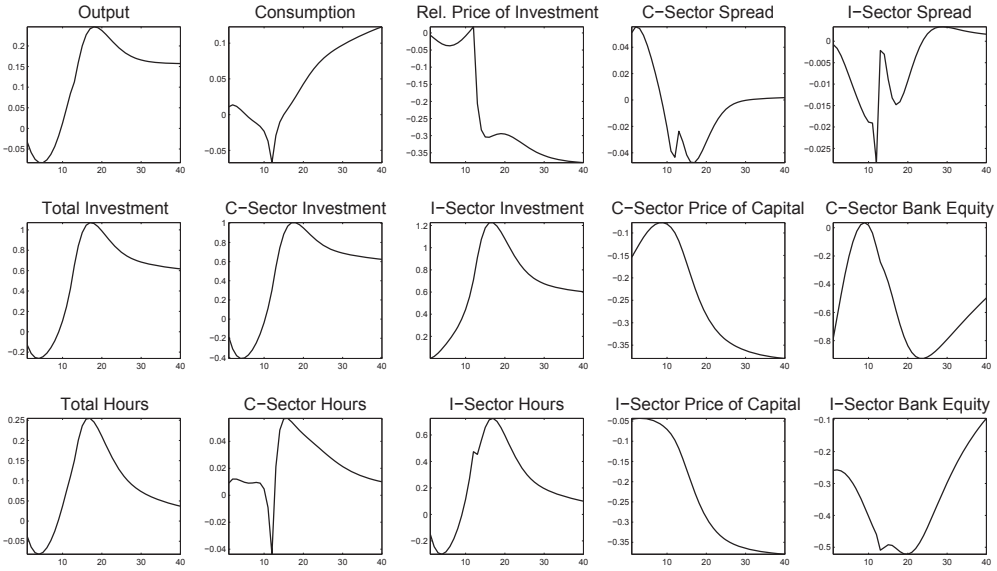


Figure 9: Responses to a one std. deviation TFP news shock (anticipated 12 quarters ahead) in the investment sector from the baseline model. The horizontal axes refer to quarters and the units of the vertical axes are percentage deviations

that the investment-specific news shock fails to generate strong co-movement in the main macroeconomic aggregates, as in the VAR model (compare figures 6 and 9). Importantly, the investment-specific shock generates countercyclical capital prices together with a decline in the relative price of investment. Although the decline in the relative price of investment conforms with the VAR evidence (see Figure 8), the decline in the price of capital contradicts the VAR results.

Why does the DSGE model generate a weak and countercyclical propagation of investment-specific news shocks while having a strong propagation of consumption-specific news shocks? To shed light on this discrepancy, we focus on the relationship between capital prices and the relative price of investment. The key equation in the theoretical model that describes

[30]The FEVD of sectoral news shocks shows that they contribute approximately evenly to the variance of the variables considered in the VAR specifications and hence to macroeconomic fluctuations. An appendix that detail FEVD of sectoral news shocks is available on request by the authors.

the price of installed capital in each sector ($x = C, I$) is

$$\hat{q}_{x,t} = \hat{p}_{i,t} + \kappa e^{2(\frac{1}{1-a_i} g_v)} \Big[\Big(\hat{i}_{x,t} - \hat{i}_{x,t-1} + \frac{1}{1-a_i} \hat{v}_t \Big) - \beta E_t \Big(\hat{i}_{x,t+1} - \hat{i}_{x,t} + \frac{1}{1-a_i} \hat{v}_{t+1} \Big) \Big] \quad (16)$$

where the variables $\hat{q}_{x,t}$, $\hat{i}_{x,t}$, $\hat{p}_{i,t}$ and $\hat{v}_t$, denote the price of installed capital, investment spending, relative price of investment, and investment-specific growth processes, respectively, expressed in log deviations from the steady state. Equation (16) shows that the price of capital ($\hat{q}_{x,t}$) depends on the relative price of investment ($\hat{p}_{i,t}$) and on movements in investment adjustment costs (the second term on the right-hand side of the equation). In the absence of adjustment costs (i.e. $\kappa = 0$), a one-to-one relationship exists between the relative price of investment and the price of capital (i.e. $\hat{q}_{x,t} = \hat{p}_{i,t}$). Thus, shocks that shift the demand for investment goods, such as the consumption-specific TFP news shock, imply a procyclical relative price of investment and price of capital. While the mechanism holds independently of financial frictions, those imply that the procyclicality in the price of capital amplifies the boom through the relaxation of the intermediaries' leverage constraint, as explained in section 6.1. By contrast, shocks that shift the supply of capital, such as investment-specific TFP news, imply a countercyclical relative price of investment and price of capital. This mechanism is evident from the responses of the DSGE model in Figure 9, and the presence of investment adjustment costs does not reverse it.[31] Intuitively, good news about future productivity in investment goods depresses the incentives for agents to increase current investment spending since installed capital today is less productive than the capital at a future time when the higher productivity materializes. The current price of capital falls in order to facilitate the postponement of investment spending in the future, in line with the dynamic responses in Figure 9. Overall, the analysis shows that the propagation of news shocks in the DSGE model is different, depending on whether sectoral news shocks shift the demand or supply of capital goods.

Before concluding, we note a few interesting considerations related to the potential diffusion of sectoral news shocks. Our DSGE model is silent on how improvements in sectoral

[31] To ensure results are robust to the degree of investment adjustment costs, we have simulated the model with the parameter κ as high as 30 and established that the model cannot generate procyclical capital prices in response to the investment-specific news at any horizon.

TFP materialize since it assumes exogenous productivity processes that are orthogonal to each other, a standard assumption in estimated structural models.[32] In a recent study, Comin et al. (2009) propose a model of endogenous costly adoption of embodied (and disembodied) technological innovations that capture the dynamics of technological diffusions. These authors find that an innovation shock that signals an expansion in the availability of new technologies and forecasts future TFP is able to explain approximately a third of the cyclical fluctuations in output, broadly consistent with the findings in our DSGE model. Importantly, they show that the endogenous procyclical adoption of innovations creates procyclical growth options (i.e. claims to future profits that result from the adoption of new innovations) that are absent in standard DSGE models with exogenous productivity, including ours. Even if the price of installed capital falls together with RPI, the procyclical growth option can rationalize a procyclical stock market, and therefore it is a promising channel to resolve the divergent results between the VAR and DSGE models.[33]

8 Conclusion

This paper examined the empirical significance and dynamic effects of aggregate and sectoral TFP news shocks in the context of financial frictions using complementary VAR and DSGE methods. The VAR model identifies a novel and robust stylized fact that shows a significant decline of the corporate bond spread, along with a broad-based expansion in activity, in anticipation of a future improvement in TFP. A DSGE model with financial frictions of the Gertler-Kyotaki type generates similar dynamic responses and detects a comparable quantitative importance of TFP news shocks to the VAR model. The consistent assessment of news shocks across methods provides support for the 'news view' of business cycles. The analysis shows that the critical mechanism for the amplification of news shocks relies on the strong linkages between leveraged equity and capital prices. The VAR model shows that

[32] See Fernandez-Villaverde et al. (2016) for a recent discussion on the issue.

[33] Chen and Wemy (2015) provide evidence that suggests the direction of spillovers is from the investment to the consumption sector.

consumption-specific TFP news shocks play a prominent role for the evolution of aggregate news shocks, and it also finds strong collinearities between sectoral and aggregate news shocks that DSGE methods are unable to detect due to the standard orthogonality condition in the exogenous disturbances. The analysis detects disagreement between methods on the role of investment-specific TFP news shocks and points to some possible solutions.

Our findings indicate two interesting extensions for future research. First, the analysis in section 7 suggests that news shocks may involve significant spillover across sectors. It would certainly be an interesting extension to enrich the theoretical model with a mechanism for technological diffusion and spillovers across sectors. With this extension, the analysis will be able to isolate the mechanisms through which expected innovations in one sector diffuse and enhance the expected productive efficiency of other sectors and the overall economy. Second, while we embed financial frictions from the credit supply side, emphasizing constraints in financial intermediaries, it would be interesting to investigate to what extent results hold for alternative ways of modelling financial frictions. Our particular transmission mechanism in the model favors the investment demand channel, which features procyclical capital prices. We believe that this key transmission channel based on procyclical movements in capital prices linked to good news about TFP prospects will continue to remain prominent in other settings as it is an essential mechanism of many models with financial frictions (see Brunnermeier et al. (2012)). However, the extent to which this channel is strengthened or weakened remains an open question for future research.

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Appendix with supplementary material (Not for publication)

A Supporting details and results

A.1 Results from a larger VAR system

We report results of a larger VAR specification that includes key observables used for the estimation of the DSGE model, namely both corporate bond spread series and bank equity. Figure 10 displays the IRFs from this specification. It is interesting to note the IRFs are qualitatively similar to the IRFs from the DSGE model displayed in Figure 4. In response to a positive TFP news shock, there is a delayed broad-based increase in activity and a decline in both sectoral corporate bond spreads. It is also interesting to note the significant increase in the bank equity in response to the positive news shock, supportive of the transmission mechanism that operates in the DSGE model.

A.2 Robustness to VAR methodology

We compare IRFs from the VAR specifications using three different methods for identifying TFP news shocks. In particular, we contrast the long-run restriction (as suggested in Forni et al. (2014)) adopted in the main body of the paper, with the Max Share method as proposed in Francis et al. (2014) and the identification scheme in Barsky and Sims (2011). While the news shock in the former method has maximal impact on TFP in the long run (at the 40 quarters horizon), the Max Share method seeks to maximize the forecast error variance of TFP in a pre-specified horizon (which we set equal to 40 quarters) and the Barsky and Sims (2011) scheme recovers the news shock by maximizing the variance of TFP over the horizons zero to forty quarters. Figures 11, 12 and 13 show the responses of the different methods for VAR specifications I-III. They suggest that the identified news shocks from the three methods are virtually identical.

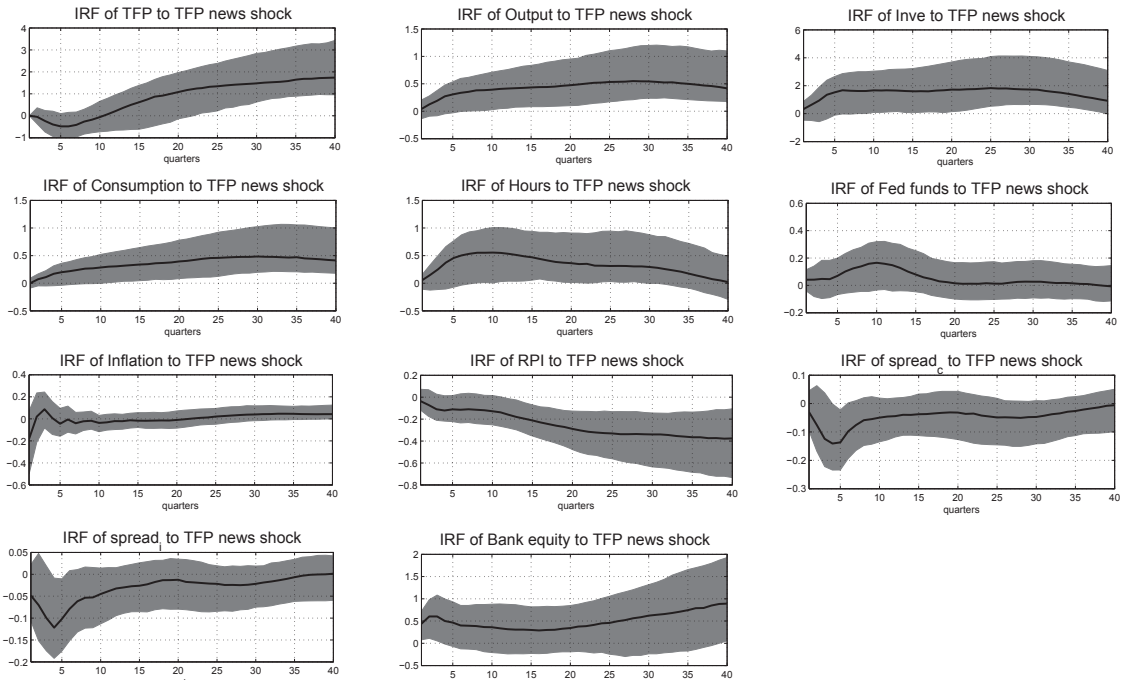


Figure 10: **Aggregate TFP news shocks.** The lines display impulse responses to an aggregate TFP news shock from a eleven variable VAR featuring TFP, consumption sector corporate bond spread, investment sector corporate bond spread, consumption, investment, output, hours, inflation, Fed funds rate, RPI and bank equity estimated with 3 lags. The shaded gray areas are the 16% and 84% posterior bands generated from the posterior distribution of VAR parameters. The horizontal axes refer to forecast horizons (quarters) and the units of the vertical axes are percentage deviations. Sample is 1990Q1-2013Q4.

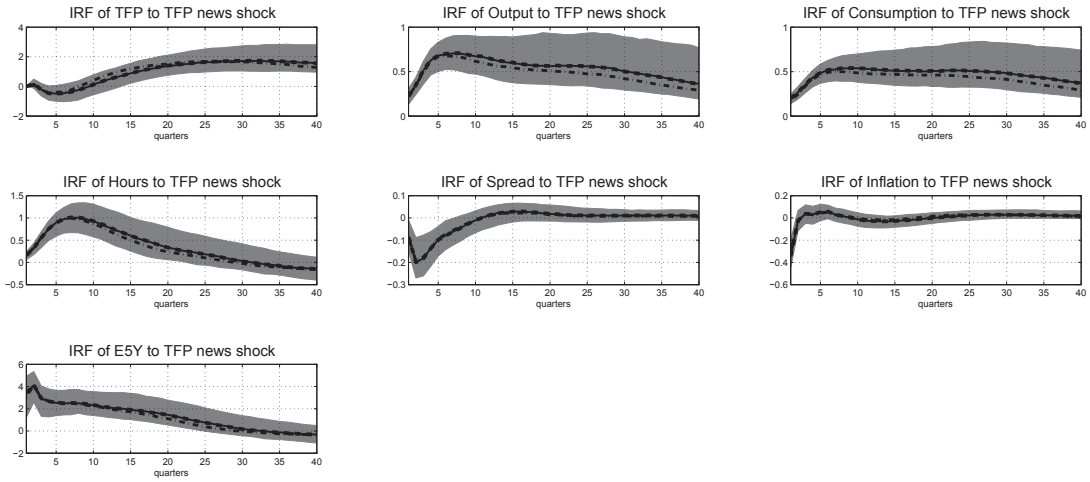


Figure 11: **Aggregate TFP news shocks. VAR Specification I.** The lines display impulse responses to an aggregate TFP news shock from a seven variable VAR featuring TFP, corporate bond spread (BAA spread), consumption, output, hours, CPI inflation, and consumer confidence (E5Y) estimated with 3 lags. The solid line is the long-run restriction method as in Forni et al. (2014), the dashed line is the Max Share news identification and the dash-dotted line is the Barsky and Sims (2011) news identification. The shaded gray areas are the 16% and 84% posterior bands generated from the posterior distribution of VAR parameters. The horizontal axes refer to forecast horizons (quarters) and the units of the vertical axes are percentage deviations. Sample is 1990Q1-2013Q4.

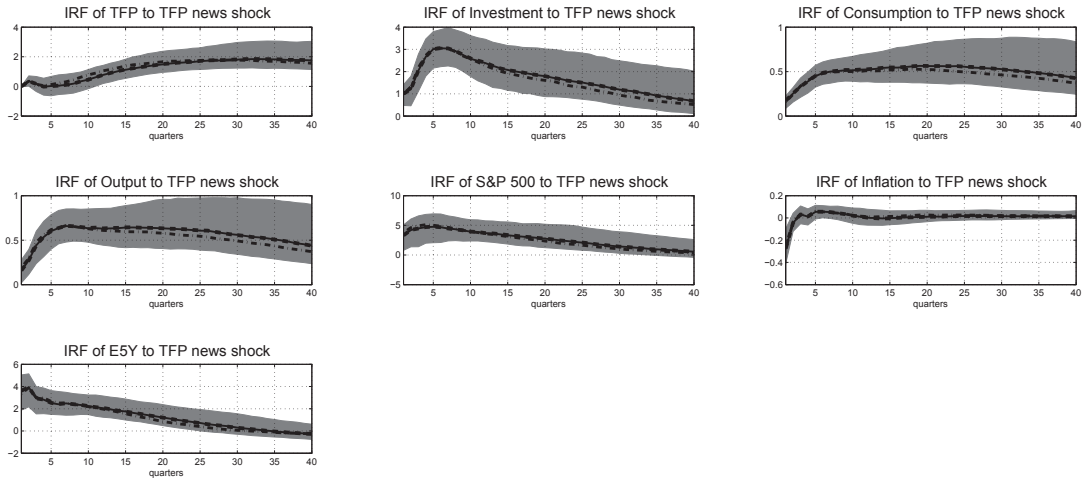


Figure 12: **Aggregate TFP news shocks. VAR specification II.** The lines display impulse responses to an aggregate TFP news shock from a seven variable VAR featuring TFP, S&P 500, consumption, investment, hours, CPI inflation, and consumer confidence (E5Y) estimated with 3 lags. The solid line is the long-run restriction method as in Forni et al. (2014), the dashed line is the Max Share news identification and the dash-dotted line is the Barsky and Sims (2011) news identification. The shaded gray areas are the 16% and 84% posterior bands generated from the posterior distribution of VAR parameters. The horizontal axes refer to forecast horizons (quarters) and the units of the vertical axes are percentage deviations. Sample is 1990Q1-2013Q4.

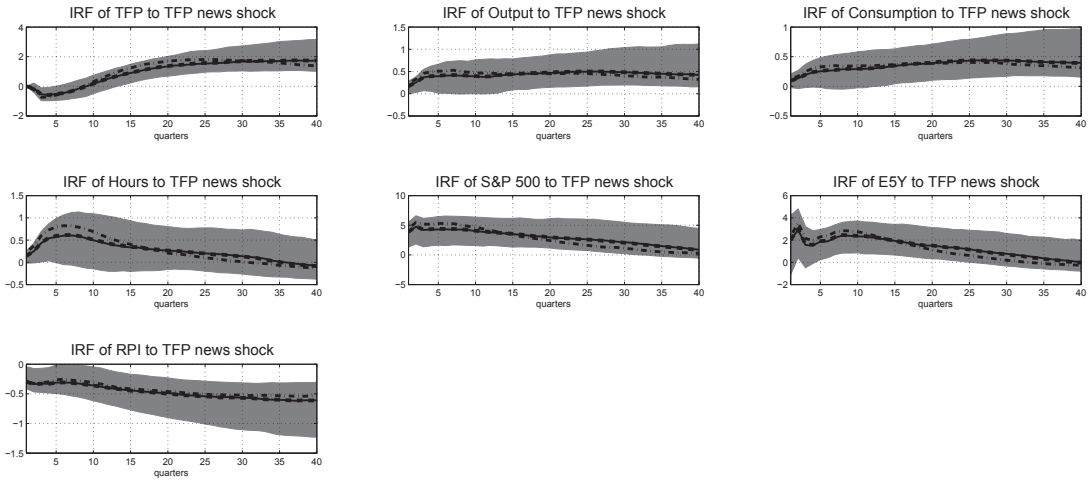


Figure 13: **Aggregate TFP news shocks. VAR specification III.** The lines display impulse responses to an aggregate, consumption specific (CS), investment specific (IS) TFP news shock from a seven variable VAR featuring TFP, S&P 500, consumption, output, hours, relative price of investment (RPI), and consumer confidence (E5Y) estimated with 3 lags. The solid line is the long-run restriction method as in Forni et al. (2014), the dashed line is the Max Share news identification and the dash-dotted line is the Barsky and Sims (2011) news identification. The shaded gray areas are the 16% and 84% confidence bands generated from the posterior distribution of VAR parameters corresponding to the specification with the aggregate TFP measure. The horizontal axes refer to forecast horizons (quarters) and the units of the vertical axes are percentage deviations. Sample is 1990Q1-2013Q4.

A.3 Specification for the Minnesota prior in the VAR

The prior for the VAR coefficients A is of the form

$$vec\,(A) \sim N\left(\underline{\beta}, \underline{V}\right),$$

where $\underline{\beta}$ is one for variables which are in log-levels, and zero for the corporate bond spread as well as inflation. The prior variance $\underline{V}$ is diagonal with elements,

$$\underline{V}_{i,jj} = \begin{cases} \frac{\underline{a}_1}{p^2} \text{ for coefficients on own lags} \\ \frac{\underline{a}_2 \sigma_{ii}}{p^2 \sigma_{jj}} \text{ for coefficients on lags of variable } j \neq i \\ \underline{a}_3 \sigma_{ii} \text{ for intercepts} \end{cases} . \tag{A.1}$$

where, p denotes the number of lags. Here σ_{ii} is the residual variance from the unrestricted p-lag univariate autoregression for variable i. The degree of shrinkage depends on the hyperparameters $\underline{a}_1, \underline{a}_2, \underline{a}_3$. We set $\underline{a}_3 = 100$ and we select $\underline{a}_1, \underline{a}_2$ by searching on a grid and selecting the prior that maximizes the in-sample fit of the VAR, as measured by the Bayesian Information Criterion.[34]

A.4 Calibration and estimation

Calibration. Table 5 describes the calibrated parameters referred to in section 4. We set the quarterly depreciation rate to be equal across sectors, $\delta_C = \delta_I = 0.025$. From the steady state restriction $\beta = \pi_C / R$, we set $\beta = 0.9974$. The shares of capital in the production functions, a_C and a_I, are assumed equal across sectors and fixed at 0.3. The steady state values for the ratios of nominal investment to consumption and government spending to output are calibrated to be consistent with the average values in the data.

The steady state sectoral inflation rates are set to the sample averages and the sectoral steady state mark-ups are assumed to be equal to 15%. We also calibrate the steady state (deterministic) growth of TFP in the consumption/investment sectors in line with the sample

[34] The grid of values we use is:
$\underline{a}_1$ = (1e-5,2e-5,3e-5,4e-5,5e-5,6e-5,7e-5,8e-5,9e-5, 1e-4,2e-4,3e-4,4e-4,5e-4,6e-4,7e-4,8e-4,9e-4, 0.001,0.002,0.003,0.004,0.005,0.006,0.007,0.008,0.009, 0.01,0.02,0.03,0.04,0.05,0.06,0.07,0.08,0.09, 0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9, 1,2,3,4,5,6,7,8,9,10),
$\underline{a}_2$ = (0.01,0.02,0.03,0.04,0.05,0.06,0.07,0.08,0.09, 0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1,2,3,4,5,6,7,8,910).
We take all possible pairs of $\underline{a}_1$ and $\underline{a}_2$ in the above grids, so we end up estimating 1540 models.

Table 5: Calibrated Parameters

Parameter	Value	Description
δ_C	0.025	Consumption sector capital depreciation
δ_I	0.025	Investment sector capital depreciation
a_c	0.3	Consumption sector share of capital
a_I	0.3	Investment sector share of capital
β	0.9974	Discount factor
$\pi_C - 1$	0.642	Steady state consumption sector net inflation rate (percent quarterly)
$\pi_I - 1$	0.080	Steady state investment sector net inflation rate (percent quarterly)
λ_p	0.15	Steady state price markup
λ_w	0.15	Steady state wage markup
g_a	0.097	Steady state C-sector TFP growth (percent quarterly)
g_v	0.490	Steady state I-sector TFP growth (percent quarterly)
$p_i \frac{i}{c}$	0.426	Steady state investment / consumption
$\frac{G}{Y}$	0.18	Steady state government spending / output
θ_B	0.96	Fraction of bankers that survive
ϖ	0.0021	Share of assets transferred to new bankers
λ_B	0.69	Fraction of funds bankers can divert
ϱ	5.47	Steady state leverage ratio
$R^B - R$	0.5	Steady state spread (percent quarterly)

Notes. β, π_C, π_I, g_a, g_v, $p_i \frac{i}{c}$, ϱ, $R^B - R$ are based on sample averages. ϖ and λ_B are set to be consistent with the average values of the leverage ratio, ϱ, and $R^B - R$.

average growth rates of output in the two sectors. This yields $g_a = 0.097\%$ and $g_v = 0.490\%$ per quarter. There are three parameters specific to financial intermediation. The parameter θ_B, which determines the banker's average life span does not have a direct empirical counterpart and is fixed at 0.96, similar to the value used by Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). This value implies an average survival time of bankers of slightly over six years. The parameters ϖ and λ_B are fixed at values which guarantee that the steady state risk premium (the average of spreads across the two sectors) and the steady state leverage ratio matches their empirical counterparts. The average of the consumption sector and investment sector credit spreads are each equal to 50 basis points in the sample. The average leverage ratio in the data is computed from the ratio of assets (excluding loans to consumers, real estate and holdings of government bonds) to equity for all U.S. insured commercial banks and is equal to 5.47.

A.5 The collinearity of sector-specific news shocks

Figures 14 and 15 display the IRFs from the VAR identified investment- and consumption-specific TFP news shock respectively.

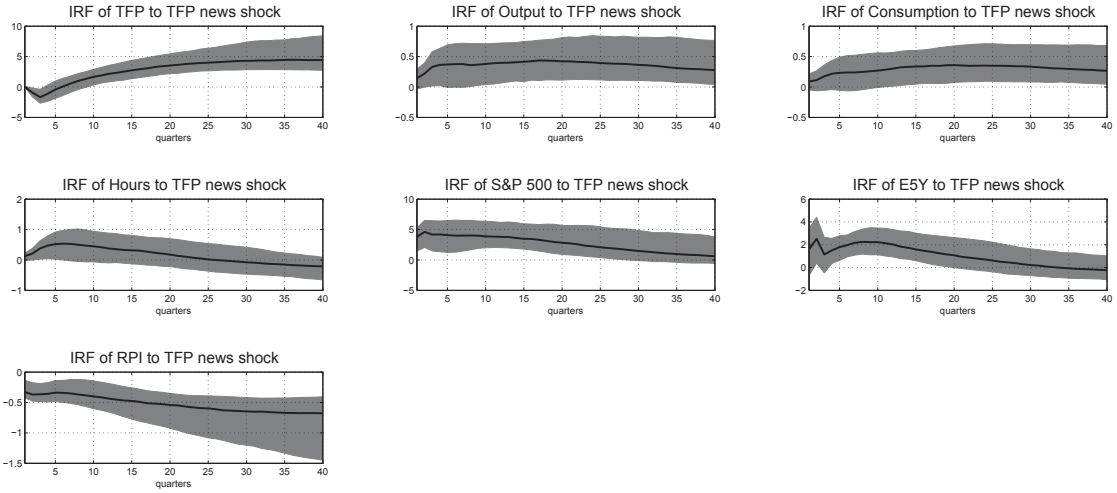


Figure 14: **Investment-specific TFP news shocks. VAR specification III.** The lines display impulse responses to an investment-specific TFP news shock from a seven variable VAR featuring TFP, S&P 500, consumption, output, hours, relative price of investment (RPI), and consumer confidence (E5Y) estimated with 3 lags. The shaded gray areas are the 16% and 84% confidence bands generated from the posterior distribution of VAR parameters corresponding to the specification with the aggregate TFP measure. The horizontal axes refer to forecast horizons (quarters) and the units of the vertical axes are percentage deviations. Sample is 1990Q1-2013Q4.

Figure 16 provides a visual confirmation of the strong collinearity of sector-specific news shocks. It displays scatter plots of sector-specific news shocks (top panels) for the different specifications of the VAR model together with scatter plots of sectoral surprise shocks (bottom panels) that are the reduced form innovations to sectoral TFP measures in the VAR model, and are orthogonal to the identified TFP news shocks. The top panels show a strong correlation between sector-specific news shocks across the different specifications of the VAR model, ranging between 0.96 and 0.98.[35] By contrast, the bottom panels point to a weak correlation between sector-specific surprise TFP shocks across the different specifications of the VAR model, consistent with the weak correlation between the two sectoral TFP growth

[35]The correlation between the sectoral and aggregate news shocks is also strong, rangeing between 0.97 and 0.99.

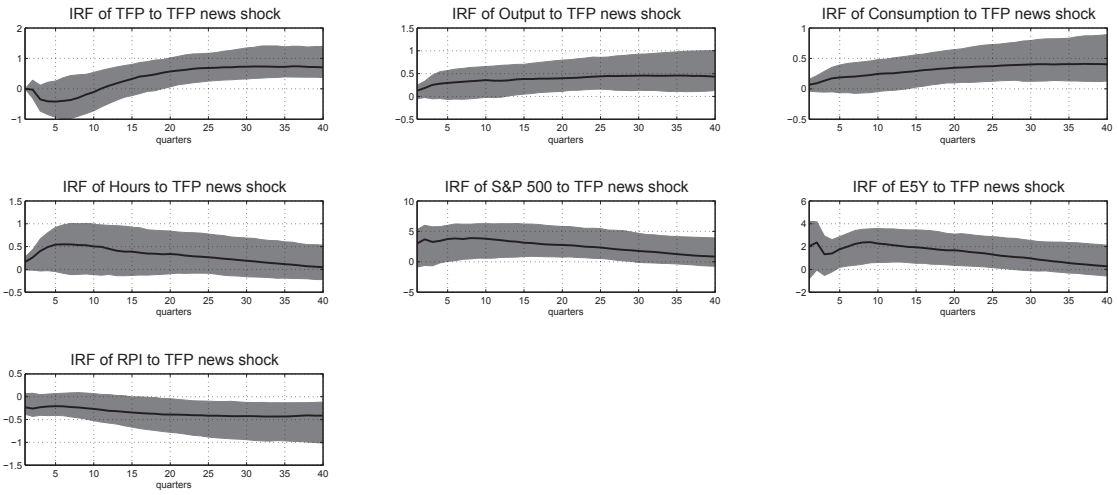


Figure 15: **Consumption-specific TFP news shocks. VAR specification III.** The lines display impulse responses to a consumption-specific TFP news shock from a seven variable VAR featuring TFP, S&P 500, consumption, output, hours, relative price of investment (RPI), and consumer confidence (E5Y) estimated with 3 lags. The shaded gray areas are the 16% and 84% confidence bands generated from the posterior distribution of VAR parameters corresponding to the specification with the aggregate TFP measure. The horizontal axes refer to forecast horizons (quarters) and the units of the vertical axes are percentage deviations. Sample is 1990Q1-2013Q4.

rates.[36]

[36] We also tested for Granger causality to investigate whether there is evidence for a direction of causation between sector-specific TFP news shocks. We cannot reject the null of no Granger causality for all the different pairs of sectoral TFP news shocks identified from the VAR model.

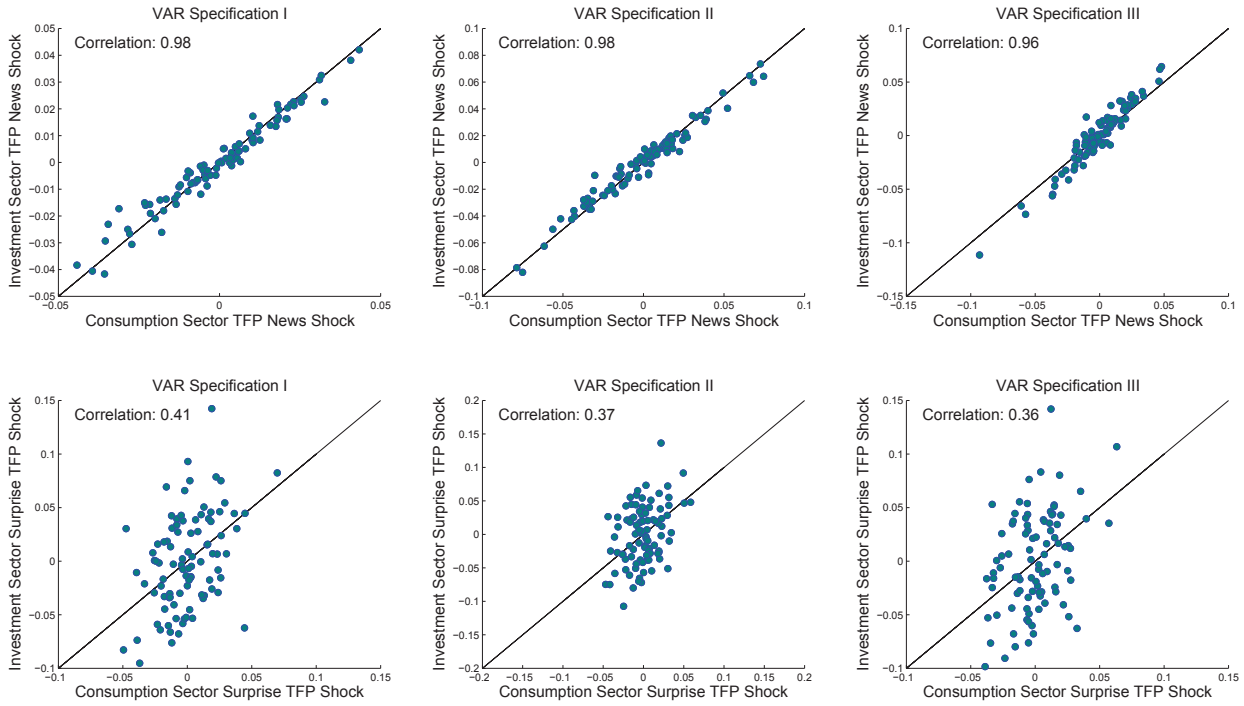


Figure 16: Scatter plots of the sectoral TFP news shocks from the VAR model (top panels) and sectoral TFP surprise shocks (bottom panels), specifications I to III.

B Data Sources and Time Series Construction

Table 6 provides an overview of the data used to construct the observables. All the data transformations we have made in order to construct the dataset used for the estimation of the model are described in detail below. As described in the main body, a subset of variables are used for estimating the various VAR specifications and they enter in levels. The data series for aggregate and consumption-specific TFP used to estimate the VARs are taken from John Fernald's website ($www.frbsf.org/economic-research/economists/jfernald/quarterly_tfp.xls$), and are described in Fernald (2014).

Sectoral definition. To allocate a sector to the consumption or investment category, we used the 2005 Input-Output tables. The Input-Output tables track the flows of goods and services across industries and record the final use of each industry's output into three broad categories: consumption, investment and intermediate uses (as well as net exports and government). First, we determine how much of a 2-digit industry's final output goes to consumption as opposed to investment or intermediate uses.

Then we adopt the following criterion: if the majority of an industry's final output is allocated to final consumption demand it is classified as a consumption sector; otherwise, if the majority of an industry's output is allocated to investment or intermediate demand, it is classified as an investment sector. Using this criterion, mining, utilities, transportation and warehousing, information, manufacturing, construction and wholesale trade industries are classified as the investment sector and retail trade, real estate, rental and leasing, professional and business services, educational services, health care and social assistance, arts, entertainment, recreation, accommodation and food services and other services except government are classified as the consumption sector.[37]

Real and nominal variables. Consumption (in current prices) is defined as the sum

[37]The investment sectors' NAICS codes are: 21 22 23 31 32 33 42 48 49 51 (except 491). The consumption sector NAICS codes are: 6 7 11 44 45 53 54 55 56 81. This information is provided by the Bureau of Economic analysis (Use Tables/Before Redefinitions/Producer Value ($http://www.bea.gov/industry/io_annual.htm$)). We have checked whether there is any migration of 2-digit industries across sectors for our sample. The only industry which changes classification (from consumption to investment) during the sample is "information" which for the majority of the sample can be classified as investment and we classify it as such.

Table 6: Time Series used to construct the observables and steady state relationships

Time Series Description	Units	Code	Source
Gross domestic product	CP, SA, billion $	GDP	BEA
Gross Private Domestic Investment	CP, SA, billion $	GPDI	BEA
Real Gross Private Domestic Investment	CVM, SA, billion $	GPDIC1	BEA
Personal Consumption Exp.: Durable Goods	CP, SA, billion $	PCDG	BEA
Real Personal Consumption Exp.: Durable Goods	CVM, SA, billion $	PCDGCC96	BEA
Personal Consumption Expenditures: Services	CP, SA, billion $	PCESV	BEA
Real Personal Consumption Expenditures: Services	CVM, SA, billion $	PCESVC96	BEA
Personal Consumption Exp.: Nondurable Goods	CP, SA, billion $	PCND	BEA
Real Personal Consumption Exp.: Nondurable Goods	CVM, SA, billion $	PCNDGC96	BEA
Civilian Noninstitutional Population	NSA, 1000s	CNP160V	BLS
Nonfarm Business Sector: Compensation Per Hour	SA, Index 2005=100	COMPNFB	BLS
Nonfarm Business Sector: Hours of All Persons	SA, Index 2005=100	HOANBS	BLS
Effective Federal Funds Rate	NSA, percent	FEDFUNDS	BG
Total Equity	NSA	EQTA	IEC
Total Assets	NSA	H.8	FRB
All Employees	SA	B-1	BLS
Average Weekly Hours	SA	B-7	BLS

CP = current prices, CVM = chained volume measures (2005 Dollars), SA = seasonally adjusted, NSA = not seasonally adjusted. BEA = U.S. Department of Commerce: Bureau of Economic Analysis, BLS = U.S. Department of Labor: Bureau of Labor Statistics and BG = Board of Governors of the Federal Reserve System, IEC = Federal Financial Institutions Examination Council, FRB = Federal Reserve Board.

of personal consumption expenditures on services and personal consumption expenditures on non-durable goods. The times series for real consumption is constructed as follows. First, we compute the shares of services and non-durable goods in total (current price) consumption. Then, total real consumption growth is obtained as the chained weighted (using the nominal shares above) growth rate of real services and growth rate of real non-durable goods. Using the growth rate of real consumption we construct a series for real consumption using 2005 as the base year. The consumption deflator is calculated as the ratio of nominal over real consumption. Inflation of consumer prices is the growth rate of the consumption deflator. Analogously, we construct a time series for the investment deflator using series for (current price) personal consumption expenditures on durable goods and gross private domestic investment and chain weight to arrive at the real aggregate. The relative price of investment is the ratio of the investment deflator and the consumption deflator. Real output is GDP expressed in consumption units by dividing current price GDP with the consumption deflator.

The hourly wage is defined as total compensation per hour. Dividing this series by the consumption deflator yields the real wage rate. Hours worked is given by hours of all persons in the non-farm business sector. All series described above as well as the equity capital series (described below) are expressed in per capita terms using the series of non-institutional population, ages 16 and over. The nominal interest rate is the effective federal funds rate. We use the monthly average per quarter of this series and divide it by four to account for the quarterly frequency of the model. The time series for hours is in logs. Moreover, all series used in estimation (including the financial time series described below) are expressed in deviations from their sample average.

Financial variables. Data for sectoral credit spreads are not directly available. However, Reuters' Datastream provides U.S. credit spreads for companies which we map into the two sectors using The North American Industry Classification System (NAICS) as explained above. A credit spread is defined as the difference between a company's corporate bond yield and the yield of a U.S. Treasury bond with an identical maturity. In construct-

ing credit spreads we only consider nonfinancial corporations and only bonds traded in the secondary market. In line with Gilchrist and Zakrajsek (2012) we make the following adjustments to the credit spread data we construct: using ratings from Standard & Poor's and Moody's, we exclude all bonds which are below investment grade as well as the bonds for which ratings are unavailable. We further exclude all spreads with a duration below one and above 30 years and exclude all credit spreads below 10 and above 5000 basis points to ensure that the time series are not driven by a small number of extreme observations. The series for the sectoral credit spreads are constructed by taking the average over all company level spreads available in a certain quarter. These two series are transformed from basis points into percent and divided by four to guarantee that they are consistent with the quarterly frequency of our model.

Steady state financial parameters. The steady state leverage ratio of financial intermediaries in the model – which helps to pin down the parameters ϖ and λ_B – is calculated by taking the sample average of the inverse of total equity over adjusted assets of all insured U.S. commercial banks available from the Federal Financial Institutions Examination Council. The same body reports a series of equity over total assets. We multiply this ratio with total assets in order to get total equity for the U.S. banking sector that we use in estimation. Total assets includes consumer loans and holdings of government bonds which we want to exclude from total assets to be consistent with the model concept. Thus, to arrive at an estimate for adjusted assets we subtract consumer, real estate loans and holdings of government and government guaranteed bonds (such as government sponsored institutions) from total assets of all insured U.S. commercial banks.

C Model Details and Derivations

We provide the model details and derivations required for solution and estimation of the model. We begin with the pricing and wage decisions of firms and households, the financial sector followed by the normalization of the model to render it stationary, the description of

the steady state and the log-linearized model equations.

C.1 Intermediate and Final Goods Producers

Intermediate producers pricing decision. A constant fraction $\xi_{p,x}$ of intermediate firms in sector $x = C, I$ cannot choose their price optimally in period t but reset their price — as in Calvo (1983) — according to the indexation rule,

$$P_{C,t}(i) = P_{C,t-1}(i)\pi_{C,t-1}^{\iota_{pC}}\pi_C^{1-\iota_{pC}},$$
$$P_{I,t}(i) = P_{I,t-1}(i)\pi_{I,t-1}^{\iota_{pI}}\pi_I^{1-\iota_{pI}}\left[\left(\frac{A_t}{A_{t-1}}\right)^{-1}\left(\frac{V_t}{V_{t-1}}\right)^{\frac{1-a_c}{1-a_i}}\right]^{\iota_{pI}},$$

where $\pi_{C,t} \equiv \frac{P_{C,t}}{P_{C,t-1}}$ and $\pi_{I,t} \equiv \frac{P_{I,t}}{P_{I,t-1}}\left(\frac{A_t}{A_{t-1}}\right)^{-1}\left(\frac{V_t}{V_{t-1}}\right)^{\frac{1-a_c}{1-a_i}}$ is gross inflation in the two sectors and π_C, π_I denote steady state values. The factor that appears in the investment sector expression adjusts for investment specific progress.

The remaining fraction of firms, $(1-\xi_{p,x})$, in sector $x = C, I$ can adjust the price in period t. These firms choose their price optimally by maximizing the present discounted value of future profits.

The resulting aggregate price index in the consumption sector is,

$$P_{C,t} = \left[(1-\xi_{p,C})\tilde{P}_{C,t}^{\frac{1}{\lambda_{p,t}^C}} + \xi_{p,C}\left(\left(\frac{\pi_{C,t-1}}{\pi}\right)^{\iota_{pC}}\pi_C^{1-\iota_{pC}}P_{C,t-1}\right)^{\frac{1}{\lambda_{p,t}^C}}\right]^{\lambda_{p,t}^C}.$$

The aggregate price index in the investment sector is,

$$P_{I,t} = \left[(1-\xi_{p,I})\tilde{P}_{I,t}^{\frac{1}{\lambda_{p,t}^I}} + \xi_{p,I}\left(P_{I,t-1}\left(\frac{\pi_{I,t-1}}{\pi}\right)^{\iota_{pI}}\pi_I^{1-\iota_{pI}}\left[\left(\frac{A_t}{A_{t-1}}\right)^{-1}\left(\frac{V_t}{V_{t-1}}\right)^{\frac{1-a_c}{1-a_i}}\right]^{\iota_{pI}}\right)^{\frac{1}{\lambda_{p,t}^I}}\right]^{\lambda_{p,t}^I}.$$

Final goods producers. Profit maximization and the zero profit condition for final good firms imply that sectoral prices of the final goods, $P_{C,t}$ and $P_{I,t}$, are CES aggregates of the prices of intermediate goods in the respective sector, $P_{C,t}(i)$ and $P_{I,t}(i)$,

$$P_{C,t} = \left[\int_0^1 P_{C,t}(i)^{\frac{1}{\lambda_{p,t}^C}}di\right]^{\lambda_{p,t}^C}, \qquad P_{I,t} = \left[\int_0^1 P_{I,t}(i)^{\frac{1}{\lambda_{p,t}^I}}di\right]^{\lambda_{p,t}^I}.$$

The elasticity $\lambda_{p,t}^x$ is the time varying price markup over marginal cost for intermediate

firms. It is assumed to follow the exogenous stochastic process,

$$\log(1+\lambda_{p,t}^{x}) = (1-\rho_{\lambda_p^x})\log(1+\lambda_p^x) + \rho_{\lambda_p^x}\log(1+\lambda_{p,t-1}^{x}) + \varepsilon_{p,t}^{x},$$

where $\rho_{\lambda_p^x} \in (0,1)$ and $\varepsilon_{p,t}^{x}$ is *i.i.d.* $N(0,\sigma^2_{\lambda_p^x})$, with $x = C, I$.

C.1.1 Household's wage setting

Each household $j \in [0,1]$ supplies specialized labor, $L_t(j)$, monopolistically as in Erceg et al. (2000). A large number of competitive "employment agencies" aggregate this specialized labor into a homogenous labor input which is sold to intermediate goods producers in a competitive market. Aggregation is done according to the following function,

$$L_t = \left[\int_0^1 L_t(j)^{\frac{1}{1+\lambda_{w,t}}} dj\right]^{1+\lambda_{w,t}}.$$

The desired markup of wages over the household's marginal rate of substitution (or wage mark-up), $\lambda_{w,t}$, follows the exogenous stochastic process,

$$\log(1+\lambda_{w,t}) = (1-\rho_w)\log(1+\lambda_w) + \rho_w \log(1+\lambda_{w,t-1}) + \varepsilon_{w,t},$$

where $\rho_w \in (0,1)$ and $\varepsilon_{w,t}$ is *i.i.d.* $N(0,\sigma^2_{\lambda_w})$.

Profit maximization by the perfectly competitive employment agencies implies the labor demand function,

$$L_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} L_t, \tag{C.1}$$

where $W_t(j)$ is the wage received from employment agencies by the supplier of labor of type j, while the wage paid by intermediate firms for the homogenous labor input is,

$$W_t = \left[\int_0^1 W_t(j)^{\frac{1}{\lambda_{w,t}}} dj\right]^{\lambda_{w,t}}.$$

Following Erceg et al. (2000), in each period, a fraction ξ_w of the households cannot freely adjust its wage but follows the indexation rule,

$$W_{t+1}(j) = W_t(j)\left(\pi_{c,t} e^{z_t + \frac{a_c}{1-a_i} v_t}\right)^{\iota_w} \left(\pi_c e^{g_a + \frac{a_c}{1-a_i} g_v}\right)^{1-\iota_w}.$$

The remaining fraction of households, $(1-\xi_w)$, chooses an optimal wage, $W_t(j)$, by maxi-

mizing,

$$E_t\Bigg\{\sum_{s=0}^{\infty}\xi_w^s\beta^s\Bigg[-b_{t+s}\varphi\frac{L_{t+s}(j)^{1+\nu}}{1+\nu}+\Lambda_{t+s}W_t(j)L_{t+s}(j)\Bigg]\Bigg\},$$

subject to the labor demand function (C.1). The aggregate wage evolves according to,

$$W_t=\Bigg\{(1-\xi_w)(\tilde{W}_t)^{\frac{1}{\lambda_w}}+\xi_w\Big[\Big(\pi_c e^{g_a+\frac{a_c}{1-a_i}g_v}\Big)^{1-\iota_w}\Big(\pi_{c,t-1}e^{z_{t-1}+\frac{a_c}{1-a_i}v_{t-1}}\Big)^{\iota_w}W_{t-1}\Big]^{\frac{1}{\lambda_w}}\Bigg\}^{\lambda_w},$$

where $\tilde{W}_t$ is the optimally chosen wage.

C.2 Physical capital producers

Capital producers in sector $x=C,I$ use a fraction of investment goods from final goods producers and undepreciated capital stock from capital services producers (as described above) to produce new capital goods, subject to investment adjustment costs as proposed by Christiano et al. (2005). These new capital goods are then sold in perfectly competitive capital goods markets to capital services producers. The technology available for physical capital production is given as,

$$O'_{x,t}=O_{x,t}+\mu_t\Big(1-S\Big(\frac{I_{x,t}}{I_{x,t-1}}\Big)\Big)I_{x,t},$$

where $O_{x,t}$ denotes the amount of used capital at the end of period t, $O'_{x,t}$ the new capital available for use at the beginning of period $t+1$. The investment adjustment cost function $S(\cdot)$ satisfies the following: $S(1)=S'(1)=0$ and $S''(1)=\kappa>0$, where "$'$"s denote differentiation. The optimization problem of capital producers in sector $x=C,I$ is given as,

$$\underset{I_{x,t},O_{x,t}}{max}\ E_t\sum_{t=0}^{\infty}\beta^t\Lambda_t\Bigg\{Q_{x,t}\Bigg[O_{x,t}+\mu_t\Big(1-S\Big(\frac{I_{x,t}}{I_{x,t-1}}\Big)\Big)I_{x,t}\Bigg]-Q_{x,t}O_{x,t}-\frac{P_{I,t}}{P_{C,t}}I_{x,t}\Bigg\},$$

where $Q_{x,t}$ denotes the price of capital (i.e. the value of installed capital in consumption units). The first order condition for investment goods is,

$$\frac{P_{I,t}}{P_{C,t}}=Q_{x,t}\mu_t\Bigg[1-S\Big(\frac{I_{x,t}}{I_{x,t-1}}\Big)-S'\Big(\frac{I_{x,t}}{I_{x,t-1}}\Big)\frac{I_{x,t}}{I_{x,t-1}}\Bigg]+\beta E_tQ_{x,t+1}\mu_{t+1}\frac{\Lambda_{t+1}}{\Lambda_t}\Bigg[S'\Big(\frac{I_{x,t+1}}{I_{x,t}}\Big)\Big(\frac{I_{x,t+1}}{I_{x,t}}\Big)^2\Bigg].$$

From the capital producer's problem it is evident that any value of $O_{x,t}$ is profit maximizing. Let $\delta_x \in (0,1)$ denote the depreciation rate of capital and $\bar{K}_{x,t-1}$ the capital stock available at the beginning of period t in sector $x = C, I$. Then setting $O_{x,t} = (1-\delta)\xi^K_{x,t}\bar{K}_{x,t-1}$ implies the available (sector-specific) capital stock in sector x, evolves according to,

$$\bar{K}_{x,t} = (1-\delta_x)\xi^K_{x,t}\bar{K}_{x,t-1} + \mu_t\left(1 - S\Big(\frac{I_{x,t}}{I_{x,t-1}}\Big)\right)I_{x,t}, \qquad x = C, I, \tag{C.2}$$

as described in the main text.

C.3 Financial Intermediaries

This section describes in detail how the setup of Gertler and Karadi (2011) is adapted for the two sector model and describes in detail how the equations for financial intermediaries in the main text are derived.

The balance sheet for the consumption or investment sector branch can be expressed as,

$$P_{C,t}Q_{x,t}S_{x,t} = P_{C,t}N_{x,t} + B_{x,t}, \qquad x = C, I,$$

where $S_{x,t}$ denotes the quantity of financial claims held by the intermediary branch and $Q_{x,t}$ denotes the sector-specific price of a claim. The variable $N_{x,t}$ represents the bank's wealth (or equity) at the end of period t and $B_{x,t}$ are the deposits the intermediary branch obtains from households. The sector-specific assets held by the financial intermediary pay the stochastic return $R^B_{x,t+1}$ in the next period. Intermediaries pay at $t+1$ the non-contingent real gross return R_t to households for their deposits made at time t. Then, the intermediary branch equity evolves over time as,

$$\begin{aligned}
N_{x,t+1}P_{C,t+1} &= R^B_{x,t+1}\pi_{C,t+1}P_{C,t}Q_{x,t}S_{x,t} - R_tB_{x,t} \\
N_{x,t+1}\frac{P_{C,t+1}}{P_{C,t}} &= R^B_{x,t+1}\pi_{C,t+1}Q_{x,t}S_{x,t} - R_t(Q_{x,t}S_{x,t} - N_{x,t}) \\
N_{x,t+1} &= \big[(R^B_{x,t+1}\pi_{C,t+1} - R_t)Q_{x,t}S_{x,t} + R_tN_{x,t}\big]\frac{1}{\pi_{C,t+1}}.
\end{aligned}$$

The premium, $R^B_{x,t+1}\pi_{C,t+1} - R_t$, as well as the quantity of assets, $Q_{x,t}S_{x,t}$, determines the growth in bank's equity above the riskless return. The bank will not fund any assets with a negative discounted premium. It follows that for the bank to operate in period i the following

inequality must hold,

$$E_t \beta^i \Lambda^B_{t+1+i}(R^B_{x,t+1+i}\pi_{C,t+1+i} - R_{t+i}) \geq 0, \qquad i \geq 0,$$

where $\beta^i \Lambda^B_{t+1+i}$ is the bank's stochastic discount factor, with,

$$\Lambda^B_{t+1} \equiv \frac{\Lambda_{t+1}}{\Lambda_t},$$

where Λ_t is the Lagrange multiplier on the household's budget equation. Under perfect capital markets, arbitrage guarantees that the risk premium collapses to zero and the relation always holds with equality. However, under imperfect capital markets, credit constraints rooted in the bank's inability to obtain enough funds may lead to positive risk premia. As long as the above inequality holds, banks will keep building assets by borrowing additional funds from households. Accordingly, the intermediary branch objective is to maximize expected terminal wealth,

$$\begin{aligned} V_{x,t} =& max E_t \sum_{i=0} (1-\theta_B)\theta_B^i \beta^i \Lambda^B_{t+1+i} N_{x,t+1+i} \\ =& max E_t \sum_{i=0} (1-\theta_B)\theta_B^i \beta^i \Lambda^B_{t+1+i} [(R^B_{x,t+1+i}\pi_{C,t+1+i} - R_{t+i}) \frac{Q_{x,t+i}S_{x,t+i}}{\pi_{C,t+1+i}} + \frac{R_{t+i}N_{x,t+i}}{\pi_{C,t+1+i}}], \end{aligned} \tag{C.3}$$

where $\theta_B \in (0,1)$ is the fraction of bankers at t that survive until period $t+1$.

Following the setup in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) the banks are limited from infinitely borrowing additional funds from households by a moral hazard/costly enforcement problem. On the one hand, the agent who works in the bank can choose, at the beginning of each period, to divert the fraction λ_B of available funds and transfer it back to the household. On the other hand, depositors can force the bank into bankruptcy and recover a fraction $1-\lambda_B$ of assets. Note that the fraction, λ_B, which intermediaries can divert is the same across sectors to guarantee that the household is indifferent between lending funds between different branches.

Given this tradeoff, depositors will only lend funds to the intermediary when the latter's maximized expected terminal wealth is larger or equal to the gain from diverting the fraction

λ_B of available funds. This incentive constraint can be formalized as,

$$V_{x,t} \geq \lambda_B Q_{x,t} S_{x,t}, \qquad 0 < \lambda_B < 1. \tag{C.4}$$

Using equation (C.3), the expression for $V_{x,t}$ can be written as the following first-order difference equation,

$$V_{x,t} = \nu_{x,t} Q_{x,t} S_{x,t} + \eta_{x,t} N_{x,t},$$

with,

$$\nu_{x,t} = E_t\{(1-\theta_B)\Lambda^B_{t+1}(R^B_{x,t+1}\pi_{C,t+1} - R_t) + \theta_B \beta Z^x_{1,t+1}\nu_{x,t+1}\},$$
$$\eta_{x,t} = E_t\{(1-\theta_B)\Lambda^B_{t+1}R_t + \theta_B \beta Z^x_{2,t+1}\eta_{x,t+1}\},$$

and,

$$Z^x_{1,t+1+i} \equiv \frac{Q_{x,t+1+i}S_{x,t+1+i}}{Q_{x,t+i}S_{x,t+i}}, \qquad Z^x_{2,t+1+i} \equiv \frac{N_{x,t+1+i}}{N_{x,t+i}}.$$

The variable $\nu_{x,t}$ can be interpreted as the expected discounted marginal gain of expanding assets $Q_{x,t}S_{x,t}$ by one unit while holding wealth $N_{x,t}$ constant. The interpretation of $\eta_{x,t}$ is analogous: it is the expected discounted value of having an additional unit of wealth, $N_{x,t}$, holding the quantity of financial claims, $S_{x,t}$, constant. The gross growth rate in assets is denoted by $Z^x_{1,t+i}$ and the gross growth rate of net worth is denoted by $Z^x_{2,t+i}$.

Then, using the expression for $V_{x,t}$, we can express the intermediary's incentive constraint (C.4) as,

$$\nu_{x,t} Q_{x,t} S_{x,t} + \eta_{x,t} N_{x,t} \geq \lambda_B Q_{x,t} S_{x,t}.$$

As indicated above, under perfect capital markets banks will expand borrowing until the risk premium collapses to zero which implies that in this case $\nu_{x,t}$ equals zero as well. Imperfect capital markets however, limit the possibilities for this kind of arbitrage because the intermediaries are constrained by their equity capital. If the incentive constraint binds it

follows that,

$$Q_{x,t}S_{x,t} = \frac{\eta_{x,t}}{\lambda_B - \nu_{x,t}} N_{x,t}$$
$$= \varrho_{x,t} N_{x,t}. \tag{C.5}$$

In this case, the quantity of assets which the intermediary can acquire depends on the equity capital, $N_{x,t}$, as well as the intermediary's leverage ratio, $\varrho_{x,t}$, limiting the bank's ability to acquire assets. This leverage ratio is the ratio of the bank's intermediated assets to equity. The bank's leverage ratio is limited to the point where its maximized expected terminal wealth equals the gains from diverting the fraction λ_B from available funds. However, the constraint (C.5) binds only if $0 < \nu_{x,t} < \lambda_B$ (given $N_{x,t} > 0$). This inequality is always satisfied with our estimates.

Using the leverage ratio (C.5) we can express the evolution of the intermediary's wealth as,

$$N_{x,t+1} = [(R^B_{x,t+1}\pi_{C,t+1} - R_t)\varrho_{x,t} + R_t]\frac{N_{x,t}}{\pi_{C,t+1}}.$$

From this equation it also follows that,

$$Z^x_{2,t+1} = \frac{N_{x,t+1}}{N_{x,t}} = \big[(R^B_{x,t+1}\pi_{C,t+1} - R_t)\varrho_{x,t} + R_t\big]\frac{1}{\pi_{C,t+1}},$$

and,

$$Z^x_{1,t+1} = \frac{Q_{x,t+1}S_{x,t+1}}{Q_{x,t}S_{x,t}} = \frac{\varrho_{x,t+1}N_{x,t+1}}{\varrho_{x,t}N_{x,t}} = \frac{\varrho_{x,t+1}}{\varrho_{x,t}} Z^x_{2,t+1}.$$

Financial intermediaries which are forced into bankruptcy are replaced by new entrants. Therefore, total wealth of financial intermediaries is the sum of the net worth of existing, $N^e_{x,t}$, and new ones, $N^n_{x,t}$,

$$N_{x,t} = N^e_{x,t} + N^n_{x,t}.$$

The fraction θ_B of bankers at $t-1$ which survive until t is equal across branches. Then,

the law of motion for existing bankers is given by,

$$N^e_{x,t} = \theta_B[(R^B_{x,t}\pi_{C,t} - R_{t-1})\varrho_{x,t-1} + R_{t-1}]\frac{N_{x,t-1}}{\pi_{C,t}}, \qquad 0 < \theta_B < 1. \tag{C.6}$$

where a main source of variation is the ex-post excess return on assets, $R^B_{x,t}\pi_{C,t} - R_{t-1}$.

New banks receive startup funds from their respective household, equal to a small fraction of the value of assets held by the existing bankers in their final operating period. Given that the exit probability is *i.i.d.*, the value of assets held by the existing bankers in their final operating period is given by $(1-\theta_B)Q_{x,t}S_{x,t}$. The transfer to new intermediaries is a fraction, ϖ, of this value, leading to the following formulation for new banker's wealth,

$$N^n_{x,t} = \varpi Q_{x,t}S_{x,t}, \qquad 0 < \varpi < 1. \tag{C.7}$$

Existing banker's net worth (C.6) and entering banker's net worth (C.7) lead to the law of motion for total net worth,

$$N_{x,t} = \big(\theta_B[(R^B_{x,t}\pi_{C,t} - R_{t-1})\varrho_{x,t-1} + R_{t-1}]\frac{N_{x,t-1}}{\pi_{C,t}} + \varpi Q_{x,t}S_{x,t}\big).$$

The excess return, $x = C, I$ can be defined as,

$$R^S_{x,t} = R^B_{x,t+1}\pi_{C,t+1} - R_t.$$

Since R_t, λ_B, ϖ and θ_B are equal across sectors, the institutional setup of the two representative banks in the two sectors is symmetric. Both branches hold deposits from households and buy assets from firms in the sector they provide specialized lending. Their performance differs because the demand for capital differs across sectors resulting in sector-specific prices of capital, $Q_{x,t}$, and nominal rental rates for capital, $R^K_{x,t}$. Note that the institutional setup of banks does not depend on firm-specific factors. Gertler and Karadi (2011) show that this implies a setup with a continuum of banks is equivalent to a formulation with a representative bank. Owing to the symmetry of the banks this also holds for our formulation of financial intermediaries in the two-sector setup.

C.4 Resource Constraints

The resource constraint in the consumption sector is,

$$C_t + (a(u_{C,t})\xi^K_{C,t}\bar{K}_{C,t-1} + a(u_{I,t})\xi^K_{I,t}\bar{K}_{I,t-1})\frac{A_t V_t^{\frac{a_c}{1-a_i}}}{V_t^{\frac{1}{1-a_i}}} = a_{lt}A_t L_{c,t}^{1-a_c}K_{c,t}^{a_c} - A_t V_t^{\frac{a_c}{1-a_i}}F_C.$$

The resource constraint in the investment sector is,

$$I_{I,t} + I_{C,t} = v_{lt}V_t L_{I,t}^{1-a_i}K_{I,t}^{a_i} - V_t^{\frac{1}{1-a_i}}F_I.$$

Hours worked are aggregated as,

$$L_t = L_{I,t} + L_{C,t}.$$

Bank equity is aggregated as,

$$N_t = N_{I,t} + N_{C,t}.$$

C.5 Stationary Economy

The model includes two non-stationary TFP shocks, A_t and V_t. This section shows how we normalize the model to render it stationary. Lower case variables denote normalized stationary variables.

The model variables can be stationarized as follows:

$$k_{x,t} = \frac{K_{x,t}}{V_t^{\frac{1}{1-a_i}}}, \qquad \bar{k}_{x,t} = \frac{\bar{K}_{x,t}}{V_t^{\frac{1}{1-a_i}}}, \qquad k_t = \frac{K_t}{V_t^{\frac{1}{1-a_i}}}, \tag{C.8}$$

$$i_{x,t} = \frac{I_{x,t}}{V_t^{\frac{1}{1-a_i}}}, \qquad i_t = \frac{I_t}{V_t^{\frac{1}{1-a_i}}}, \qquad c_t = \frac{C_t}{A_t V_t^{\frac{a_c}{1-a_i}}}, \tag{C.9}$$

$$r^K_{C,t} = \frac{R^K_{C,t}}{P_{C,t}}A_t^{-1}V_t^{\frac{1-a_c}{1-a_i}}, \qquad r^K_{I,t} = \frac{R^K_{I,t}}{P_{C,t}}A_t^{-1}V_t^{\frac{1-a_c}{1-a_i}}, \qquad w_t = \frac{W_t}{P_{C,t}A_t V_t^{\frac{a_c}{1-a_i}}}. \tag{C.10}$$

From

$$\begin{aligned}\frac{P_{I,t}}{P_{C,t}} &= \frac{mc_{C,t}}{mc_{I,t}}\frac{1-a_c}{1-a_i}\frac{A_t}{V_t}\left(\frac{K_{I,t}}{L_{I,t}}\right)^{-a_i}\left(\frac{K_{C,t}}{L_{C,t}}\right)^{a_c} \\ &= \frac{mc_{C,t}}{mc_{I,t}}\frac{1-a_c}{1-a_i}A_t V_t^{\frac{a_c-1}{1-a_i}}\left(\frac{k_{I,t}}{L_{I,t}}\right)^{-a_i}\left(\frac{k_{C,t}}{L_{C,t}}\right)^{a_c},\end{aligned}$$

follows that,

$$p_{i,t} = \frac{P_{I,t}}{P_{C,t}} A_t^{-1} V_t^{\frac{1-a_c}{1-a_i}}. \tag{C.11}$$

and the multipliers are normalized as,

$$\lambda_t = \Lambda_t A_t V_t^{\frac{a_c}{1-a_i}}, \qquad \phi_{x,t} = \Phi_{x,t} V_t^{\frac{1}{1-a_i}}. \tag{C.12}$$

where $\Phi_{x,t}$ denotes the multiplier on the respective capital accumulation equation. Using the growth of investment, it follows that the prices of capital can be normalized as,

$$q_{x,t} = Q_{x,t} A_t^{-1} V_t^{\frac{1-a_c}{1-a_i}}.$$

with the price of capital in sector x, defined as,

$$q_{x,t} = \phi_{x,t}/\lambda_t, \quad x = C, I.$$

Using the growth of capital, it follows,

$$s_{x,t} = \frac{S_{x,t}}{V_t^{\frac{1}{1-a_i}}}.$$

Then, it follows from entering bankers wealth equation (C.7) that,

$$n_{x,t}^n = N_{x,t}^n A_t^{-1} V_t^{\frac{-a_c}{1-a_i}}.$$

Total wealth, wealth of existing and entering bankers has to grow at the same rate,

$$n_{x,t}^e = N_{x,t}^e A_t^{-1} V_t^{\frac{-a_c}{1-a_i}}, \qquad n_{x,t} = N_{x,t} A_t^{-1} V_t^{\frac{-a_c}{1-a_i}}.$$

C.5.1 Intermediate goods producers

Firm's production function in the consumption sector:

$$c_t = a_{lt} L_{C,t}^{1-a_c} k_{C,t}^{a_c} - F_C. \tag{C.13}$$

Firm's production function in the investment sector:

$$i_t = v_{lt} L_{I,t}^{1-a_i} k_{I,t}^{a_i} - F_I. \tag{C.14}$$

Marginal costs in the consumption sector:

$$mc_{C,t} = (1-a_c)^{a_c-1} a_c^{-a_c} (r^K_{C,t})^{a_c} w_t^{1-a_c} a_{lt}^{-1}. \tag{C.15}$$

Marginal costs in the investment sector:

$$mc_{I,t} = (1-a_i)^{a_i-1} a_i^{-a_i} w_t^{1-a_i} (r^K_{I,t})^{a_i} v_{lt}^{-1} p_{i,t}^{-1}, \qquad \text{with} \quad p_{i,t} = \frac{P_{I,t}}{P_{C,t}}. \tag{C.16}$$

Capital labour ratios in the two sectors:

$$\frac{k_{C,t}}{L_{C,t}} = \frac{w_t}{r^K_{C,t}} \frac{a_c}{1-a_c}, \qquad \frac{k_{I,t}}{L_{I,t}} = \frac{w_t}{r^K_{I,t}} \frac{a_i}{1-a_i}. \tag{C.17}$$

C.5.2 Firms' pricing decisions

Price setting equation for firms that change their price in sector $x = C, I$:

$$0 = E_t \left\{ \sum_{s=0}^{\infty} \xi^s_{p,x} \beta^s \lambda_{t+s} \tilde{x}_{t+s} \left[\tilde{p}_{x,t} \tilde{\Pi}_{t,t+s} - (1+\lambda^x_{p,t+s}) mc_{x,t+s} \right] \right\}, \tag{C.18}$$

with

$$\tilde{\Pi}_{t,t+s} = \prod_{k=1}^{s} \left[\left(\frac{\pi_{x,t+k-1}}{\pi_x} \right)^{\iota_{px}} \left(\frac{\pi_{x,t+k}}{\pi_x} \right)^{-1} \right] \quad \text{and} \quad \tilde{x}_{t+s} = \left(\frac{\tilde{P}_{x,t}}{P_{x,t}} \tilde{\Pi}_{t,t+s} \right)^{-\frac{1+\lambda^x_{p,t+s}}{\lambda^x_{p,t+s}}} x_{t+s}$$

$$\text{and} \quad \frac{\tilde{P}_{x,t}}{P_{x,t}} = \tilde{p}_{x,t}.$$

Aggregate price index in the consumption sector:

$$1 = \left[(1-\xi_{x,p}) (\tilde{p}_{x,t})^{\frac{1}{\lambda^x_{p,t}}} + \xi_{x,p} \left[\left(\frac{\pi_{x,t-1}}{\pi_x} \right)^{\iota_{px}} \left(\frac{\pi_{x,t}}{\pi_x} \right)^{-1} \right]^{\frac{1}{\lambda^x_{p,t}}} \right]^{\lambda^x_{p,t}}.$$

It further holds that

$$\frac{\pi_{I,t}}{\pi_{C,t}} = \frac{p_{i,t}}{p_{i,t-1}}. \tag{C.19}$$

C.5.3 Household's optimality conditions and wage setting

Marginal utility of income:

$$\lambda_t = \frac{b_t}{c_t - h c_{t-1} \left(\frac{A_{t-1}}{A_t} \right) \left(\frac{V_{t-1}}{V_t} \right)^{\frac{a_c}{1-a_i}}} - \beta h \frac{b_{t+1}}{c_{t+1} \left(\frac{A_{t+1}}{A_t} \right) \left(\frac{V_{t+1}}{V_t} \right)^{\frac{a_c}{1-a_i}} - h c_t}. \tag{C.20}$$

Euler equation:

$$\lambda_t = \beta E_t \lambda_{t+1} \Big(\frac{A_t}{A_{t+1}}\Big)\Big(\frac{V_t}{V_{t+1}}\Big)^{\frac{a_c}{1-a_i}} R_t \frac{1}{\pi_{c,t+1}}.$$

Labor supply

$$\lambda_t w_t = b_t \varphi (L_{C,t} + L_{I,t})^{\nu},$$

C.5.4 Capital services

Optimal capital utilization:

$$r^K_{C,t} = a'_C(u_{C,t}), \qquad r^K_{I,t} = a'_I(u_{I,t}).$$

Definition of capital services:

$$k_{C,t} = u_{C,t}\xi^K_{C,t}\bar{k}_{C,t-1}\Big(\frac{V_{t-1}}{V_t}\Big)^{\frac{1}{1-a_i}}, \qquad k_{I,t} = u_{I,t}\xi^K_{I,t}\bar{k}_{I,t-1}\Big(\frac{V_{t-1}}{V_t}\Big)^{\frac{1}{1-a_i}}. \tag{C.21}$$

Optimal choice of available capital in sector $x = C, I$:

$$\phi_{x,t} = \beta E_t \xi^K_{x,t+1}\left\{\lambda_{t+1}\Big(\frac{V_t}{V_{t+1}}\Big)^{\frac{1}{1-a_i}}(r^K_{x,t+1}u_{x,t+1} - a(u_{x,t+1})) + (1-\delta)E_t\phi_{x,t+1}\Big(\frac{V_t}{V_{t+1}}\Big)^{\frac{1}{1-a_i}}\right\}, \tag{C.22}$$

C.5.5 Physical capital producers

Optimal choice of investment in sector $x = C, I$:

$$\begin{aligned}\lambda_t p_{i,t} =& \phi_{x,t}\mu_t\left[1 - S\Big(\frac{i_{x,t}}{i_{x,t-1}}\Big(\frac{V_t}{V_{t-1}}\Big)^{\frac{1}{1-a_i}}\Big) - S'\Big(\frac{i_{x,t}}{i_{x,t-1}}\Big(\frac{V_t}{V_{t-1}}\Big)^{\frac{1}{1-a_i}}\Big)\frac{i_{x,t}}{i_{x,t-1}}\Big(\frac{V_t}{V_{t-1}}\Big)^{\frac{1}{1-a_i}}\right] \\ &+ \beta E_t \phi_{x,t+1}\mu_{t+1}\Big(\frac{V_t}{V_{t+1}}\Big)^{\frac{1}{1-a_i}}\left[S'\Big(\frac{i_{x,t+1}}{i_{x,t}}\Big(\frac{V_{t+1}}{V_t}\Big)^{\frac{1}{1-a_i}}\Big)\Big(\frac{i_{x,t+1}}{i_{x,t}}\Big(\frac{V_{t+1}}{V_t}\Big)^{\frac{1}{1-a_i}}\Big)^2\right].\end{aligned} \tag{C.23}$$

Accumulation of capital in sector $x = C, I$:

$$\bar{k}_{x,t} = (1-\delta_x)\xi^K_{x,t}\bar{k}_{x,t-1}\Big(\frac{V_{t-1}}{V_t}\Big)^{\frac{1}{1-a_i}} + \mu_t\left(1 - S\Big(\frac{i_{x,t}}{i_{x,t-1}}\Big(\frac{V_t}{V_{t-1}}\Big)^{\frac{1}{1-a_i}}\Big)\right)i_{x,t}, \tag{C.24}$$

C.5.6 Household's wage setting

Household's wage setting:

$$E_t \sum_{s=0}^{\infty} \beta^s \xi_w^s \lambda_{t+s} \tilde{L}_{t+s} \left[\tilde{w}_t \tilde{\Pi}_{t,t+s}^w - (1+\lambda_{w,t+s}) b_{t+s} \varphi \frac{\tilde{L}_{t+s}^{\nu}}{\lambda_{t+s}} \right] = 0, \tag{C.25}$$

with

$$\tilde{\Pi}_{t,t+s}^w = \prod_{k=1}^{s} \left[\left(\frac{\pi_{C,t+k-1} e^{a_{t+k-1} + \frac{a_c}{1-a_i} v_{t+k-1}}}{\pi_c e^{g_a + \frac{a_c}{1-a_i} g_v}} \right)^{\iota_w} \left(\frac{\pi_{C,t+k} e^{a_{t+k} + \frac{a_c}{1-a_i} v_{t+k}}}{\pi_C e^{g_a + \frac{a_c}{1-a_i} g_v}} \right)^{-1} \right]$$

and

$$\tilde{L}_{t+s} = \left(\frac{\tilde{w}_t \tilde{\Pi}_{t,t+s}^w}{w_{t+s}} \right)^{-\frac{1+\lambda_{w,t+s}}{\lambda_{w,t+s}}} L_{t+s}.$$

Wages evolve according to

$$w_t = \left\{ (1-\xi_w) \tilde{w}_t^{\frac{1}{\lambda_{w,t}}} + \xi_w \left[\left(\frac{\pi_{c,t-1} e^{a_{t-1} + \frac{a_c}{1-a_i} v_{t-1}}}{\pi_c e^{g_a + \frac{a_c}{1-a_i} g_v}} \right)^{l_w} \left(\frac{\pi_{c,t} e^{a_t + \frac{a_c}{1-a_i} v_t}}{\pi_c e^{g_a + \frac{a_c}{1-a_i} g_v}} \right)^{-1} w_{t-1} \right]^{\frac{1}{\lambda_{w,t}}} \right\}^{\lambda_{w,t}}.$$

C.5.7 Financial Intermediation

The stationary stochastic discount factor can be expressed as,

$$\lambda_{t+1}^B = \frac{\lambda_{t+1}}{\lambda_t}.$$

Then, one can derive expressions for $\nu_{x,t}$ and $\eta_{x,t}$,

$$\nu_{x,t} = E_t \{ (1-\theta_B) \lambda_{t+1}^B \frac{A_t}{A_{t+1}} \left(\frac{V_t}{V_{t+1}} \right)^{\frac{a_c}{1-a_i}} (R_{x,t+1}^B \pi_{C,t+1} - R_t) + \theta_B \beta z_{1,t+1}^x \nu_{x,t+1} \},$$

$$\eta_{x,t} = E_t \{ (1-\theta_B) \lambda_{t+1}^B \frac{A_t}{A_{t+1}} \left(\frac{V_t}{V_{t+1}} \right)^{\frac{a_c}{1-a_i}} R_t + \theta_B \beta z_{2,t+1}^x \eta_{x,t+1} \},$$

with

$$z_{1,t+1+i}^x \equiv \frac{q_{x,t+1+i} s_{x,t+1+i}}{q_{x,t+i} s_{x,t+i}} \frac{A_{t+1}}{A_t} \left(\frac{V_{t+1}}{V_t} \right)^{\frac{a_c}{1-a_i}}, \qquad z_{2,t+1+i}^x \equiv \frac{n_{x,t+1+i}}{n_{x,t+i}} \frac{A_{t+1}}{A_t} \left(\frac{V_{t+1}}{V_t} \right)^{\frac{a_c}{1-a_i}}.$$

It follows that if the bank's incentive constraint binds it can be expressed as,

$$\nu_{x,t} q_{x,t} s_{x,t} + \eta_{x,t} n_{x,t} = \lambda_B q_{x,t} s_{x,t}$$

$$\Leftrightarrow q_{x,t} s_{x,t} = \varrho_{x,t} n_{x,t},$$

with the leverage ratio given as,

$$\varrho_{x,t} = \frac{\eta_{x,t}}{\lambda_B - \nu_{x,t}}.$$

It further follows that:

$$z^x_{2,t+1} = \frac{n_{x,t+1}}{n_{x,t}} \frac{A_{t+1}}{A_t} \Big(\frac{V_{t+1}}{V_t}\Big)^{\frac{a_c}{1-a_i}} = \big[(R^B_{x,t+1}\pi_{C,t+1} - R_t)\varrho_{x,t} + R_t\big] \frac{1}{\pi_{C,t+1}},$$

and

$$z^x_{1,t+1} = \frac{q_{x,t+1}s_{x,t+1}}{q_{x,t}s_{x,t}} \frac{A_{t+1}}{A_t} \Big(\frac{V_{t+1}}{V_t}\Big)^{\frac{a_c}{1-a_i}} = \frac{\varrho_{x,t+1}n_{x,t+1}}{\varrho_{x,t}n_{x,t}} \frac{A_{t+1}}{A_t} \Big(\frac{V_{t+1}}{V_t}\Big)^{\frac{a_c}{1-a_i}} = \frac{\varrho_{x,t+1}}{\varrho_{x,t}} z^x_{2,t+1}.$$

The normalized equation for bank's wealth accumulation is,

$$n_{x,t} = \Big(\theta_B[(R^B_{x,t}\pi_{C,t} - R_{t-1})\varrho_{x,t-1} + R_{t-1}] \frac{A_{t-1}}{A_t} \Big(\frac{V_{t-1}}{V_t}\Big)^{\frac{a_c}{1-a_i}} \frac{n_{x,t-1}}{\pi_{C,t}} + \varpi q_{x,t}s_{x,t}\Big).$$

The borrow in advance constraint:

$$\bar{k}_{x,t+1} = s_{x,t}.$$

The leverage equation:

$$q_{x,t}s_{x,t} = \varrho_{x,t}n_{x,t}.$$

Bank's stochastic return on assets can be described in normalized variables as:

$$R^B_{x,t+1} = \frac{r^K_{x,t+1}u_{x,t+1} + q_{x,t+1}(1-\delta_x) - a(u_{x,t+1})}{q_{x,t}} \xi^K_{x,t+1} \frac{A_{t+1}}{A_t} \Big(\frac{V_{t+1}}{V_t}\Big)^{-\frac{1-a_c}{1-a_i}},$$

knowing from the main model that

$$r^K_{x,t} = \frac{R^K_{x,t}}{P_{x,t}} A_t^{-1} V_t^{\frac{1-a_c}{1-a_i}}.$$

C.5.8 Monetary policy and market clearing

Monetary policy rule:

$$\frac{R_t}{R} = \Big(\frac{R_{t-1}}{R}\Big)^{\rho_R} \Big[\Big(\frac{\pi_{C,t}}{\pi_C}\Big)^{\phi_\pi} \Big(\frac{y_t}{y_{t-1}}\Big)^{\phi_{\Delta Y}}\Big]^{1-\rho_R} \eta_{mp,t},$$

Resource constraint in the consumption sector:

$$c_t + (a(u_{C,t})\xi^K_{C,t}\bar{k}_{C,t-1} + a(u_{I,t})\xi^K_{I,t}\bar{k}_{I,t-1}) \Big(\frac{V_{t-1}}{V_t}\Big)^{\frac{1}{1-a_i}} = a_{lt}L^{1-a_c}_{C,t}k^{a_c}_{C,t} - F_C.$$

Resource constraint in the investment sector:

$$i_t = v_{lt} L_{I,t}^{1-a_i} k_{I,t}^{a_i} - F_I.$$

Definition of GDP:

$$y_t = c_t + p_{i,t} i_t + \Big(1 - \frac{1}{g_t}\Big) y_t. \tag{C.26}$$

Moreover

$$L_t = L_{I,t} + L_{C,t}, \qquad i_t = i_{C,t} + i_{I,t}, \qquad n_t = n_{C,t} + n_{I,t}.$$

C.6 Steady State

This section describes the model's steady state.

From the optimal choice of available capital (C.22) and the optimal choice of investment (C.23) in both sectors:

$$r_C^K = \left(\frac{e^{\frac{1}{1-a_i} g_v}}{\beta} - (1 - \delta_C)\right) p_i, \tag{C.27}$$

$$r_I^K = \left(\frac{e^{\frac{1}{1-a_i} g_v}}{\beta} - (1 - \delta_I)\right) p_i. \tag{C.28}$$

From firm's price setting in both sectors (C.18),

$$mc_C = \frac{1}{1 + \lambda_p^C}, \qquad mc_I = \frac{1}{1 + \lambda_p^I}. \tag{C.29}$$

Using equations (C.29) and imposing knowledge of the steady state expression for r_C^K and r_I^K, one can derive expressions for the steady state wage from the equations that define marginal costs in the two sectors ((C.15) and (C.16)).

Consumption sector:

$$w = \left(\frac{1}{1 + \lambda_p^C} (1 - a_c)^{1-a_c} a_c^{a_c} (r_C^K)^{-a_c}\right)^{\frac{1}{1-a_c}}. \tag{C.30}$$

Investment sector:

$$w = \left(\frac{1}{1 + \lambda_p^I} (1 - a_i)^{1-a_i} a_i^{a_i} (r_I^K)^{-a_i} p_i\right)^{\frac{1}{1-a_i}}. \tag{C.31}$$

Since labour can move across sectors the steady state wage has to be the same in the consumption and investment sector. The equality is verified by p_i. An expression for p_i can be found by setting (C.30) equal to (C.31):

$$\begin{aligned}
&\Big(\frac{1}{1+\lambda_p^C}(1-a_c)^{1-a_c}a_c^{a_c}(r_C^K)^{-a_c}\Big)^{\frac{1}{1-a_c}} = \Big(\frac{1}{1+\lambda_p^I}(1-a_i)^{1-a_i}a_i^{a_i}(r_I^K)^{-a_i}p_i\Big)^{\frac{1}{1-a_i}} \\
\Leftrightarrow&\Big(\frac{1}{1+\lambda_p^C}(1-a_c)^{1-a_c}a_c^{a_c}\Big(\frac{e^{\frac{1}{1-a_i}g_v}}{\beta}-(1-\delta_C)\Big)^{-a_c}p_i^{-a_c}\Big)^{\frac{1}{1-a_c}} \\
&= \Big(\frac{1}{1+\lambda_p^I}(1-a_i)^{1-a_i}a_i^{a_i}\Big(\frac{e^{\frac{1}{1-a_i}g_v}}{\beta}-(1-\delta_I)\Big)^{-a_i}p_i^{-a_i}p_i\Big)^{\frac{1}{1-a_i}} \\
\Leftrightarrow&p_i = \frac{\frac{1}{1+\lambda_p^C}(1-a_c)^{1-a_c}a_c^{a_c}\Big(\frac{e^{\frac{1}{1-a_i}g_v}}{\beta}-(1-\delta_C)\Big)^{-\alpha_c}}{\Big[\frac{1}{1+\lambda_p^I}(1-a_i)^{1-a_i}a_i^{a_i}\Big(\frac{e^{\frac{1}{1-a_i}g_v}}{\beta}-(1-\delta_I)\Big)^{-\alpha_i}\Big]^{\frac{1-a_c}{1-a_i}}}.
\end{aligned} \tag{C.32}$$

Knowing w, r_C^K and r_I^K, the expressions given in (C.17) can be used to find the steady state capital-to-labour ratios in the two sectors:

$$\frac{k_C}{L_C} = \frac{w}{r_C^K}\frac{a_c}{1-a_c}, \tag{C.33}$$

$$\frac{k_I}{L_I} = \frac{w}{r_I^K}\frac{a_i}{1-a_c}. \tag{C.34}$$

The zero profit condition for intermediate goods producers in the consumption sector, $c - r_C^K k_C - wL_C = 0$, and (C.13) imply:

$$\begin{aligned}
&L_C^{1-a_c}k_C^{a_c} - F_C - r_C^K k_C - wL_C = 0 \\
\Leftrightarrow&\frac{F_C}{L_C} = \Big(\frac{k_C}{L_C}\Big)^{a_c} - r_C^K\frac{k_C}{L_C} - w.
\end{aligned}$$

Analogously the zero profit condition for intermediate goods producers in the investment sector, $i - r_I^K k_I - wL_I = 0$, and (C.14) imply:

$$\frac{F_I}{L_I} = \Big(\frac{k_I}{L_I}\Big)^{a_i} - r_I^K\frac{k_I}{L_I} - w.$$

These expressions pin down the steady state consumption-to-labour and investment-to-labour ratios which follow from the intermediate firms' production functions ((C.13) and

(C.14)):

$$\frac{c}{L_C} = \left(\frac{k_C}{L_C}\right)^{a_c} - \frac{F_C}{L_C}, \qquad \frac{i}{L_I} = \left(\frac{k_I}{L_I}\right)^{a_i} - \frac{F_I}{L_I}.$$

$$1 + \lambda_p^C = \frac{c + F_C}{c} \Leftrightarrow \lambda_p^C c = F_C, \qquad \text{and} \qquad 1 + \lambda_p^I = \frac{i + F_I}{i} \Leftrightarrow \lambda_p^I i = F_I.$$

This and the steady state consumption-to-labour ratio can be used to derive an expression for steady state consumption:

$$\begin{aligned} c &= \left(\frac{k_C}{L_C}\right)^{a_c} L_C - F_C \\ \Leftrightarrow c &= \left(\frac{k_C}{L_C}\right)^{a_c} L_C - \lambda_p^C c \\ \Leftrightarrow c &= \frac{1}{1 + \lambda_p^C}\left(\frac{k_C}{L_C}\right)^{a_c} L_C. \end{aligned}$$

Analogously one can derive an expression for steady state investment:

$$i = \frac{1}{1 + \lambda_p^I}\left(\frac{k_I}{L_I}\right)^{a_i} L_I.$$

Combining these two expressions leads to,

$$\begin{aligned} p_i \frac{i}{c} &= \frac{\frac{1}{1+\lambda_p^I}\left(\frac{k_I}{L_I}\right)^{a_i} L_I}{\frac{1}{1+\lambda_p^C}\left(\frac{k_C}{L_C}\right)^{a_c} L_C} p_i \\ \Leftrightarrow \frac{L_I}{L_C} &= p_i \frac{i}{c} \frac{\frac{1}{1+\lambda_p^C}\left(\frac{k_C}{L_C}\right)^{a_c}}{\frac{1}{1+\lambda_p^I}\left(\frac{k_I}{L_I}\right)^{a_i}} p_i^{-1}. \end{aligned}$$

Total labour L is set to unity in the steady state. However, since a_i and a_c are not necessarily calibrated to be equal one needs to fix another quantity in addition to $L = 1$. We fix the steady state investment-to-consumption ratio, $p_i \frac{i}{c}$, which equals 0.399 in the data. This allows us to derive steady state expressions for labour in the two sectors. Steady state labour in the investment sector is given by

$$L_I = 1 - L_C, \tag{C.35}$$

and the two equations above imply that steady state labour in the consumption sector can

be expressed as,

$$L_C = \left(1 + p_i \frac{i}{c} \frac{\frac{1}{1+\lambda_p^C}\left(\frac{k_C}{L_C}\right)^{a_c}}{\frac{1}{1+\lambda_p^I}\left(\frac{k_I}{L_I}\right)^{a_i}} p_i^{-1}\right)^{-1}. \tag{C.36}$$

The steady state values for labour in the two sectors imply:

$$k_C = \frac{k_C}{L_C} L_C, \quad k_I = \frac{k_I}{L_I} L_I, \quad c = \frac{c}{L_C} L_C, \quad i = \frac{i}{L_I} L_I, \quad F_C = \frac{F_C}{L_C} L_C, \quad F_I = \frac{F_I}{L_I} L_I.$$

It follows from (C.21) that,

$$k_C = \bar{k}_C e^{-\frac{1}{1-a_i} g_v}, \qquad \text{and} \qquad k_I = \bar{k}_I e^{-\frac{1}{1-a_i} g_v}.$$

The accumulation equation of available capital (C.24) can be used to solve for investment in the two sectors:

$$i_C = k_C\big(e^{\frac{1}{1-a_i} g_v} - (1-\delta_C)\big), \tag{C.37}$$

$$i_I = k_I\big(e^{\frac{1}{1-a_i} g_v} - (1-\delta_I)\big). \tag{C.38}$$

From the definition of GDP (C.26):

$$y = c + p_i i + \Big(1 - \frac{1}{g}\Big) y.$$

From the marginal utility of income (C.20):

$$\lambda = \frac{1}{c - hce^{-g_a - \frac{a_c}{1-a_i} g_v}} - \frac{\beta h}{ce^{g_a + \frac{a_c}{1-a_i} g_v} - hc}.$$

From the household's wage setting (C.25)

$$\sum_{s=0}^{\infty} \beta^s \xi_w^s \lambda L\big[w - (1+\lambda_w)\varphi \frac{L^\nu}{\lambda}\big] = 0,$$

follows the expression for L:

$$w - (1-\lambda_w)\varphi \frac{L^\nu}{\lambda} = 0 \quad \Rightarrow \quad L = \Big[\frac{w\lambda}{(1+\lambda_w)\varphi}\Big]^{\frac{1}{\nu}}.$$

This expression can be solved for φ to be consistent with $L = 1$:

$$1 = \left[\frac{w\lambda}{(1+\lambda_w)\varphi}\right]^{\frac{1}{\nu}}$$
$$\Leftrightarrow \varphi = \frac{\lambda w}{1+\lambda_w}.$$

It further holds from equation (C.19) that,

$$\frac{\pi_I}{\pi_C} = e^{g_a - \frac{1-a_c}{1-a_i} g_v}$$

A system of 10 equations (C.27, C.28, C.30, C.32, C.33, C.34, C.35, C.36, C.37, C.38) can be solved for the 10 steady state variables k_C, k_I, w, i_C, i_I, r_C^K, r_I^K, L_C, L_I and p_i. The steady state values for the remaining variables follow from the expressions above.

Given these steady state variables, the remaining steady state values which are mainly related to financial intermediaries can be derived as follows.

The nominal interest rate is given from the Euler equation as,

$$R = \frac{1}{\beta} e^{g_a + \frac{a_c}{1-a_i} g_v} \pi_C.$$

The bank's stationary stochastic discount factor can be expressed in the steady state as

$$\lambda^B = 1.$$

The steady state borrow in advance constraint implies that

$$\bar{k}_x = s_x.$$

The steady state price of capital is given by

$$q_{x,t} = p_{i,t}.$$

The steady state leverage equation is set equal to it's average value in the data over the sample period.

$$\frac{q_x s_x}{n_x} = \varrho_x = 5.47.$$

The parameters ϖ and λ_B help to align the value of the leverage ratio and the corporate bond spread with their empirical counterparts. Using the calibrated value for θ_B, the average

value for the leverage ratio (5.47) and the weighted quarterly average of the corporate spreads ($R_x^B - R = 0.5\%$) allows calibrating ϖ using the bank's wealth accumulation equation,

$$\varpi = \left[1 - \theta_B[(R_x^B \pi_C - R)\varrho_x + R]e^{-g_a - \frac{a_c}{1-a_i} g_v} \frac{1}{\pi_C}\right] \left(\frac{q_x s_x}{n_x}\right)^{-1}.$$

Given the non-linearity in the leverage ratio, we solve numerically for the steady state expressions for η and ν using,

$$\nu_x = (1-\theta_B)\lambda^B e^{-g_a - \frac{a_c}{1-a_i} g_v}(R_x^B \pi_C - R) + \theta_B \beta z_1^x \nu_x,$$
$$\eta_x = (1-\theta_B)\lambda^B e^{-g_a - \frac{a_c}{1-a_i} g_v} R + \theta_B \beta z_2^x \eta_x,$$

with

$$z_2^x = \left[(R_x^B \pi_C - R)\varrho_x + R\right]\frac{1}{\pi_C}, \qquad \text{and} \qquad z_1^x = z_2^x,$$

and the steady state leverage ratio,

$$\varrho_x = \frac{\eta_x}{\lambda_B - \nu_x}.$$

C.7 Log-linearized Economy

This section collects the log-linearized model equations. The log-linear deviations of all variables are defined as

$$\hat{\varsigma}_t \equiv \log \varsigma_t - \log \varsigma,$$

except for

$$\hat{z}_t \equiv z_t - g_a,$$
$$\hat{v}_t \equiv v_t - g_v,$$
$$\hat{\lambda}_{p,t}^C \equiv \log(1 + \lambda_{p,t}^C) - \log(1 + \lambda_p^C),$$
$$\hat{\lambda}_{p,t}^I \equiv \log(1 + \lambda_{p,t}^I) - \log(1 + \lambda_p^I),$$
$$\hat{\lambda}_{w,t} \equiv \log(1 + \lambda_{w,t}) - \log(1 + \lambda_w).$$

C.7.1 Firm's production function and cost minimization

Production function for the intermediate good producing firm (i) in the consumption sector:

$$\hat{c}_t = \frac{c + F_I}{c}[\hat{a}_{lt} + a_c \hat{k}_{C,t} + (1 - a_c)\hat{L}_{C,t}].$$

Production function for the intermediate good producing firm (i) in the investment sector:

$$\hat{i}_t = \frac{i + F_I}{i}[\hat{v}_{lt} + a_i \hat{k}_{I,t} + (1 - a_i)\hat{L}_{I,t}].$$

Capital-to-labour ratios for the two sectors:

$$\hat{r}^K_{C,t} - \hat{w}_t = \hat{L}_{C,t} - \hat{k}_{C,t}, \qquad \hat{r}^K_{I,t} - \hat{w}_t = \hat{L}_{I,t} - \hat{k}_{I,t}. \tag{C.39}$$

Marginal cost in both sectors:

$$\hat{mc}_{C,t} = a_c \hat{r}^K_{C,t} + (1 - a_c)\hat{w}_t - \hat{a}_{lt}, \qquad \hat{mc}_{I,t} = a_i \hat{r}^K_{I,t} + (1 - a_i)\hat{w}_t - \hat{v}_{lt} - \hat{p}_{i,t}. \tag{C.40}$$

C.7.2 Firm's prices

Price setting equation for firms that change their price in sector $x = C, I$:

$$0 = E_t\left\{ \sum_{s=0}^{\infty} \xi^s_{p,x} \beta^s \left[\hat{\tilde{p}}_{x,t} \hat{\tilde{\Pi}}_{t,t+s} - \hat{\lambda}^x_{p,t+s} - \hat{mc}_{x,t+s} \right] \right\},$$

with

$$\hat{\tilde{\Pi}}_{t,t+s} = \sum_{k=1}^{s} [\iota_{p_x} \hat{\pi}_{t+k-1} - \hat{\pi}_{t+k}].$$

Solving for the summation

$$\begin{aligned}
\frac{1}{1 - \xi_{p,x}\beta} \hat{\tilde{p}}_{x,t} =& E_t\left\{ \sum_{s=0}^{\infty} \xi^s_{p,x} \beta^s \big[- \hat{\Pi}_{t,t+s} + \hat{\lambda}^x_{p,t+s} + \hat{mc}_{x,t+s} \big] \right\} \\
=& - \hat{\Pi}_{t,t} + \hat{\lambda}^x_{p,t} + \hat{mc}_{x,t} - \frac{\xi_{p,x}\beta}{1 - \xi_{p,x}\beta} \hat{\Pi}_{t,t+1} \\
&+ \xi_{p,x}\beta E_t\left\{ \sum_{s=1}^{\infty} \xi^{s-1}_{p,x} \beta^{s-1} \big[- \hat{\Pi}_{t+1,t+s} + \hat{\lambda}^x_{p,t+s} + \hat{mc}_{x,t+s} \big] \right\} \\
=& \hat{\lambda}^x_{p,t} + \hat{mc}_{x,t} + \frac{\xi_{p,x}\beta}{1 - \xi_{p,x}\beta} E_t\big[\hat{\tilde{p}}_{x,t+1} - \hat{\Pi}_{t,t+1} \big],
\end{aligned}$$

where we used $\hat{\Pi}_{t,t} = 0$.

Prices evolve as

$$0 = (1-\xi_{p,x})\hat{\tilde{p}}_{x,t} + \xi_{p,x}(\iota_{p_x}\hat{\pi}_{t-1} - \hat{\pi}),$$

from which we obtain the Phillips curve in sector $x = C, I$:

$$\begin{aligned}\hat{\pi}_{x,t} &= \frac{\beta}{1+\iota_{p_x}\beta}E_t\hat{\pi}_{x,t+1} + \frac{\iota_{p_x}}{1+\iota_{p_x}\beta}\hat{\pi}_{x,t-1} + \kappa_x \hat{mc}_{x,t} + \kappa_x \hat{\lambda}^x_{p,t}, \qquad \text{(C.41)}\\ \text{with} \quad \kappa_x &= \frac{(1-\xi_{p,x}\beta)(1-\xi_{p,x})}{\xi_{p,x}(1+\iota_{p_x}\beta)}.\end{aligned}$$

From equation (C.19) it follows that

$$\hat{\pi}_{I,t} - \hat{\pi}_{C,t} = \hat{p}_{I,t} - \hat{p}_{I,t-1}.$$

C.7.3 Households

Marginal utility:

$$\begin{aligned}\hat{\lambda}_t =& \frac{e^G}{e^G - h\beta}\left[\hat{b}_t + \left(\hat{z}_t + \frac{a_c}{1-a_i}\hat{v}_t\right) - \left(\frac{e^G}{e^G-h}\left(\hat{c}_t + \hat{z}_t + \frac{a_c}{1-a_i}\hat{v}_t\right) - \frac{h}{e^G-h}\hat{c}_{t-1}\right)\right]\\ &- \frac{h\beta}{e^G-h\beta}E_t\left[\hat{b}_{t+1} - \left(\frac{e^G}{e^G-h}\left(\hat{c}_{t+1} + \hat{z}_{t+1} + \frac{a_c}{1-a_i}\hat{v}_{t+1}\right) - \frac{h}{e^G-h}\hat{c}_t\right)\right]\\ \Leftrightarrow \hat{\lambda}_t =& \alpha_1 E_t\hat{c}_{t+1} - \alpha_2\hat{c}_t + \alpha_3\hat{c}_{t-1} + \alpha_4\hat{z}_t + \alpha_5\hat{b}_t + \alpha_6\hat{v}_t, \qquad \text{(C.42)}\end{aligned}$$

with

$$\begin{aligned}&\alpha_1 = \frac{h\beta e^G}{(e^G-h\beta)(e^G-h)}, \quad \alpha_2 = \frac{e^{2G}+h^2\beta}{(e^G-h\beta)(e^G-h)}, \quad \alpha_3 = \frac{he^G}{(e^G-h\beta)(e^G-h)},\\ &\alpha_4 = \frac{h\beta e^G\rho_z - he^G}{(e^G-h\beta)(e^G-h)}, \quad \alpha_5 = \frac{e^G-h\beta\rho_b}{e^G-h\beta}, \quad \alpha_6 = \frac{(h\beta e^G\rho_v - he^G)\frac{a_c}{1-a_i}}{(e^G-h\beta)(e^G-h)},\\ &e^G = e^{g_a + \frac{a_c}{1-a_i}g_v}.\end{aligned}$$

This assumes the shock processes for $\hat{z}_t$ and $\hat{b}_t$.

Euler equation:

$$\hat{\lambda}_t = \hat{R}_t + E_t\Big(\hat{\lambda}_{t+1} - \hat{z}_{t+1} - \hat{v}_{t+1}\frac{a_c}{1-a_i} - \hat{\pi}_{C,t+1}\Big). \tag{C.43}$$

C.7.4 Investment and Capital

Capital utilization in both sectors:

$$\hat{r}^K_{C,t} = \chi_C \hat{u}_{C,t}, \qquad \hat{r}^K_{I,t} = \chi_I \hat{u}_{I,t}, \qquad \text{where} \quad \chi_x = \frac{a''_x(1)}{a'_x(1)}. \tag{C.44}$$

Choice of investment for the consumption sector:

$$\begin{aligned}\hat{q}_{C,t} =& e^{2(\frac{1}{1-a_i}g_v)}\kappa\Big(\hat{i}_{C,t} - \hat{i}_{C,t-1} + \frac{1}{1-a_i}\hat{v}_t\Big) - \beta e^{2(\frac{1}{1-a_i}g_v)}\kappa E_t\Big(\hat{i}_{C,t+1} - \hat{i}_{C,t} + \frac{1}{1-a_i}\hat{v}_{t+1}\Big) \\ &+ \hat{p}_{i,t} - \hat{\mu}_t,\end{aligned} \tag{C.45}$$

with $\hat{q}_{C,t} = \hat{\phi}_{C,t} - \hat{\lambda}_t$.

Choice of investment for the investment sector:

$$\begin{aligned}\hat{q}_{I,t} =& e^{2(\frac{1}{1-a_i}g_v)}\kappa\Big(\hat{i}_{I,t} - \hat{i}_{I,t-1} + \frac{1}{1-a_i}\hat{v}_t\Big) - \beta e^{2(\frac{1}{1-a_i}g_v)}\kappa E_t\Big(\hat{i}_{I,t+1} - \hat{i}_{I,t} + \frac{1}{1-a_i}\hat{v}_{t+1}\Big) \\ &+ \hat{p}_{i,t} - \hat{\mu}_t,\end{aligned} \tag{C.46}$$

with $\hat{q}_{I,t} = \hat{\phi}_{I,t} - \hat{\lambda}_t$.

Capital services input in both sectors:

$$\hat{k}_{C,t} = \hat{u}_{C,t} + \xi^K_{C,t} + \hat{\bar{k}}_{C,t-1} - \frac{1}{1-a_i}\hat{v}_t, \qquad \hat{k}_{I,t} = \hat{u}_{I,t} + \xi^K_{I,t} + \hat{\bar{k}}_{I,t-1} - \frac{1}{1-a_i}\hat{v}_t. \tag{C.47}$$

Capital accumulation in the consumption and investment sector:

$$\hat{\bar{k}}_{C,t} = (1-\delta_C)e^{-\frac{1}{1-a_i}g_v}\Big(\hat{\bar{k}}_{C,t-1} + \xi^K_{C,t} - \frac{1}{1-a_i}\hat{v}_t\Big) + \Big(1 - (1-\delta_C)e^{-\frac{1}{1-a_i}g_v}\Big)\hat{i}_{C,t}, \tag{C.48}$$

$$\hat{\bar{k}}_{I,t} = (1-\delta_I)e^{-\frac{1}{1-a_i}g_v}\Big(\hat{\bar{k}}_{I,t-1} + \xi^K_{I,t} - \frac{1}{1-a_i}\hat{v}_t\Big) + \Big(1 - (1-\delta_I)e^{-\frac{1}{1-a_i}g_v}\Big)\hat{i}_{I,t}. \tag{C.49}$$

C.7.5 Wages

The wage setting equation for workers renegotiating their salary:

$$0 = E_t\Big\{\sum_{s=0}^{\infty}\xi_w^s\beta^s\Big[\hat{\tilde{w}}_t + \hat{\tilde{\Pi}}^w_{t,t+s} - \hat{\lambda}_{w,t+s} - \hat{b}_{t+s} - \nu\hat{\tilde{L}}_{t+s} + \hat{\lambda}_{t+s}\Big]\Big\},$$

with

$$\hat{\tilde{\Pi}}^w_{t,t+s} = \sum_{k=1}^{s}\Big[\iota_w\Big(\hat{\pi}_{c,t+k-1} + \hat{z}_{t+k-1} + \frac{a_c}{1-a_i}\hat{v}_{t+k-1}\Big) - \Big(\hat{\pi}_{c,t+k} + \hat{z}_{t+k} + \frac{a_c}{1-a_i}\hat{v}_{t+k}\Big)\Big],$$

and

$$\hat{\tilde{L}}_{t+s} = \hat{L}_{t+s} - \Big(1+\frac{1}{\lambda_w}\Big)\big(\hat{\tilde{w}}_t + \hat{\tilde{\Pi}}^w_{t,t+s} - \hat{w}_{t+s}\big).$$

Then using the labor demand function,

$$\begin{aligned}
0 =& E_t\Big\{\sum_{s=0}^{\infty}\xi_w^s\beta^s\Big[\hat{\tilde{w}}_t + \hat{\tilde{\Pi}}^w_{t,t+s} - \hat{\lambda}_{w,t+s} - \hat{b}_{t+s} \\
&- \nu\Big(\hat{L}_{t+s} - \Big(1+\frac{1}{\lambda_w}\Big)\big(\hat{\tilde{w}}_t + \hat{\tilde{\Pi}}^w_{t,t+s} - \hat{w}_{t+s}\big)\Big) + \hat{\lambda}_{t+s}\Big]\Big\} \\
\Leftrightarrow 0 =& E_t\Big\{\sum_{s=0}^{\infty}\xi_w^s\beta^s\Big[\hat{\tilde{w}}_t\Big(1+\nu\Big(1+\frac{1}{\lambda_w}\Big)\Big) + \hat{\tilde{\Pi}}^w_{t,t+s} - \hat{\lambda}_{w,t+s} - \hat{b}_{t+s} \\
&- \nu\Big(\hat{L}_{t+s} - \Big(1+\frac{1}{\lambda_w}\Big)\big(\hat{\tilde{\Pi}}^w_{t,t+s} - \hat{w}_{t+s}\big)\Big) + \hat{\lambda}_{t+s}\Big]\Big\}.
\end{aligned}$$

Solving for the summation,

$$\begin{aligned}
\frac{\nu_w}{1-\xi_w\beta}\hat{\tilde{w}}_t =& E_t\Big\{\sum_{s=0}^{\infty}\xi_w^s\beta^s\Big[-\Big(1+\nu\big(1+\frac{1}{\lambda_w}\big)\Big)\hat{\tilde{\Pi}}^w_{t,t+s} + \hat{\psi}_{t+s}\Big]\Big\} \\
=& -\nu_w\hat{\tilde{\Pi}}^w_{t,t} + \hat{\psi}_t + E_t\Big\{\sum_{s=0}^{\infty}\xi_w^s\beta^s\Big[-\nu_w\hat{\tilde{\Pi}}^w_{t,t+s} + \hat{\psi}_{t+s}\Big]\Big\} \\
=& \hat{\psi}_t - \frac{\xi_w\beta}{1-\xi_w\beta}\nu_w\hat{\Pi}^w_{t,t+1} + \xi_w\beta E_t\Big\{\sum_{s=0}^{\infty}\xi_w^s\beta^s[-\nu_w\hat{\Pi}^w_{t+1,t+1+s} + \hat{\psi}_{t+1+s}]\Big\} \\
=& \hat{\psi}_t + \frac{\xi_w\beta}{1-\xi_w\beta}\nu_w E_t\big[\hat{\tilde{w}}_{t+1} - \hat{\tilde{\Pi}}^w_{t,t+1}\big]. \qquad \text{(C.50)}
\end{aligned}$$

where

$$\begin{aligned}
\hat{\psi}_t &\equiv \hat{\lambda}_{w,t} + \hat{b}_t + \nu\hat{L}_t + \nu\Big(1+\frac{1}{\lambda_w}\Big)\hat{w}_t - \hat{\lambda}_t, \qquad \text{(C.51)} \\
\nu_w &\equiv 1 + \nu\Big(1+\frac{1}{\lambda_w}\Big),
\end{aligned}$$

and recall that $\hat{\tilde{\Pi}}^w_{t,t} = 0$.

Wages evolve as,

$$\hat{w}_t = (1-\xi_w)\hat{\tilde{w}}_t + \xi_w\left(\hat{w}_{t-1} + \iota_w\hat{\pi}_{c,t-1} + \iota_w\Big(\hat{z}_{t-1} + \frac{a_c}{1-a_i}\hat{v}_{t-1}\Big) - \hat{\pi}_{c,t} - \hat{z}_t - \frac{a_c}{1-a_i}\hat{v}_t\right)$$

$$\Leftrightarrow \hat{w}_t = (1-\xi_w)\hat{\tilde{w}}_t + \xi_w(\hat{w}_{t-1} + \hat{\tilde{\Pi}}^w_{t,t-1}). \tag{C.52}$$

Equation (C.52) can be solved for $\hat{\tilde{w}}_t$. This expression, as well as the formulation for $\hat{\psi}_t$ given in (C.51) can be plugged into equation (C.50). After rearranging this yields the wage Phillips curve,

$$\begin{aligned}\hat{w}_t =& \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\beta}{1+\beta}E_t\hat{w}_{t+1} - \kappa_w\hat{g}_{w,t} + \frac{\iota_w}{1+\beta}\hat{\pi}_{c,t-1} - \frac{1+\beta\iota_w}{1+\beta}\hat{\pi}_{c,t} \\ &+ \frac{\beta}{1+\beta}E_t\hat{\pi}_{c,t+1} + \kappa_w\hat{\lambda}_{w,t} + \frac{\iota_w}{1+\beta}\big(\hat{z}_{t-1} + \frac{a_c}{1-a_i}\hat{v}_{t-1}\big) \\ &- \frac{1+\beta\iota_w-\rho_z\beta}{1+\beta}\hat{z}_t - \frac{1+\beta\iota_w-\rho_v\beta}{1+\beta}\frac{a_c}{1-a_i}\hat{v}_t.\end{aligned} \tag{C.53}$$

where

$$\kappa_w \equiv \frac{(1-\xi_w\beta)(1-\xi_w)}{\xi_w(1+\beta)\big(1+\nu\big(1+\frac{1}{\lambda_w}\big)\big)},$$

$$\hat{g}_{w,t} \equiv \hat{w}_t - (\nu\hat{L}_t + \hat{b}_t - \hat{\lambda}_t).$$

C.7.6 Financial sector

The part of the economy concerned with the banking sector is described by the following equations:

The stochastic discount factor:

$$\hat{\lambda}^B_t = \hat{\lambda}_t - \hat{\lambda}_{t-1}. \tag{C.54}$$

Definition of ν for $x = C, I$:

$$\begin{aligned}\hat{\nu}_{x,t} =&(1-\theta_B\beta z_1^x)[\hat{\lambda}^B_{t+1} - \hat{z}_{t+1} - \frac{a_c}{1-a_i}\hat{v}_{t+1}] \\ &+ \frac{1-\theta_B\beta z_1^x}{R_x^B\pi_C - R}[R_x^B\pi_C\hat{R}^B_{x,t+1} + R_x^B\pi_C\hat{\pi}_{C,t+1} - R\hat{R}_t] + \theta_B\beta z_1^x[\hat{z}^x_{1,t+1} + \hat{\nu}_{x,t+1}]. \end{aligned} \tag{C.55}$$

Definition of η:

$$\begin{aligned}\hat{\eta}_{x,t} =&(1-\theta_B\beta z_2^x)[\hat{\lambda}^B_{t+1} - \hat{z}_{t+1} - \frac{a_c}{1-a_i}\hat{v}_{t+1} + \hat{R}_t] \\ &+ \theta_B\beta z_2^x[\hat{z}^x_{2,t+1} + \hat{\eta}_{t+1}], \qquad x = C, I. \end{aligned} \tag{C.56}$$

Definition of z_1:

$$\hat{z}^x_{1,t} = \hat{\varrho}_{x,t} - \hat{\varrho}_{x,t-1} + \hat{z}^x_{2,t}, \qquad x = C, I. \tag{C.57}$$

Definition of z_2 for $x = C, I$:

$$\hat{z}^x_{2,t} = \frac{\pi_C}{(R_x^B - R)\varrho_x + R}[R_x^B\varrho_x[\hat{R}^B_{x,t} + \hat{\pi}_{C,t}] + \frac{R}{\pi_C}(1-\varrho_x)\hat{R}_{t-1} + (R_x^B\pi_C - R)\frac{\varrho_x}{\pi_C}\hat{\varrho}_{x,t-1}] - \hat{\pi}_{C,t}. \tag{C.58}$$

The leverage ratio:

$$\hat{\varrho}_{x,t} = \hat{\eta}_{x,t} + \frac{\nu}{\lambda_B - \nu}\hat{\nu}_{x,t}, \qquad x = C, I. \tag{C.59}$$

The leverage equation:

$$\hat{q}_{x,t} + \hat{s}_{x,t} = \hat{\varrho}_{x,t} + \hat{n}_{x,t}. \tag{C.60}$$

The bank's wealth accumulation equation

$$\begin{aligned}\hat{n}_{x,t} =&\theta_B\frac{\varrho_x}{\pi_C}e^{-g_a - \frac{a_c}{1-a_i}g_v}\Big[R_x^B\pi_C[\hat{R}^B_{x,t} + \hat{\pi}_{C,t}] + \Big(\frac{1}{\varrho_x} - 1\Big)R\hat{R}_{t-1} + (R_x^B\pi_C - R)\hat{\varrho}_{x,t-1}\Big] \\ &+ \frac{\theta_B}{\pi_C}e^{-g_a - \frac{a_c}{1-a_i}g_v}[(R_x^B\pi_C - R)\varrho_x + R]\Big[-\hat{z}_t - \frac{a_c}{1-a_i}\hat{v}_t + \hat{n}_{x,t-1} - \hat{\pi}_{C,t}\Big] \\ &+ (1 - \frac{\theta_B}{\pi_C}e^{-g_a - \frac{a_c}{1-a_i}g_v}[(R_x^B\pi_C - R)\varrho_x + R])[\hat{q}_{x,t} + \hat{s}_{x,t}], \qquad x = C, I. \end{aligned} \tag{C.61}$$

The borrow in advance constraint:

$$\hat{\bar{k}}_{x,t+1} = \hat{s}_{x,t}, \qquad x = C, I. \tag{C.62}$$

The bank's stochastic return on assets in sector $x = C, I$:

$$\hat{R}^B_{x,t} = \frac{1}{r^K_x + q_x(1-\delta_x)}[r^K_x(\hat{r}^K_{x,t} + \hat{u}_{x,t}) + q_x(1-\delta_x)\hat{q}_{x,t}] - \hat{q}_{x,t-1} + \xi^K_{x,t} + \hat{z}_t - \frac{1-a_c}{1-a_i}\hat{v}_t. \tag{C.63}$$

Excess (nominal) return:

$$\hat{R}^S_{x,t} = \frac{R^B_x \pi_C}{R^B_x \pi_C - R}(\hat{R}^B_{x,t+1} + \hat{\pi}_{C,t+1}) - \frac{R}{R^B_x \pi_C - R}\hat{R}_t, \qquad x = C, I. \tag{C.64}$$

C.7.7 Monetary policy and market clearing

Monetary policy rule:

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)\Big[\phi_\pi \hat{\pi}_{c,t} + \phi_{\Delta Y}(\hat{y}_t - \hat{y}_{t-1})\Big] + \hat{\eta}_{mp,t} \tag{C.65}$$

Resource constraint in the consumption sector:

$$\hat{c}_t + \Big(r^K_C \frac{\bar{k}_C}{c}\hat{u}_{C,t} + r^K_I \frac{\bar{k}_I}{c}\hat{u}_{I,t}\Big)e^{-\frac{1}{1-a_i}g_v} = \frac{c+F_c}{c}[\hat{a}_{lt} + a_c \hat{k}_{C,t} + (1-a_c)\hat{L}_{C,t}] \tag{C.66}$$

Resource constraint in the investment sector:

$$\hat{i}_t = \frac{i+F_I}{i}[\hat{v}_{lt} + a_i \hat{k}_{I,t} + (1-a_i)\hat{L}_{I,t}] \tag{C.67}$$

Definition of GDP:

$$\hat{y}_t = \frac{c}{c+p_i i}\hat{c}_t + \frac{p_i i}{c+p_i i}(\hat{i}_t + \hat{p}_{i,t}) + \hat{g}_t. \tag{C.68}$$

Market clearing:

$$\frac{L_C}{L}\hat{L}_{C,t} + \frac{L_I}{L}\hat{L}_{I,t} = \hat{L}_t, \quad \frac{i_C}{i}\hat{i}_{C,t} + \frac{i_I}{i}\hat{i}_{I,t} = \hat{i}_t, \quad \frac{n_C}{n}\hat{n}_{C,t} + \frac{n_I}{n}\hat{n}_{I,t} = \hat{n}_t. \tag{C.69}$$

C.7.8 Exogenous processes

The 11 exogenous processes of the model can be written in log-linearized form as follows:

Price markup in sector $x = C, I$:

$$\hat{\lambda}^x_{p,t} = \rho_{\lambda^x_p}\hat{\lambda}^x_{p,t-1} + \varepsilon^x_{p,t}. \tag{C.70}$$

The TFP growth (consumption sector):

$$\hat{z}_t = \rho_z \hat{z}_{t-1} + \varepsilon_t^z. \tag{C.71}$$

The TFP growth (investment sector):

$$\hat{v}_t = \rho_v \hat{v}_{t-1} + \varepsilon_t^v. \tag{C.72}$$

Wage markup:

$$\hat{\lambda}_{w,t} = \rho_w \hat{\lambda}_{w,t-1} + \varepsilon_{w,t}. \tag{C.73}$$

Preference:

$$\hat{b}_t = \rho_b \hat{b}_{t-1} + \varepsilon_t^b. \tag{C.74}$$

Monetary policy:

$$\hat{\eta}_{mp,t} = \varepsilon_t^{mp}. \tag{C.75}$$

Government spending:

$$\hat{g}_t = \rho_g \hat{g}_{t-1} + \varepsilon_t^g. \tag{C.76}$$

The Marginal Efficiency of Investment (MEI):

$$\hat{\mu}_t = \rho_\mu \hat{\mu}_{t-1} + \varepsilon_t^\mu \tag{C.77}$$

The TFP stationary (consumption sector):

$$\hat{a}_{lt} = \rho_{a_l} \hat{a}_{l,t-1} + \varepsilon_t^{a_l}. \tag{C.78}$$

The TFP stationary (investment sector):

$$\hat{v}_{lt} = \rho_{v_l} \hat{v}_{l,t-1} + \varepsilon_t^{v_l}. \tag{C.79}$$

The entire log-linear model is summarized by equations (C.39) - (C.49) and (C.53) -

(C.69) as well as the shock processes (C.70) - (C.79).

C.8 Measurement equations

For estimation, model variables are linked with observables using measurement equations. Letting a superscript "d" denote observable series, then the model's measurement equations are as follows:

Real consumption growth,

$$\Delta C_t^d \equiv \log\left(\frac{C_t}{C_{t-1}}\right) = \log\left(\frac{c_t}{c_{t-1}}\right) + \hat{z}_t + \frac{a_c}{1-a_i}\hat{v}_t,$$

Real investment growth,

$$\Delta I_t^d \equiv \log\left(\frac{I_t}{I_{t-1}}\right) = \log\left(\frac{i_t}{i_{t-1}}\right) + \frac{1}{1-a_i}\hat{v}_t,$$

Real wage growth,

$$\Delta W_t^d \equiv \log\left(\frac{W_t}{W_{t-1}}\right) = \log\left(\frac{w_t}{w_{t-1}}\right) + \hat{z}_t + \frac{a_c}{1-a_i}\hat{v}_t,$$

Real output growth,

$$\Delta Y_t^d \equiv \log\left(\frac{Y_t}{Y_{t-1}}\right) = \log\left(\frac{y_t}{y_{t-1}}\right) + \hat{z}_t + \frac{a_c}{1-a_i}\hat{v}_t,$$

Consumption sector inflation,

$$\pi_{C,t}^d \equiv \pi_{C,t} = \hat{\pi}_{C,t} \quad \text{and} \quad \hat{\pi}_{C,t} = \log(\pi_{C,t}) - \log(\pi_C),$$

Relative price of investment

$$\Delta\left(\frac{P_t^I}{P_t^C}\right)^d \equiv \log\left(\frac{p_t^i}{p_{t-1}^i}\right) + \hat{z}_t + \frac{a_c - 1}{1-a_i}\hat{v}_t,$$

Total hours worked,

$$L_t^d \equiv \log L_t = \hat{L}_t,$$

Nominal interest rate (federal funds rate),

$$R_t^d \equiv \log R_t = \log \hat{R}_t,$$

Consumption sector corporate spread,

$$R_{C,t}^{S,d} \equiv \log R_{C,t}^S = \frac{R_x^B \pi_C}{R_x^B \pi_C - R}(\log \hat{R}_{C,t+1}^B + \log \hat{\pi}_{C,t+1}) - \frac{R}{R_x^B \pi_C - R}\log \hat{R}_t,$$

Investment sector corporate spread,

$$R_{I,t}^{S,d} \equiv \log R_{I,t}^{S} = \frac{R_x^B \pi_C}{R_x^B \pi_C - R}(\log \hat{R}_{I,t+1}^{B} + \log \hat{\pi}_{C,t+1}) - \frac{R}{R_x^B \pi_C - R} \log \hat{R}_t,$$

Real total equity capital growth,

$$\begin{aligned}\Delta N_t^d \equiv & \log\Big(\frac{N_t}{N_{t-1}}\Big) \\ = & e^{g_a + \frac{a_c}{1-a_i} g_v}\Big(\frac{n_C}{n_C + n_I}(\hat{n}_{C,t} - \hat{n}_{C,t-1}) + \frac{n_I}{n_C + n_I}(\hat{n}_{I,t} - \hat{n}_{I,t-1}) + \hat{z}_t + \frac{a_c}{1-a_i}\hat{v}_t\Big).\end{aligned}$$