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Is risk the fuel of the business cycle? Financial frictions and oil market disturbances

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Is Risk the Fuel of the Business Cycle? Financial Frictions and Oil Market Disturbances

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Abstract

I estimate a dynamic stochastic general equilibrium (DSGE) model for the United States that incorporates oil market shocks and risk shocks working through credit market frictions. The findings of this analysis indicate that risk shocks play a crucial role during the Great Recession and the Dot-Com bubble but not during other economic downturns. Credit market frictions do not amplify persistent oil market shocks. This result holds as long as entry and exit rates of entrepreneurs are independent of the business cycle.

Keywords: financial frictions, NK-DSGE models, oil price, recessions, risk

JEL classification: E32, E37, E44, Q43

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1 Introduction

All recessions in the United States since 1990 have in common that oil prices increase right before the recession starts. An increase in oil prices itself only modestly increases costs for firms and consumers of durable consumption goods. At the same time credit declines and the interest rate premium for more risky assets increases, as well as bankruptcy rates. So can oil price fluctuations trigger a reduction in credit and increase financial risk premiums? This paper investigates this question by extending and estimating the standard New-Keynesian dynamic stochastic general equilibrium (henceforth **NK-DSGE**) model with credit market frictions and oil as production factor (Bernanke 1983, Bernanke et al. 1999, Christiano et al. 2005, 2014, Kilian 2008).

Since the Great Recession of 2007-2009 a frequently held assumption in macroeconomics that financial markets play a minor role in real economic variables has been challenged by multiple scholars and credit market variables have been incorporated into many quantitative theoretical and empirical models. This allows for interdependence between financial markets and real economic variables. Asymmetric information in combination with costly state verification or borrowing limits will drive a wedge between returns on safe and risky assets. Macroeconomic models incorporating such channels allow for a deeper understanding of the interaction between financial markets and economic fluctuations (Brunnermeier 2009, Brunnermeier & Sannikov 2014, Buera & Shin 2013, Del Negro et al. 2017, Eden 2017, Jermann & Quadrini 2012, Khan & Thomas 2013, López-Salido et al. 2017, Mian & Sufi 2014).

Christiano et al. (2014) (hereafter **CMR**) show that financial market frictions can be an important driver of the US business cycle. They employ an NK-DSGE model, building upon the foundational work of Smets & Wouters (2003), Christiano et al. (2005), and Smets & Wouters (2007) (henceforth **CEE**). They extend the model in Bernanke et al. (1999), with time-varying productivity dispersion in the capital formation process. Their estimations reveal that shocks to the credit market, referred to as risk shocks, can account for a substantial portion of the variance in US GDP growth. This finding requires the inclusion of quantitative financial variables such as credit growth and net worth to the set of observable variables. Additionally, the estimated persistence in prices, wages, and consumption has to be rather high to support the dominant role of risk shocks in shaping GDP growth.

Another strand of literature aims at clarifying the role of oil prices for the business cycle. The Gulf War in the 1990s and the Russian invasion of Ukraine in 2022 are visible in the US business cycle through higher inflation coinciding with higher oil price fluctuations. There is a vast literature investigating the causes of oil price fluctuations. Kilian (2008) shows that rising oil prices can be either a result of higher demand due to

Table 1: Overview of models

Abbreviation	Description
CEE	The workhorse model introduced by Christiano et al. (2005). It is a balanced growth model with price and wage rigidities.
CMR	The model introduced by Christiano et al. (2014) is based on Christiano et al. (2005) and includes financial frictions as described in Bernanke et al. (1999).
CEE–Oil	The CEE model with oil as a production factor.
CMR–Oil	The CMR model with oil as a production factor.

business cycle booms or oil supply shocks mainly associated with political conflicts in oil-exporting countries. Oil price surges before the Great Recession can be explained by higher economic activity, while oil price increases in 1990 reflect uncertainty about oil supply due to uncertainty triggered by the Iraq invasion of Kuwait (Kilian 2008, p. 904). Baumeister et al. (2022) show that factors driving oil price fluctuations are rather global than local, implying a more exogenous nature of oil price fluctuations to the US business cycle. Kilian (2008) and Elder & Serletis (2009) provide different channels for how oil and financial markets might be interdependent. However, structural models incorporating oil market disturbances and financial market frictions are still rare.

This paper extends both models by CMR and CEE to include oil as a production factor (henceforth **CMR–Oil**). The extended version of the CEE model (henceforth **CEE–Oil**) serves as the benchmark model. A nested constant elasticity of substitution (henceforth **CES**) production function allows to account for different degrees of substitution between production factors. The production sector is modeled as consisting of two layers: the top layer combining labour and a composite production factor. The next layer combines oil and capital services to the composite production factor. In each layer, the production factors might be complements or substitutes, with the Cobb-Douglas production function as a particular case.

A detailed historical decomposition analysis spanning from 1984 to 2022 underscores that the primary drivers of the United States business cycle during this period do not originate from either risk shocks stemming from financial frictions or oil supply shocks.¹ However, during the Great Recession and the Dot Com Bubble, I find that risk shocks do play a significant role in shaping economic outcomes. The Great Recession in particular can largely be attributed to risk shocks, as evidenced by the heightened external finance premium (Brunnermeier et al. 2021). When considering the COVID-

¹The sample begins with the second quarter of 1984 because data on oil taxes from the Organization of Petroleum Exporting Countries is only accessible from that point onward.

19 recession, risk shocks do not emerge as the primary driving force, highlighting the unique nature of this economic downturn (Eichenbaum et al. 2022, Guntin et al. 2023). The analysis confirms the findings by Christiano et al. (2014) that risk shocks exhibit their most significant impact during economic recessions, while their influence diminishes considerably during periods of economic stability. However, this paper contrary to the motivation for the financial accelerator by Bernanke et al. (1999), shows that oil price fluctuations are not amplified by credit market frictions and are not able to explain the observed decline in credit and the increase in the external finance premium during the last four recessions in the United States.

Moreover, while monetary policy shocks are amplified through the financial accelerator mechanism, the same does not hold true for oil supply shocks. This observation stands in contrast to the findings suggested by Bernanke et al. (1999). There are two reasons for that the financial accelerator amplifies oil supply shocks only if they have low persistence. In this case, overall effects on economic activity are small. Secondly, oil supply shocks lead to increased marginal costs but lack a direct endogenous connection to the entry and exit decisions of entrepreneurs which would be necessary to be amplified by the financial accelerator. While surges in oil supply costs result in higher bankruptcy rates, they do not affect the market entry and exit rates of entrepreneurs in the model. It confirms previous research showing that the existence of financial accelerator mechanisms depends on a multitude of factors (Bigio & La'O 2020, Leibovici 2021, Moll 2014).

This paper shows that oil price increases in combination with a classical financial accelerator can increase the external finance premium as well as bankruptcy rates. Contrary to the motivation by Bernanke et al. (1999) for the financial accelerator the effect of oil price increases on economic activity is not amplified by credit market frictions.

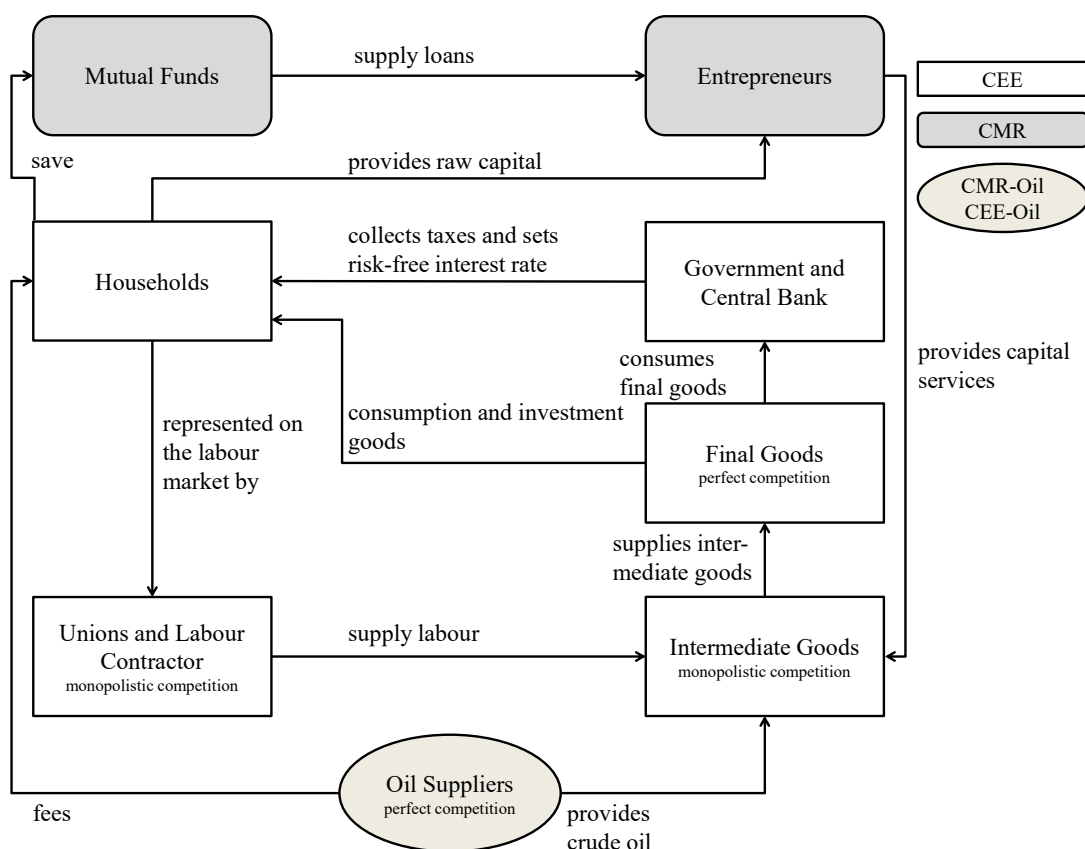
The structure of the paper is as follows. First, I will describe the different model versions (Section 2), especially focusing on the extension of CEE and CMR models. Afterwards, I will describe the estimation procedure (Section 3). The findings of this study are systematically presented in Section 4. Subsequently, these results are critically analyzed and discussed in Section 5. Section 6 concludes the paper.

2 Model

This section provides an overview of the implemented models. Figure 1 presents a visual summary of all the model versions. To begin, the section will provide a non-technical explanation of the CEE model. Next, it will outline the adjustments made by CMR to incorporate the financial accelerator into the CEE model. Finally, it will document

the alterations made to incorporate oil as a production factor into both the CEE and CMR models. The CEE and CMR models are closed economy models without trade with the rest of the world. Balke & Brown (2018) develops an open economy model with oil as a production factor. The model extension with oil as a production factor assumes away exports and imports of other goods and services to isolate the interaction between oil and financial frictions. Oil suppliers are either domestic producers or oil importers to account for the changing composition of oil consumption over the sample and the implication for GDP.

Figure 1: Models overview



Source: own exhibition.

Note: The diagram illustrates relationships between the different agents in the model. Rectangles represent agents present in the CEE model, rounded rectangles represent agents present in the CMR model and ellipses represent agents present in the CEE-Oil and CMR-Oil model.

2.1 CEE

The baseline NK-DSGE model is depicted in Figure 1 and the equations are reported in Appendix C.1.² I generally follow the description of Christiano et al. (2014) to describe the baseline DSGE model. All households j_h provide capital services K^s and hours worked h in each period t . Households either consume C or invest I final goods into their raw capital stock \bar{K}_{t-1} purchased at the price $P_{t+\kappa}$. The price of investment goods follows a different long-run trend captured by $\Upsilon^{t+\kappa}\mu_{\Upsilon,t+\kappa}$. The raw capital stock depreciates at a constant fraction δ . Capital services $K_t^s = u_t \bar{K}_{t-1}$ are rented to intermediate goods-producing firms. Households face utilization costs $a(u_t)$ and investment adjustment cost $\mathcal{S}(\frac{I_t}{I_{t-1}})$. Investment adjustment costs depend on the growth rate of investment. The stock of raw capital evolves according to the standard law of motion. Households can buy and sell raw capital from other households at price $Q_{\bar{K},t+\kappa}$. Firms are owned by households, which receive firm profits $(\Delta_{j_h,t+\kappa})$.

The government charges a tax rate on consumption τ^c , labour τ^l and capital income τ^K . The government also collects taxes $Tax_{t+\kappa}$ and provides lump-sum transfers $Tr_{t+\kappa}$. Government expenditures G_t are financed by tax revenues and public debt. Households can purchase bonds B_t and get an interest rate R_t . Households live infinitely and maximize intertemporal discounted utility (1) subject to their budget constraint (2).

$$\max_{\substack{\bar{K}_{j_h,t+\kappa+1}, I_{j_h,t+\kappa} \\ C_{j_h,t+\kappa}, B_{j_h,t+\kappa+1}}} E_0 \sum_{\kappa=0}^{\infty} \beta^\kappa \left[\zeta_{c,t+\kappa} \left\{ \ln(C_{j_h,t+\kappa} - bC_{j_h,t+\kappa-1}) \right\} - \psi_L \int_0^1 \frac{h_{j_h,j_l,t+\kappa}^{1+\sigma_L}}{1+\sigma_L} dj_l \right], \quad (1)$$

$$\begin{aligned} \text{s.t. } & (1 + \tau^c)P_{t+\kappa}C_{j_h,t+\kappa} + B_{j_h,t+\kappa+1} + \left(\frac{P_{t+\kappa}}{\Upsilon^{t+\kappa}\mu_{\Upsilon,t+\kappa}} \right) I_{j_h,t+\kappa} + Tax_{t+\kappa} + Q_{\bar{K},t+\kappa} (1 - \delta)\bar{K}_{t+\kappa} \\ & = (1 - \tau^l) \int_0^1 W_{j_h,j_l,t+\kappa} h_{j_h,j_l,t+\kappa} dj_l + R_{t+\kappa} B_{t+\kappa} + Q_{\bar{K},t+\kappa} \bar{K}_{j_h,t+\kappa+1} + \Delta_{j_h,t+\kappa} + Tr_{j_h,t+\kappa}. \end{aligned} \quad (2)$$

Households discount the future with the discount factor β . In each period household utility depends positively on the change in the current consumption level to the previous period and a demand preference shock $\zeta_{c,t+\kappa}$. Habit persistence b measures how important the current change in consumption is for utility. Working is associated with disutility ψ_L , where the inverse Frisch elasticity σ^L measures how sensitive labour supply is to changes in wages. In each period the budget constraint (2) is binding.

Firms j_f use capital services K^s and homogenous working hours l to produce intermediate goods $Y_{j_f,t}$. A Cobb-Douglas function combines the two primary production

²All symbols are explained in Table 5, Table 6, Table 7, Table 8 and Table 9 in the Appendix.

factors. Firms have to pay wages W_t and a rental price for capital services $\tilde{r}_t^k P_t$. One can derive the demand for production factors from cost minimization subject to a given amount of output. Therefore, marginal costs S_t depend directly on the market prices for the primary production factors. Fixed costs ensure zero profits in steady-state and reduce the incentives for new firms to enter the market (see Christiano et al. 2010).

$$\begin{aligned}
& \min_{l_{j_f,t}, K_{j_f,t}^s} W_t l_{j_f,t} + P_t \tilde{r}_t^k K_{j_f,t}^s, \\
& \text{s.t. } Y_{j_f,t} = \epsilon_t \left(\frac{K_{j_f,t}^s}{\Upsilon^{t-1}} \right)^{\alpha_K} (\epsilon_t^h z_t l_{j_f,t})^{\alpha_N} - \phi_t z_t, \\
& l_{j_f,t} > 0, K_{j_f,t}^s > 0.
\end{aligned} \tag{3}$$

These intermediate goods are imperfect substitutes to produce a final good Y_t using a constant elasticity of substitution production function. Substitution between the different products determines the markup λ^f in the long run. Profit maximization of the final goods producer (4) implies that the overall price index P_t is a weighted average over all prices set by intermediate goods producers.

$$\begin{aligned}
& \max_{Y_{j_f,t}} P_t Y_t - \int_0^1 P_{j_f,t} Y_{j_f,t} dj_f, \\
& \text{s.t. } Y_t = \left(\int_0^1 Y_{j_f,t}^{\frac{1}{\lambda^f}} dj_f \right)^{\lambda^f}.
\end{aligned} \tag{4}$$

Intermediate goods-producing firms have price-setting power. They set their price $P_{j_f,t}$ to maximize expected discounted profits. Only a random fraction $1 - \xi^p$ is allowed in each period to reset their price. All other intermediate firms update their prices according to an indexation rule $\tilde{\pi}_t P_{j_f,t-1}$. This two-stage production process, in combination with random price-setting, allows to model price rigidity. Further, it ensures that price inflation π_t can influence real economic variables in the model. The inter-temporal expected discounted profit (5) is maximized by choosing an optimal price \tilde{P}_t , subject to the demand for intermediate products (6).

$$\max_{\tilde{P}_t} \mathbb{E}_t \sum_{\kappa=0}^{\infty} (\beta \xi^p)^\kappa \lambda_{t+\kappa} (\tilde{\Pi}_{t,t+\kappa} \tilde{P}_t Y_{j_f,t+\kappa} - S_{t+\kappa} Y_{j_f,t+\kappa}), \tag{5}$$

$$\text{s.t. } Y_{j_f,t+\kappa} = Y_{t+\kappa} \left(\frac{\tilde{\Pi}_{t,t+\kappa} \tilde{P}_t}{P_{t+\kappa}} \right)^{-\frac{\lambda^f}{\lambda^f-1}}. \tag{6}$$

Unions represent different types of labour, j_l and sell them to a labour contractor. Labour contractors sell homogenous labour l_t to the intermediate goods-producing firm. A CES aggregation function bundles different types of labour. The parameter λ^w determines the degree of substitutability between the different types of labour. Total hours worked in each year in the economy is denoted by h_t . Similar to the problem of the intermediate goods producing firm only a fraction of unions $1 - \xi^w$ is allowed to reset the wage. All other unions will reset their wage according to an indexation rule $W_{j_l,t} = \tilde{\pi}_t^w W_{j_l,t-1}$. Unions reset the wage to maximize the expected discounted wage bill less the foregone utility of the household working (7), subject to the demand for the specific type of labour by labour contractors (8). Unions take into account the disutility imposed on households by supplying labour to the intermediate goods-producing firms.

$$\max_{\tilde{W}_t} E_t \sum_{\kappa=0}^{\infty} (\beta \xi^w)^\kappa \left[\lambda_{t+\kappa} \tilde{W}_t \tilde{\Pi}_{t,t+\kappa}^w h_{j_l,t+\kappa} (1 - \tau_{t+\kappa}^l) - \psi_L \frac{h_{j_l,t+\kappa}^{1+\sigma_L}}{1 + \sigma_L} \right], \quad (7)$$

$$\text{s.t. } h_{j_l,t+\kappa} = l_{t+\kappa} \left(\frac{\tilde{\Pi}_{t,t+\kappa}^w \tilde{W}_t}{W_{t+\kappa}} \right)^{\frac{\lambda^w}{1-\lambda^w}}. \quad (8)$$

Fiscal policy reflected by government expenditures G_t are exogenous. Monetary policy sets the risk-free interest rate for bonds according to a Taylor rule (9). The risk-free interest rate R_t responds to deviations in previous inflation π_{t-1} from its target and in GDP growth $\frac{C_{t-1}+I_{t-1}+G_{t-1}}{C_{t-2}+I_{t-2}+G_{t-2}}$ from its potential (see Bernanke et al. 1999).³

$$\frac{1 + R_t}{1 + \bar{R}} = \left(\frac{1 + R_{t-1}}{1 + \bar{R}} \right)^{\tilde{\rho}} \left\{ \left(\frac{\pi_{t-1}}{\bar{\pi}} \right)^{1+\tilde{a}_\pi} \left(\frac{\mu_{t-1}^z}{\bar{\mu}^z} \frac{c_{t-1} + \frac{i_{t-1}}{\mu_{t-1}^\gamma} + g_{t-1}}{c_{t-2} + \frac{i_{t-2}}{\mu_{t-2}^\gamma} + g_{t-2}} \right)^{\tilde{a}_{\Delta y}} \right\}^{1-\tilde{\rho}} + \frac{\sigma^{x^p}}{4} x_t^p. \quad (9)$$

The economy follows a balanced growth path. All real variables have a common stochastic trend $z_t = \mu_t^z z_{t-1}$. This trend reflects long-run technological change leading to economic growth. Nominal variables are scaled by the nominal price level $P_t = \pi_t P_{t-1}$. Capital follows the common stochastic trend and has a specific deterministic trend of Υ^t . Temporary deviations from the balanced growth path are the result of shocks hitting the economy. The standard model comprises a shock to government expenditure g_t , total factor productivity ϵ_t , labour productivity ϵ_t^h , price mark-up shocks ϵ_t^p , wage mark-up shock ϵ_t^w , technological growth rate μ_t^z , shocks

³Christiano et al. (2014) use in their paper the monetary policy rule as stated in (9), with expected inflation and current GDP growth instead of past values.

to the relative price of investment μ^{Υ} , consumption preference shock ζ_t^c , and investment adjustment cost shocks ζ_t^i . All shocks follow an autoregressive moving average (henceforth **ARMA**) process. Each shock is driven by a white noise process $\eta^{j_s}, j_s \in \{g, \epsilon, \epsilon^h, \epsilon^p, \epsilon^w, \mu^z, \mu^{\Upsilon}, \zeta^c, \zeta^i\}$.

2.2 CMR

CMR introduces entrepreneurs j_E and mutual funds j_{MF} to the CEE model. Appendix C.2 reports different equations and modifications of the CMR model compared to the CEE model. In principle, the financial accelerator mechanism is caused by a conflict of interest between two agents (see Bernanke et al. 1999). Mutual funds use deposits (raw capital) from households to provide loans $B_{j_E, t+1}$ at the gross nominal interest rate Z_{t+1} to entrepreneurs. Mutual funds pay an interest rate R_t for household deposits. Entrepreneurs are owned by households and can either borrow or use their net worth $N_{j_E, t}$ to produce effective capital $K_{j_E, t+1} = \omega_t \bar{K}_{j_E, t+1}$. Each household j_h owns a continuum of entrepreneurs j_E . All entrepreneurs experience in each period an idiosyncratic productivity shock ω_t , which follows a log-normal distribution with an expectation equal to one and time-varying standard deviation σ_t . The idiosyncratic productivity shock decides how much of the raw capital transforms into effective capital. Households still own raw capital, but they sell it to entrepreneurs in each period at a price $Q_{\bar{K}, t-1}$. Mutual funds are operating under perfect competition to supply loans to entrepreneurs j_E using deposits from households. These entrepreneurs are able to repay their loans with probability $1 - F_t(\bar{\omega}_{t+1})$, if their idiosyncratic productivity shock ω is bigger than a critical threshold $\bar{\omega}$. Entrepreneurs with an idiosyncratic productivity shock below this threshold file for bankruptcy. Mutual funds need to verify whether entrepreneurs are bankrupt or not. This monitoring process is associated with costs $d_{cost}(\bar{\omega})_t$, which are proportional by a factor μ to the assets of the bankrupt entrepreneurs. The expected value of the assets of bankrupt entrepreneurs is given by $G_t(\bar{\omega}_{t+1})(1 + R_{t+1}^k)Q_{\bar{K}, t}\bar{K}_{j_E, t+1}$. The term $G_t(\bar{\omega}_{t+1})$ represents the expected value of ω for bankrupt entrepreneurs. Costly state verification is an agency problem. Further, it introduces a wedge between the risk-free interest rate and the total return on raw capital R_t^k . This wedge is the credit spread and is a consequence of debt financing by entrepreneurs. Entrepreneurs choose the leverage ratio $L_t = \frac{N_{j_E, t} + B_{j_E, t+1}}{N_{j_E, t}}$ to maximize their expected profits subject to the cash constraint imposed by mutual funds. They

solve the following optimization problem

$$\begin{aligned} \max_{L_t} E_t \left[\int_{\bar{\omega}_{t+1}}^{\infty} \{(1 + R_{t+1}^k)\omega Q_{\bar{K},t} K_{jE,t+1} - B_{jE,t+1}(1 + Z_{t+1})\} f(\omega) d\omega \right] \quad (10) \\ \text{s.t. } \{1 - F_t(\bar{\omega}_{t+1})\}(1 + Z_{t+1})B_{jE,t+1} + (1 - \mu)G_t(\bar{\omega}_{t+1})(1 + R_{t+1}^k)Q_{\bar{K},t}\bar{K}_{jE,t+1} \dots \\ \geq B_{jE,t+1}(1 + R_t). \end{aligned}$$

Entrepreneurs do not accumulate infinite wealth because of an exogenous survival rate of γ_t . They receive transfers from their households W_t^e each period. Entrepreneurs leaving the market $1 - \gamma_t$ can consume a share Θ of their assets and transfer the remaining share of assets to households. The inclusion of entrepreneurs alternates the resource constraint. The resource constraint derived from the budget constraint of households includes monitoring costs and transfers of entrepreneurs to households (see (11)). CMR include shocks to the survival rate of entrepreneurs η_t^γ and shocks to risk σ_t . These shocks are either anticipated η_t^s for $s \in [1, 8]$ or unanticipated η_t^σ .

Long-term bonds $B_{j_h,t}^L$ are also part of the model to control for variations in the term structure between short-term and long-term bonds. The spread between interest rates $\frac{1+R_t^L}{1+R_t}$ is determined by a term structure shock η_t^{term} .⁴

2.3 CEE and CMR with oil

This section describes the inclusion of oil markets into the CEE and CMR models. Oil production, consumption and prices have a deterministic trend of Υ^{O^t} , which follows the approach for raw capital in CEE and CMR. A nested CES production function is introduced rather than the particular case of a Cobb-Douglas production function. Introducing oil to the model modifies the budget constraint of the representative household and introduces supply curves for oil producers. Firms demand oil to produce intermediate goods.

2.3.1 The representative household

The households optimization problem is the same as in CMR except that the budget constraint features revenues from selling allowances to extract oil to local producers O_t^d . Households provide labour $h_{j_h,j_l,t}$ of type $j_l \in [0, 1]$, raw capital $\bar{K}_{j_h,t}$ at price $Q_{\bar{K},t}$, consume final goods $C_{j_h,t}$ and invest into raw capital $I_{j_h,t}$. Further, they can purchase government bonds of one-quarter maturity $B_{j_h,t+1}$ and four-quarter maturity $B_{j_h,t+4}^L$.

⁴One can use long-run government bonds that have a one-year maturity and not a ten-year maturity. The one-year maturity requires fewer auxiliary variables for the leads included in the model. Solving the model is less time-consuming, and therefore the estimation time is faster. Further, it allows running parameter identification tests discussed in Section 3.

The budget constraint is

$$\begin{aligned}
& (1 + \tau^c)P_t C_{j_h,t} + B_{j_h,t+1} + B_{j_h,t+4}^L + \left(\frac{P_{t+k}}{\Upsilon^t \mu_{\Upsilon,t}}\right) I_{j_h,t} + Q_{\bar{K},t} \bar{K}_{j_h,t+1} + Tax_{t+\kappa} \quad (11) \\
& = (1 - \tau^l) \int_0^1 W_{j_h,j_l,t} h_{j_h,j_l,t} dj_l + R_t B_{j_h,t} + (R_t^L)^4 B_{j_h,t}^L + Q_{\bar{K},t} (1 - \delta) \bar{K}_{j_h,t} + \Delta_{j_h,t} \\
& \quad + (1 - \Theta)(1 - \gamma_t) \{1 - \Gamma_{t-1}(\bar{\omega}_t)\} R_t^k Q_{\bar{K},t-1} \bar{K}_{j_h,t} + \Gamma^d(O_{j_h,t}^d) + Tr_{t+\kappa}.
\end{aligned}$$

The modification of the budget constraint implies a modification of the resource constraint as well. One can drop the index j_h for households under the assumption of representative households. Total profits of domestic firms Δ_t include expenditures for oil $P_t^O O_t$ used in the production process. Oil is the only tradable production factor. One could also assume that domestic households do not possess all active oil suppliers in the US. Further, households receive transfers from entrepreneurs $(1 - \Theta)(1 - \gamma_t) \{1 - \Gamma_{t-1}(\bar{\omega}_t)\} R_t^k Q_{\bar{K},t-1} \bar{K}_{j_h,t}$ leaving the market, after they consumed a fraction of their assets Θ . Oil consumption from domestic producers and imports has different implications for the income channel. The change in net oil imports for households and the resulting implications for the resource constraint. It allows me to include the time-varying positive and negative effects of changing net oil imports on the gross domestic product.

2.3.2 Oil producers

There exists a continuum $j_p \in [0, 1]$ of domestic oil producers (d) and oil importers (im) with access to infinite oil reserves. Infinite oil reserves imply that oil prices do not increase as a response to a depletion of resources (Hotelling 1931). Increasing oil prices leads to more exploration activity such that the infinite oil reserve assumption is a plausible simplification for a medium-term analysis (Bergholt et al. 2019). All domestic oil producers are identical, and the same is true for all oil importers. The homogeneity of suppliers rules out market power in the crude oil market. Domestic intermediate goods-producing firms buy oil $O_{j_p,t}^{d,im}$ for the same price P_t^O . Oil producers need to acquire the allowance and rig services to extract a barrel of oil from their respective households. It is also possible that the government sells the allowances and rig services to the household and transfers the revenues through tax cuts or subsidies. The price of allowances per barrel $\Gamma^{O,d,im}(O_t^{d,im})$ is a function of the current extraction level $O_t^{d,im}$. Firms maximize profits by choosing the amount of oil to extract

$$\max_{O_{jp,t}^{d,im}} P_t^O (1 - \tau_t^O) O_{jp,t}^{d,im} - \Gamma_t^{O,d,im}(O_{jp,t}^{d,im}). \quad (12)$$

The model simplifies the more complex tax system for oil production in the United States by a tax rate as a share of revenues τ^O . Different cost functions for foreign and domestic oil producers allow to capture the change in net oil imports and the composition of oil consumption over time.

The solution to the optimization problem is straightforward and represents the supply curve of the respective oil producers

$$\begin{aligned} P_t^O (1 - \tau^O) &= \frac{\partial \Gamma_t^{O,d,im}(O_t^{d,im})}{\partial O_t^{d,im}} = \frac{\partial \left(\frac{\zeta_t^{O,d,im}}{\Upsilon^{O^t} \gamma^{O,d,im}} O_t^{d,im} \right)^{1+\sigma^O}}{\partial O_t^{d,im}} \\ &= \left(\frac{\zeta_t^{O,d,im}}{\Upsilon^{O^t} \gamma^{O,d,im}} \right)^{1+\sigma^O} \left(O_t^{d,im} \right)^{\sigma^O}. \end{aligned} \quad (13)$$

Oil producers adjust the amount of oil supply to oil price fluctuations. Oil supply is either elastic or inelastic and depends on the parameter σ^O . The inverse price elasticity needs to be non-negative to ensure the existence of a maximum to the profit maximization problem. It also provides an upward-sloping supply curve. A lower elasticity implies a steeper supply curve resembling an empirically plausible inelastic oil supply. Domestic and foreign oil producers have the same price elasticity, but different cost functions. Differences in the extraction cost $\gamma^{O,d,im} > 0$ of the respective reserves drive long-run differences in the supply curve. Idiosyncratic temporary shocks $\zeta_t^{O,d,im} > 0$ allow for temporary changes in the costs to supply oil. The exploitation of oil reservoirs might entail temporarily different extraction costs depending on the remaining reserves or the quality of the oil extracted. Providing imported oil also requires transportation costs, which fluctuate over time. Total oil consumption in one period is domestic production, fewer oil exports plus oil imports. Therefore, the following identity has to hold in each period.

$$O_t = O_t^d - O_t^{ex} + O_t^{im}. \quad (14)$$

Domestic oil producers serve domestic and foreign demand. Under perfect competition, domestic oil suppliers have no price-setting power, which results in identical prices for foreign and domestic customers. A foreign demand shock ($\zeta^{O.ex}$) for domestic

oil represents the export share. Therefore, the following relation is specified

$$O_t^{ex} = \zeta_t^{O,ex} O_t^d. \quad (15)$$

The exogenous process $\zeta^{O,ex}$ follows an auto-regressive process of order one and defines the share of exported oil.

2.3.3 The representative firm

Firms (j_f) produce intermediate goods $Y_{j_f,t}$ using capital services $K_{j_f,t}^s$, hours of homogeneous labour $l_{j_f,t}$ and oil $O_{j_f,t}$. The production function for gross output $X_{j_f,t} = X(M_{j_f,t}, l_{j_f,t})$ is a nested constant elasticity of substitution function. Each firm has access to the same technology and can substitute between labour and a composite production factor $M_{j_f,t} = M(O_{j_f,t}, K_{j_f,t}^s)$ from capital services and oil. The elasticity of substitution in production, denoted by η^M and ranging between 0 and infinity, measures the ease with which firms can replace labour with other factors of production. The degree of substitution between oil and capital services is captured by the elasticity of substitution $\eta^O \in (0, \infty)$. Distribution parameters $\alpha_M \in (0, 1)$ and $\alpha_O \in (0, 1)$ define identical factor prices expenditure shares for capital-labour composite and oil production factors.

$$X(M_{j_f,t}, l_{j_f,t}) = \begin{cases} \epsilon_t M_{j_f,t}^{\alpha_M} (z_t l_{j_f,t})^{1-\alpha_M} & \text{if } \eta^M = 1, \\ \epsilon_t \left[(\alpha_M)^{\frac{1}{\eta^M}} M_{j_f,t}^{\frac{\eta^M-1}{\eta^M}} + (1-\alpha_M)^{\frac{1}{\eta^M}} (z_t l_{j_f,t})^{\frac{\eta^M-1}{\eta^M}} \right]^{\frac{\eta^M}{\eta^M-1}} & \text{otherwise,} \end{cases} \quad (16)$$

$$M(O_{j_f,t}, K_{j_f,t}^s) = \begin{cases} \left(\epsilon_t^O \frac{O_{j_f,t}}{\Upsilon^{O^t}} \right)^{\alpha_O} \left(\epsilon_t^K \frac{K_{j_f,t}^s}{\Upsilon^{t-1}} \right)^{1-\alpha_O} & \text{if } \eta^O = 1, \\ \left\{ (1-\alpha_O)^{\frac{\eta^O-1}{\eta^O}} \left(\epsilon_t^K \frac{K_{j_f,t}^s}{\Upsilon^{t-1}} \right)^{\frac{\eta^O-1}{\eta^O}} + (\alpha_O)^{\frac{1}{\eta^O}} \left(\epsilon_t^O \frac{O_{j_f,t}}{\Upsilon^{O^t}} \right)^{\frac{\eta^O-1}{\eta^O}} \right\}^{\frac{\eta^O}{\eta^O-1}} & \text{otherwise.} \end{cases} \quad (17)$$

It requires a suitable capital stock to use crude oil efficiently. The composition of the capital stock is crucial for the ability of firms and households to abandon oil consumption. The effectiveness of the workforce depends less on crude oil usage. However, it is also possible to model labour and capital in one nest and combine the composite production factor with crude oil in the final stage. Nevertheless, the model follows the approach by Balke & Brown (2018) to model oil and capital services in one CES layer.

Firms face fixed costs $\phi_t z_t$ to produce net output $Y_{j_f,t}$, where $\bar{\phi}$ is set such that

there are no profits in steady-state. Fixed costs ensure that profits are zero so that no new firm enters the market in a steady state. The intermediate good-producing firms minimize the costs for a given production level.

$$Y_{j_f,t} = \begin{cases} X_{j_f,t} - \phi_t z_t, & \text{if } X_{j_f,t} > \phi_t z_t, \\ 0, & \text{else.} \end{cases} \quad (18)$$

Temporary total factor productivity shocks ϵ_t , temporary capital specific factor productivity shocks ϵ_t^K , temporary oil factor productivity shocks ϵ_t^O can change production factor demand. The optimization problem is

$$\begin{aligned} \min_{l_{j_f,t}, K_{j_f,t}^s, O_{j_f,t}} & W_t l_{j_f,t} + P_t \tilde{r}_t^k K_{j_f,t}^s + P_t^O O_{j_f,t}, \\ \text{s.t.} & Y_{j_f,t} = X(M(O_{j_f,t}, K_{j_f,t}^s), l_{j_f,t}) - \phi_t z_t, \\ & l_{j_f,t} > 0, K_{j_f,t}^s > 0, O_{j_f,t} > 0, M_{j_f,t} > 0, Y_{j_f,t} > 0. \end{aligned} \quad (19)$$

The corresponding Lagrangian, ignoring the non-negativity constraints, of the problem is

$$\mathcal{L}_t^{\text{F},\min} = W_t l_{j_f,t} + P_t \tilde{r}_t^k K_{j_f,t}^s + P_t^O O_{j_f,t} + S_t \{Y_{j_f,t} - (X(M_{j_f,t}, l_{j_f,t}) - \phi_t z_t)\}. \quad (20)$$

The first order conditions to (20) describe the demand for production factors by the representative firms.

$$\frac{\partial \mathcal{L}_t^{\text{F},\min}}{\partial l_{j_f,t}} : 0 = W_t - S_t z_t \frac{\eta^M - 1}{\eta^M} \epsilon_t (\alpha_N)^{\frac{1}{\eta^O}} \left(\frac{X_{j_f,t}}{l_{j_f,t}} \right)^{\frac{1}{\eta^M}}, \quad (21)$$

$$\frac{\partial \mathcal{L}_t^{\text{F},\min}}{\partial K_{j_f,t}^s} : 0 = P_t \tilde{r}_t^k - P_t^M (1 - \alpha_O)^{\frac{1}{\eta^O}} (\Upsilon^{t-1})^{-\rho^O} (\epsilon_t^K)^{\rho^O} \left(\frac{M_{j_f,t}}{K_{j_f,t}^s} \right)^{\frac{1}{\eta^O}}, \quad (22)$$

$$\frac{\partial \mathcal{L}_t^{\text{F},\min}}{\partial O_{j_f,t}} : 0 = P_t^O - P_t^M (\alpha_O)^{\frac{1}{\eta^O}} (\Upsilon^{Ot})^{-\rho^O} (\epsilon_t^O)^{\rho^O} \left\{ \frac{M_{j_f,t}}{O_{j_f,t}} \right\}^{\frac{1}{\eta^O}}, \quad (23)$$

$$\frac{\partial \mathcal{L}_t^{\text{F},\min}}{\partial S_t} : 0 = X_{j_f,t} - X(l_{j_f,t}, M_{j_f,t}), \quad (24)$$

$$P_t^M = S_t z_t^{\rho^M} \epsilon_t \alpha_M^{\frac{1}{\eta^M}} \left(\frac{X_{j_f,t}}{l_{j_f,t}} \right)^{\frac{1}{\eta^M}}.$$

The constraint of the cost minimization is the CES production function for output. Oil-capital composite goods have a shadow value P_t^M equal to the marginal product $\frac{\partial X_{j_f,t}}{\partial M_{j_f,t}}$ times marginal costs S_t .

3 Model Estimation for the US

I outline the estimation procedure, providing a short explanation of the data used to estimate the structural model using standard Bayesian estimation techniques. Conventional screening tools for parameter identification analyze the estimated model.⁵ Analyzing the structural parameter estimates for both the model with and without financial accelerator and oil markets enables us to determine whether the variations in results can be attributed to differences in these estimates.

3.1 Estimation procedure

One of the primary challenges in estimating medium-sized dynamic stochastic general equilibrium (DSGE) models is parameter identification. The Random Walk Metropolis-Hastings (RWMH) algorithm is utilized, to ensure convergence. The data used for estimating the model includes observable variables introduced by Smets & Wouters (2003) and Christiano et al. (2005). These variables encompass GDP growth, the GDP deflator as a measure of inflation, consumption growth, investment growth, hours worked, wage growth, the federal funds rate, and the relative price of investment. Additionally, the model includes variables to capture fluctuations in the financial market, as discussed by Christiano et al. (2014). These variables include the change in net worth measured by the DOW Jones Wilshire 5000 index, credit growth, and the interest-rate spread between BAA-rated corporate bonds and government bonds with a 10-year maturity. The observable for the term structure is based on 1-year constant maturity US government bonds.⁶

Additional observable variables related to the oil market are part of the CMR-Oil model. These variables include domestic crude oil production, consumption, imports, and changes in oil stocks. The Energy Information Administration (EIA) provides the necessary monthly historical data for these variables.⁷ The refinery acquisition cost of imported oil, adjusted for inflation, is also observable and used to measure the growth in real oil prices. The growth rates in domestic crude oil production imported crude oil, and changes in oil stocks, along with crude oil exports, indirectly capture oil consumption in the US.⁸ Further, taxes paid by oil producers are reported by the Organization of Petroleum Exporting Countries (OPEC).⁹

In the calibration process, the model is calibrated to match certain long-run rela-

⁵The Online Appendix provides a more detailed description.

⁶BEA (2023), BIS (2023), BLS (2023), FED (2023), Wilshire (2023).

⁷EIA (2023).

⁸The Online Appendix contains figures for all observable variables and test results for stationary observable variables.

⁹OPEC (2023).

tionships or steady-state values. Parameters such as the rental rate, net output shares, consumption, investment, government expenditure, and the risk-free interest rate are calibrated accordingly.¹⁰

I use similar priors for structural parameters as Christiano et al. (2014). The standard deviation of shocks and persistence parameters have identical priors as in Cantore et al. (2015). Table 10 reports the prior distributions for all 41 parameters. Some commonly used parameters are not estimated, such as indexation parameters for inflation and wages ι^{w,μ^z} and habit formation b , as they lead to unidentified parameters or high correlation issues. Additionally, the steady-state bankruptcy probability $F(\bar{\omega}_t)$ is not estimated, and the share of assets used to monitor bankrupt entrepreneurs (μ) is calibrated to ensure consistency with previous research. The signal correlation parameter is estimated indirectly through an auxiliary parameter $\sigma(\xi^s, \xi^{s+1})$ to ensure that the estimated correlation is bounded between -1 and 1.

For estimating how capital-oil can be substituted with labour, I specify the prior being a gamma distribution, setting the mean at 1 and the standard deviation at 0.2, following Cantore et al. (2015). Similarly, for both the elasticity of oil supply and demand, I use a gamma distribution for the priors. Specifically, the inverse of oil supply elasticity is assigned a prior mean of 10, which implies an actual oil supply elasticity of 0.1, a figure that aligns with the prior used for the oil demand elasticity in Baumeister & Hamilton (2019).

3.2 Comparison of structural parameters

The interaction between oil and financial markets in the model might change the estimation results for the structural parameters common to both models. Table 2 reports the posterior mean for the different model parameters. The elasticity of substitution between the capital-oil composite production factor and hours worked is above one excluding the financial accelerator and below one including it. Credibility intervals for the posterior mean of the CEE–Oil model overlap with the CMR–Oil model. Both models’ posterior mean intervals of the inverse supply elasticity of oil overlap. The same is true for the demand elasticity of oil. Note, that the demand elasticity is above the prior mean and the supply elasticity below the prior mean. Therefore, oil demand reacts more to price changes than oil supply.

For the CMR–Oil model the posterior mean credibility intervals of the curvature parameter of investment and capital utilization overlap with the CEE–Oil models’ credibility interval. The posterior mean credibility interval also overlaps with the Calvo parameter representing wage and price stickiness. Calvo parameters for price and wage

¹⁰The Online Appendix contains details about the algorithms to find the steady state.

Table 2: Estimation results for structural parameters

Model	CEE–Oil model	CMR–Oil model
elasticity of substitution between energy-capital composite good and labour	1.24	0.91
η^M	[0.95, 1.58]	[0.69, 1.23]
curvature of investment adjustment cost	15.53	14.24
S'	[12.75, 18.50]	[11.37, 16.90]
curvature of utilization cost	0.89	0.83
$\sigma^{a(u)}$	[0.72, 1.07]	[0.66, 1.01]
weight on output growth in Taylor rule	0.25	0.21
$\tilde{a}_{\Delta y}$	[0.18, 0.32]	[0.15, 0.28]
weight on inflation in Taylor rule	-	-
\tilde{a}_π	[-]	[-]
Calvo parameter wages	0.77	0.81
ξ^w	[0.70, 0.83]	[0.74, 0.86]
Calvo parameter prices	0.89	0.90
ξ^p	[0.88, 0.91]	[0.89, 0.91]
AR(1) coefficient for risk free interest rate	0.87	0.91
$\hat{\rho}$	[0.86, 0.89]	[0.90, 0.91]
demand price elasticity for oil consumption	0.12	0.13
η^O	[0.08, 0.17]	[0.09, 0.19]
inverse supply price elasticity for oil production	6.88	7.01
σ^O	[5.44, 8.93]	[5.52, 9.21]

Notes: The posterior mean and the 90% highest probability density (HPD) interval for the respective parameters in parentheses are reported.

rigidity are above the prior mean and indicate an average two-and-a-half-year duration of prices. The monetary policy parameter for output is very similar between both models. However, the monetary policy instrument is more rigid in the CMR–Oil model compared to the CEE–Oil model.¹¹

The comparison of structural parameters reveals no tremendous difference between both models. Therefore, results for the variance and historical decomposition are mainly driven by different model equations.

4 US Business Cycle with Oil and Financial Market Disturbances

The estimated model can decompose the US business cycle into different sources. First, a variance decomposition analyses the drivers of the business cycle from a long-term perspective, while a historical decomposition reveals the actual contributions of different external variations for the years 1984 to 2022. Impulse response curves to positive oil supply cost shocks ($\eta^{\zeta^o}, \eta^{\zeta^{o,im}}$) unravel the underlying mechanisms explaining differential decomposition results concerning oil supply shocks. Temporary market equilibria enhance the comprehension of how positive oil supply cost shocks' propagation mech-

¹¹The Online Appendix contains estimation results for persistence parameters and standard deviations.

anisms differ with and without a financial accelerator.

4.1 Historical and variance decomposition

Table 3 presents the theoretical breakdown of how different factors contribute to the variation in national account variables according to three models: CMR, CEE–Oil, and CMR–Oil. For the CEE–Oil and CMR–Oil models, this breakdown is calculated using the posterior distribution. In contrast, the CMR model is based on parameters estimated by Christiano et al. (2014). According to the CMR model, risk shocks account for approximately 27% of the total variation in GDP growth. The contribution of risk to the variation ranges from 3% to 9% for the CMR–Oil and CEE–Oil models, as determined by the posterior distribution.¹² Therefore, risk shocks are only a minor driver of GDP growth rates. Shocks to equity and the term structure are other financial shocks with a greater contribution to GDP growth compared to risk shocks. In addition to the Taylor rule persistence parameters for consumption, inflation and wages are responsible for the drop. A lower persistence of prices and wages affects the contribution of risk to GDP growth. Less persistent habits lead to a lower contribution of risk to consumption behaviour.

Demand, monetary policy and technology shocks are the main drivers of GDP growth in both models. The introduction of financial frictions to the baseline model with oil leads to an increase in the contribution of monetary policy shocks and a decline in the contribution of investment shocks to the theoretical variance of GDP growth. Risk shocks and the marginal efficiency of investment are the main drivers of the growth rate in capital formation. As stated in Bernanke et al. (1999), the financial accelerator mechanism can amplify small shocks such as discretionary monetary policy. The theoretical variance decomposition shows that unexpected movements in the federal funds rate contribute between 18% and 26% to the theoretical variance of GDP growth for the model with a financial accelerator. The contribution ranges between 13% and 19% for the CEE–Oil model. In contrast, the results can not verify the statement that the financial accelerator mechanism amplifies oil market shocks. In contrast, for the reported aggregates oil market shocks contribute less to GDP growth, consumption and investment with a financial accelerator. Here the main reason is, that risk shocks explain more of the variance in investment and reduce the contribution previously attributed to the oil market shocks.¹³

Risk and the marginal efficiency of investment shocks mainly drive investment according to the variance decomposition. Figure 2 depicts the historical contribution of

¹²The parameter values are reported in the Online Appendix.

¹³The Online Appendix contains theoretical variance decomposition for the oil market variables.

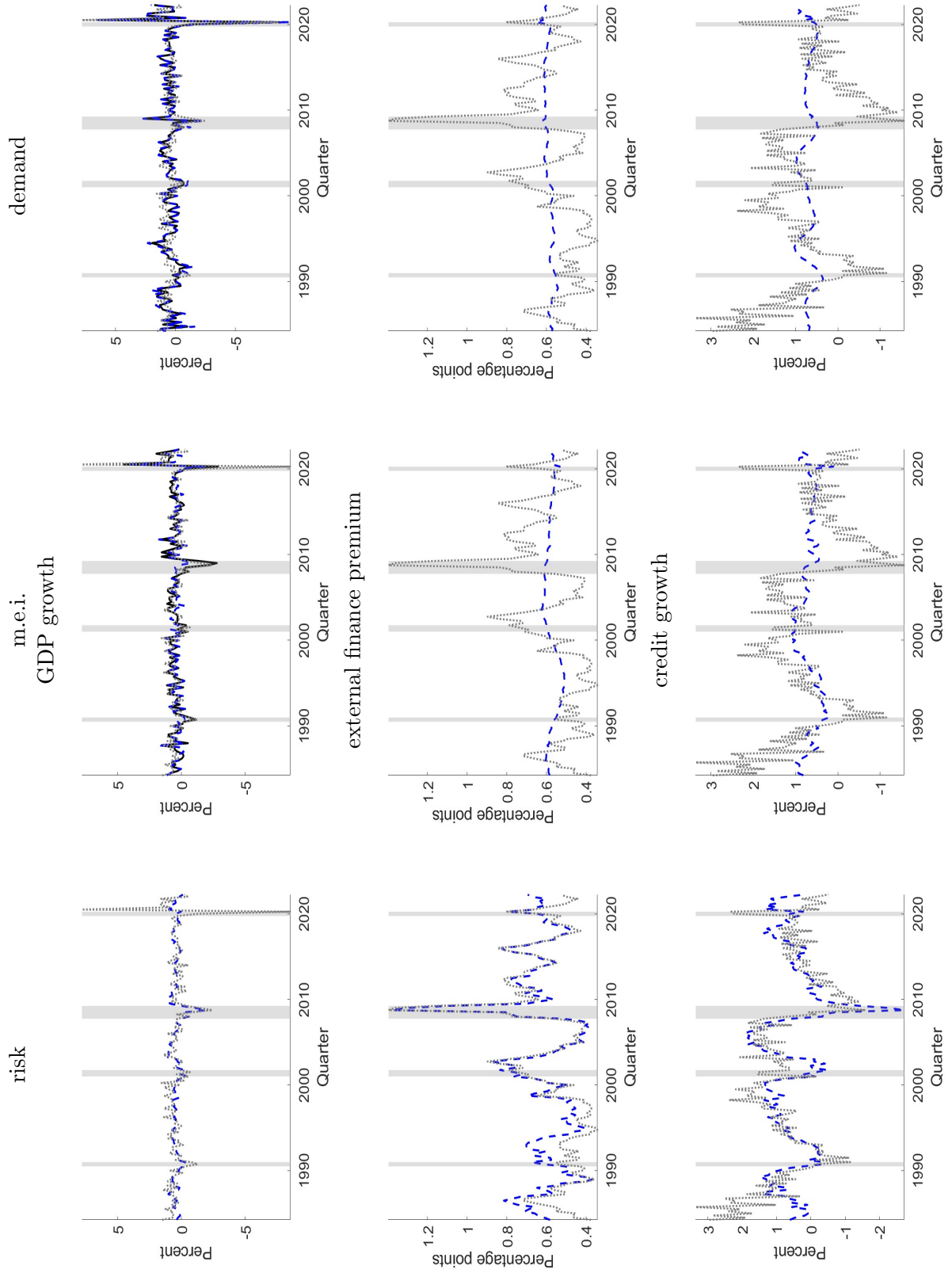
Table 3: Variance decomposition for national account variables

Variable	risk	investment	demand	financial	M.P.	markup	technol.	oil
GDP growth								
CMR	27.2	12.1	24.5	0.7	1.3	25.3	9.0	0.0
CEE–Oil	0.0	21.2	36.4	0.0	15.6	7.9	18.3	0.4
CMR–Oil	[0.0, 0.0]	[18.2, 24.4]	[31.1, 41.7]	[0.0, 0.0]	[12.9, 18.7]	[6.2, 10.0]	[12.8, 23.9]	[0.2, 0.6]
	[3.0, 8.5]	[10.5, 15.2]	[29.1, 39.8]	[3.7, 13.3]	[18.0, 25.8]	[3.8, 6.4]	[8.1, 14.4]	[0.1, 0.5]
inflation								
CMR	21.0	17.3	6.8	0.5	1.5	39.3	13.6	0.0
CEE–Oil	0.0	5.2	11.0	0.0	5.9	53.4	23.8	0.5
CMR–Oil	[0.0, 0.0]	[3.3, 7.3]	[6.0, 15.6]	[0.0, 0.0]	[3.6, 8.1]	[47.3, 59.7]	[17.9, 29.3]	[0.2, 0.8]
	[4.8, 13.9]	[0.5, 1.3]	[7.7, 16.5]	[5.9, 31.8]	[5.7, 12.1]	[24.1, 39.7]	[11.6, 22.3]	[0.2, 0.8]
federal funds rate								
CMR	39.9	28.6	9.1	1.0	3.7	12.3	5.4	0.0
CEE–Oil	0.0	7.5	16.2	0.0	26.6	20.4	28.6	0.5
CMR–Oil	[0.0, 0.0]	[4.6, 10.2]	[7.3, 23.9]	[0.0, 0.0]	[21.5, 32.1]	[15.8, 25.0]	[20.2, 35.6]	[0.2, 0.8]
	[5.9, 18.1]	[0.5, 1.3]	[8.3, 23.7]	[9.4, 43.0]	[11.5, 22.8]	[6.2, 13.4]	[9.4, 21.8]	[0.1, 0.6]
investment growth								
CMR	54.4	32.9	0.9	1.6	0.5	8.5	1.1	0.0
CEE–Oil	0.0	87.1	0.5	0.0	1.0	3.8	6.8	0.5
CMR–Oil	[0.0, 0.0]	[83.6, 90.6]	[0.3, 0.7]	[0.0, 0.0]	[0.6, 1.4]	[2.4, 5.2]	[4.2, 9.2]	[0.2, 0.8]
	[11.9, 31.4]	[28.2, 50.1]	[0.2, 0.5]	[16.7, 45.5]	[1.9, 4.2]	[1.0, 2.1]	[0.7, 1.6]	[0.1, 0.2]
consumption growth								
CMR	22.0	20.2	31.3	0.6	0.9	19.3	5.7	0.0
CEE–Oil	0.0	0.2	57.6	0.0	22.7	6.9	12.3	0.2
CMR–Oil	[0.0, 0.0]	[0.1, 0.3]	[51.2, 63.1]	[0.0, 0.0]	[18.5, 27.1]	[5.1, 8.6]	[7.5, 17.3]	[0.1, 0.3]
	[0.3, 1.0]	[0.0, 0.1]	[47.7, 59.2]	[0.2, 2.2]	[24.5, 34.5]	[3.9, 6.6]	[5.6, 12.1]	[0.1, 0.5]
wage growth								
CMR	3.2	2.5	0.9	0.1	0.1	11.3	82.0	0.0
CEE–Oil	0.0	0.1	0.1	0.0	0.1	6.9	92.7	0.1
CMR–Oil	[0.0, 0.0]	[0.1, 0.2]	[0.0, 0.1]	[0.0, 0.0]	[0.0, 0.1]	[5.3, 8.3]	[88.8, 96.2]	[0.0, 0.1]
	[0.2, 0.6]	[0.0, 0.1]	[0.0, 0.2]	[0.2, 1.5]	[0.0, 0.1]	[4.8, 7.6]	[89.1, 94.8]	[0.0, 0.1]

Note: Theoretical contribution of each shock group in percent to the total variance of the respective variable is reported. Results for the CMR model are computed using the parameter values of Christiano et al. (2014). The variance decomposition for the CEE–Oil and CMR–Oil models are reported for the estimated posterior distribution. Values in parentheses represent the 90% HPD interval of the model parameters. The shock groups are reported in Table 4.

the marginal efficiency of investment (m.e.i.), risk shocks and demand shocks to GDP growth. The inclusion of financial frictions reduces the contribution of the marginal efficiency of investment, especially during the Great Recession (through investment growth). The historical decomposition also reveals that risk shocks are the main driver of external finance premiums and credit growth. Further, the external finance premium reached its maximum observed value during the financial crisis, and this coincides with the time risk that contributed the most to GDP and investment growth. The marginal efficiency of investment on the other side has only a small impact on the external finance premium and credit growth. The model attributes the COVID-19 recession to shocks from the demand side. Most of the historical business cycle fluctuation in GDP growth originates from the demand side, while demand shocks play no role in financial market variables. Oil market shocks did not drive GDP growth, but also not the increase in oil prices before the Great Recession (Figure 6 in the Appendix).

Figure 2: Historical contribution of risk, m.e.i. and demand shocks



Note: The solid black line represents the historical decomposition for the CEE-Oil model, the dashed blue line for the CMR-Oil model, and the dotted grey line the observed data. Shaded areas represent the National Bureau of Economic Research recessions as reported on <https://www.nber.org/cycles.html>.

4.2 Impulse response functions

The variance and historical decomposition both mainly reveal a crowding-out of the marginal efficiency of investment shocks for risk shocks. Bernanke et al. (1999) state that the financial accelerator can amplify the impact of small shocks such as discretionary monetary policy. The variance decomposition reveals a little amplification effect for monetary policy shocks, but the opposite for oil market disturbances.

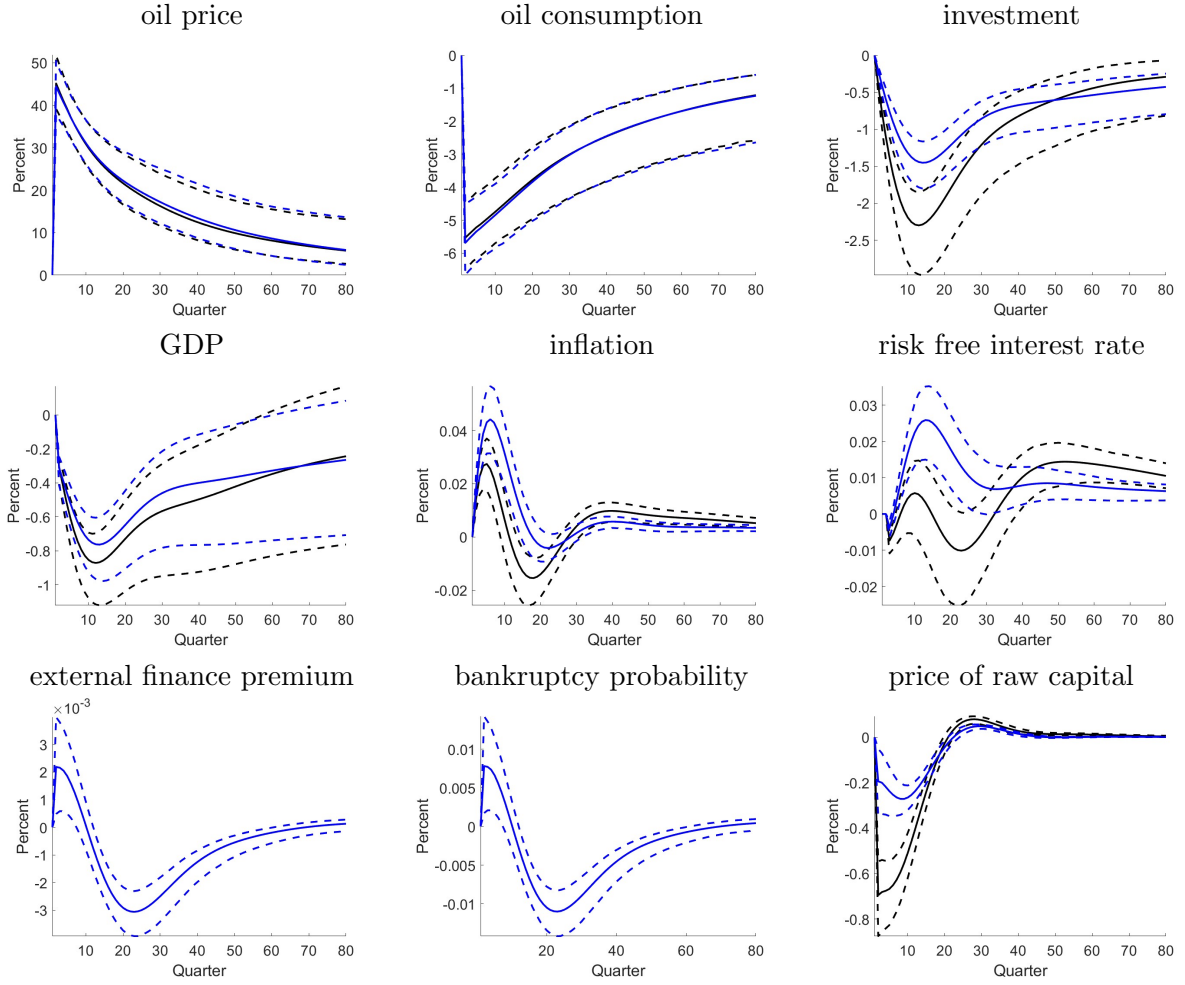
Figure 3 illustrates the response to temporary rises in oil supply costs across various variables. Both domestic and foreign oil supply shocks lead to a simultaneous 50% increase in oil prices. Oil consumption experiences a marginal decrease of around 5%, highlighting the limited sensitivity of oil demand to price changes. Investment exhibits a drop of roughly 2% with the financial accelerator mechanism, while without credit market frictions, the reduction is about 2.5%. The resulting decrease in GDP is practically identical in both model variations. Inflation sees an equivalent increase regardless of the presence of a financial accelerator. The monetary policy rule magnifies the GDP reduction through an increase in the risk-free interest rate to counter observed inflation. Although the external finance premium and bankruptcy probability both increase, the investment decrease is less pronounced when compared to the model lacking a financial accelerator. The decline in raw capital prices is milder in the presence of a financial accelerator compared to its absence.

The persistence of oil supply shocks plays a crucial role in the observed dampening effect on investment in a model that includes a financial accelerator, as compared to a model without one. Figure 4 illustrates the impulse response functions for oil supply shocks with different levels of persistence. Specifically, I consider two scenarios: less persistent oil supply shocks, which have a half-life of less than 5 quarters, and persistent oil supply shocks, which have a half-life of more than 30 quarters.

When comparing the models with and without a financial accelerator, it is observed that they exhibit similar responses for the oil price and the rental rate of capital, given the same level of persistence in the oil supply shocks. However, when it comes to investment, a notable difference emerges. In the case of persistent oil supply shocks, investment experiences a greater decline compared to less persistent shocks.

Furthermore, the presence of a financial accelerator further influences the impact on investment. For low persistent oil supply shocks, the financial accelerator magnifies the effect, leading to a more pronounced decrease in investment. On the other hand, for more persistent oil supply shocks, the initial impact on investment is dampened by the financial accelerator. In addition to its effects on investment, the presence of a financial accelerator also influences the impact on consumption. Specifically, when it comes to highly persistent oil supply shocks, the financial accelerator exhibits an

Figure 3: Impulse response functions for temporary rises in oil supply costs

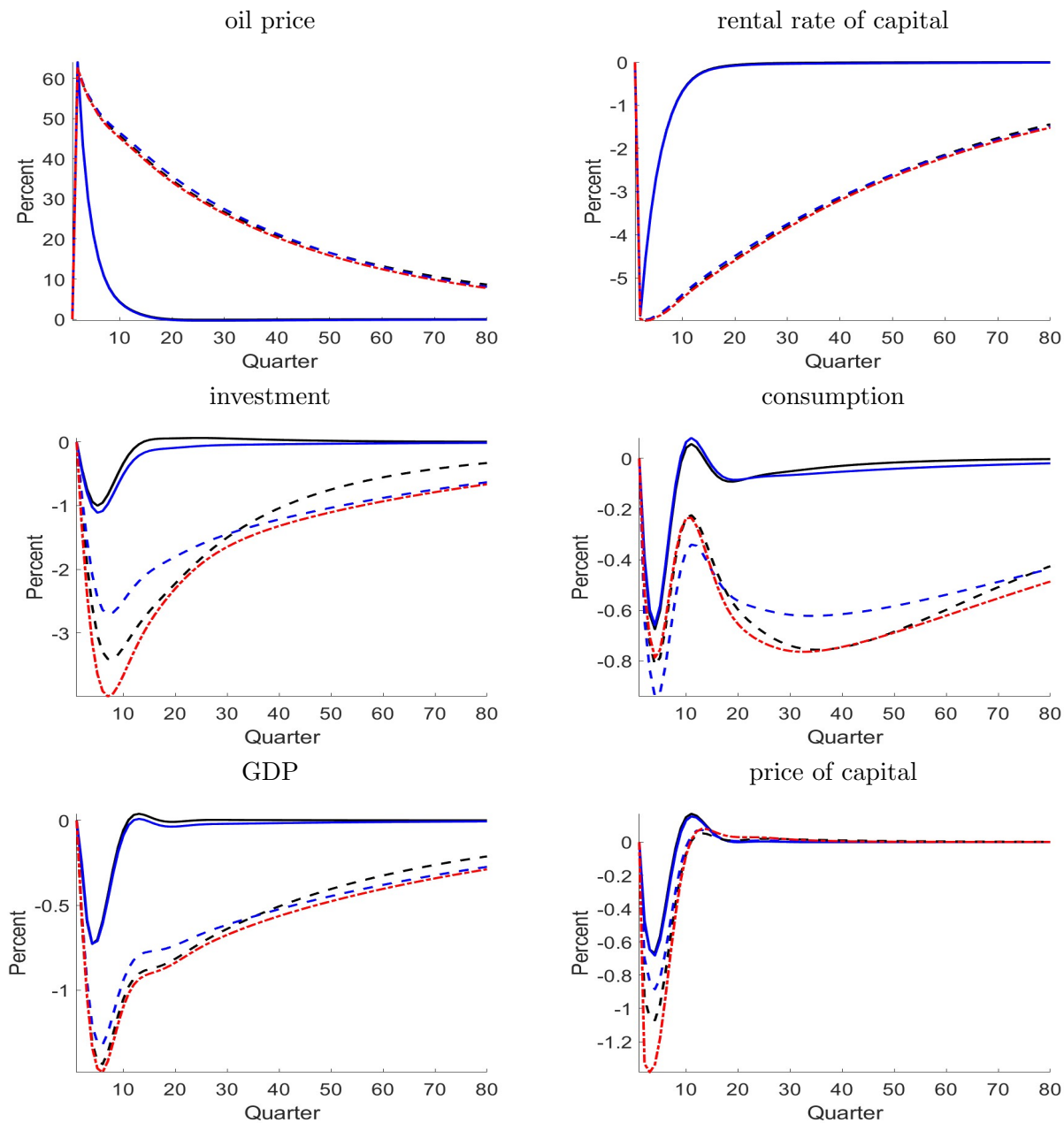


Note: Variables are expressed as a percentage deviation from the sample mean/steady state. The solid black line represents the impulse response function at the posterior mean for the CEE–Oil model and the solid blue line for the CMR–Oil model. Dashed lines represent the 90% HPD interval based on 1200 draws from the posterior distribution.

opposite pattern compared to investment for consumption. Instead of dampening the effect, it amplifies the impact on consumption. This means that for highly persistent oil supply shocks, the financial accelerator leads to a more pronounced decrease in consumption. The price of capital responds almost identically to less persistent shocks in both models. The price of raw capital declines stronger for more persistent oil supply shocks, but the decline is less pronounced for the model with the financial accelerator.

Both models trigger similar adjustments in oil consumption, oil prices, capital utilization and rental rates, but a significant dissimilarity arises in the determination of the raw price of capital. Without the financial accelerator, households’ Euler equation equates marginal benefits and costs related to additional raw capital, considering future and current consumption possibilities (30). In contrast, the model with the financial accelerator involves entrepreneurs, who optimize their leverage ratios by balancing

Figure 4: Impulse responses to oil supply shocks ($\eta^{o,d,im}$) with different persistence levels

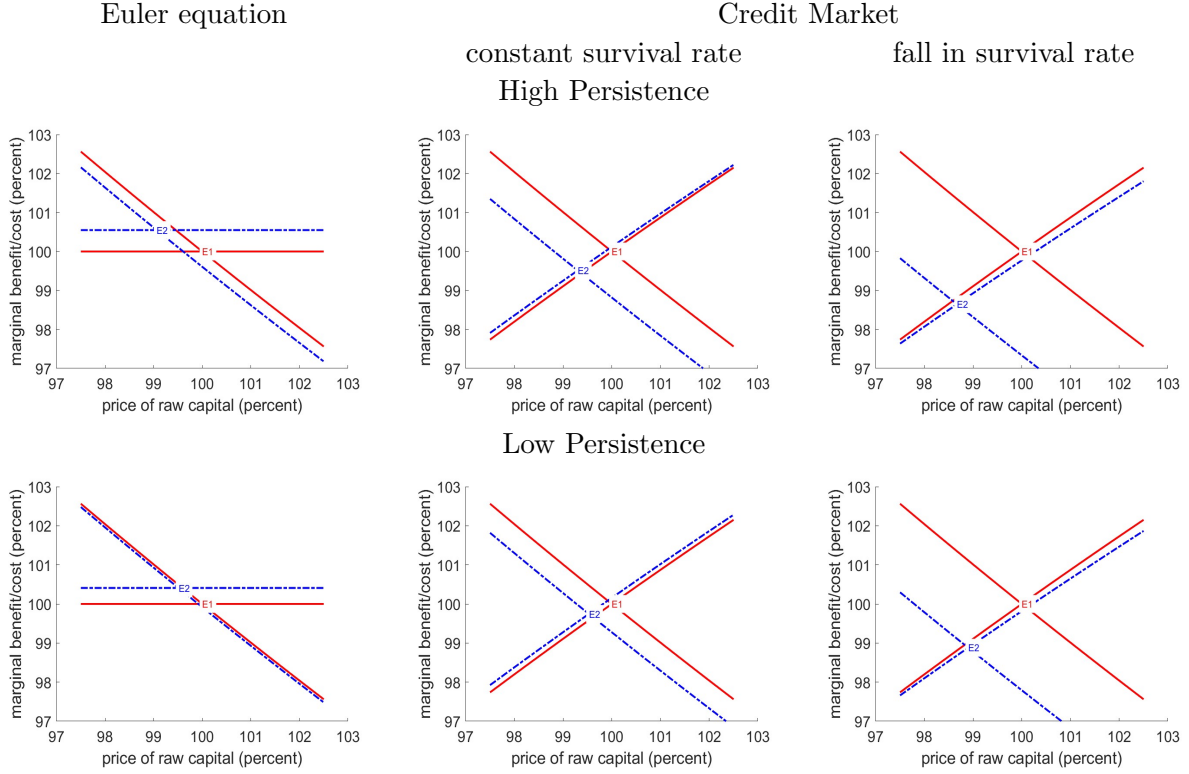


Note: Variables are expressed as a percentage deviation from the sample mean/steady state. The solid black line represents the impulse response function for the CEE–Oil model and the solid blue line for the CMR–Oil model with low persistent oil supply shocks. Dashed lines represent shocks for high persistent oil supply shocks. Furthermore, red dashed-dotted lines illustrate the impulse responses to oil supply shocks in conjunction with a simultaneous reduction in the survival rate of entrepreneurs. This particular scenario mirrors a decline in the survival rate by 0.5 percentage points witnessed during the Gulf War recession in the 1990s.

marginal profits and costs, accounting for interest payments, bankruptcy probabilities, and mutual fund profits. The required raw capital price change is lower in the model with the financial accelerator, leading to varied investment decisions by households in

both versions of the model. Therefore, the representative household reduces investment more in the model without a financial accelerator compared to the model with a financial accelerator due to a smaller price of raw capital. The smaller price of raw capital reflects a lower evaluation of investments into the capital stock today for the household compared to the entrepreneur.

Figure 5: Equilibria in response to oil supply shocks ($\eta^{s^{o,d,im}}$)



Note: Variables are expressed as a percentage deviation from the sample mean/steady state. The solid red line represents the initial equilibrium and the dashed blue line is the equilibrium four quarters after the shock occurred. All common parameters between the two model versions are identical. The Euler equation (30) depicts the marginal costs of giving up a unit of consumption today and the marginal benefit in the future. The capital market refers to the raw capital price fulfilling the first order condition of entrepreneurs (70) incorporating the leverage ratio implied by the mutual fund zero profit condition (69).

Entrepreneurs, unlike households, need equity to fund their purchase of raw capital and to provide capital services. The process of forming equity is influenced by the predetermined rate at which entrepreneurs remain in business. Essentially, a higher likelihood of entrepreneurs staying in business, all else being equal, increases their present value placed on future equity. Unlike households, entrepreneurs tend to accumulate equity, which in turn enhances the value of raw capital and mitigates the reduction in investment levels. The extent of the decrease in the marginal benefits from investment is linked to the survival rate of entrepreneurs; a higher rate results in a more sustained process of equity accumulation. Over time, the economy is expected

to revert to its stable equilibrium as anticipated by entrepreneurs, with the fixed rate of entrepreneur survival affecting how quickly equity accumulates in the economy. A lower survival rate signifies a more pronounced decrease in investments by households, due to their diminished expectations for future equity. Thus, the set rate at which entrepreneurs exit the market is a key factor affecting investment reactions. For example, a drop in the survival rate similar to what was observed during the Gulf War in the 1990s would lead to a more pronounced reaction to oil supply shocks, as illustrated by the red dashed-dotted line in Figure 5.

5 Discussion

The results indicate that neither oil market disturbances nor financial market frictions play a predominant role in shaping the US business cycle considering a sample period with various recessions, including the mild recession triggered by oil price surges in the 1990s. A historical decomposition exercise reveals that risk shocks, notably through an increase in the external finance premium, amplify the recessions triggered by the Gulf War, the Dot-com bubble, and the Great Recession. Brunnermeier et al. (2021) show that the external finance premium has predictive power to identify upcoming recessions. Conversely, demand shocks emerge as the key catalyst behind the COVID-19 recession, reflecting a substantial decline in both investment and consumption, in alignment with prior research (Eichenbaum et al. 2022, Guntin et al. 2023). Furthermore, the analysis indicates that risk shocks are primarily responsible for three of the aforementioned recessions, with the exclusion of the financial accelerator mechanism attributing these downturns to shocks in the marginal efficiency of investment. Notably, shocks to the marginal efficiency of investment do not exhibit the ability to explain the joint behaviour of credit growth, external finance premium and net worth (Christiano et al. 2014). Anticipated risk shocks in combination with nominal rigidities are able to explain slow recoveries after sudden drops in macroeconomic variables during recessions in line with Ordoñez (2013) and Favilukis et al. (2020). Additionally, we observe that oil supply shocks are only accountable for oil price increases during the Gulf War recession, while the oil price surges preceding the Great Recession can be attributed to demand shocks confirming Kilian (2008).

Despite oil supply shocks not being considered a primary driver of the US business cycle, their impact can vary significantly depending on their persistence, as revealed through impulse response analysis. Highly persistent oil supply shocks exhibit more severe implications for the business cycle but do not show an amplification effect of the financial accelerator when independent survival rates of entrepreneurs are considered. Moll (2014) and Eden (2017) state that the effect of financial market imperfections can

vary depending on the persistence of the shocks and the degree of asymmetric information. The amplification of oil supply shocks depends on the contemporaneous response of survival rates. The upcoming process of decarbonization in the economy has important implications for fossil fuel prices, which, in turn, may affect the survival rates of companies reliant on fossil fuel-based technologies. While low-carbon technologies may offer partial compensation, it is essential to acknowledge that higher CO₂ prices, as indicated by Aghion et al. (2016), can stimulate directed technical change but also lead to the short-term exit of existing businesses due to increased marginal costs and reduced profitability. In the financial accelerator model, the higher exit rates are captured by lower survival rates of entrepreneurs, emphasizing the need for models that establish a direct link between survival rates and marginal costs. Regarding the transition period, business cycle models should incorporate endogenous survival rates of entrepreneurs, drawing insights from the business dynamism literature, as highlighted by Crouzet & Mehrotra (2020) and Clementi & Palazzo (2016), to provide robust policy recommendations. Moreover, sectoral structures, as emphasized by Bigio & La'O (2020), are critical determinants in these models, affecting amplification mechanisms and labour market dynamics, particularly in terms of wage rigidity and sectoral reallocation, which can have significant implications for the economy. It is worth noting that the effect of financial market frictions, as studied in this research for a large, advanced economy like the US, may differ for small open and developing economies, as indicated by prior studies (Buera & Shin 2013, Bustos et al. 2020, David et al. 2016, Gabaix & Maggiori 2015, Ji et al. 2023, Leibovici 2021), highlighting the importance of considering the unique characteristics of each economy in future research. Previous studies also derived optimal policies to overcome capital market imperfections (Lanteri & Rampini 2023, Stein 2012). These policies can depend on the respective institutional and development stages of the respective economy.

6 Conclusion

Bayesian estimation using parameter identification and convergence analysis reveals that neither oil market disruptions nor financial market frictions are primary drivers of the US business cycle over the analyzed period, which encompasses recessions like the Gulf War, Dot-com bubble, Great Recession, and COVID-19 pandemic.

A historical decomposition detects the primary drivers of these recessions. Risk shocks, particularly through their impact on the external finance premium, are key contributors to the Gulf War, the Dot-com bubble, and the Great Recession. Conversely, demand shocks take the spotlight in explaining the COVID-19 recession, reflecting substantial declines in both investment and consumption.

The persistence of oil cost supply shocks determines their business cycle effects. Highly persistent shocks trigger more severe fluctuations in the business cycle, but there is no amplification effect via the financial accelerator. In addition, the amplification depends on the contemporaneous response of entrepreneurs' survival rates.

These findings have implications for the models applied for business cycle analysis during the upcoming process of decarbonization. It underscores the need for models to establish a direct link between individual economic activity and business dynamism. Classical financial accelerator models tend to underestimate the impact of oil supply shocks because bankruptcies only capture a small share of overall market entry and exit decisions.

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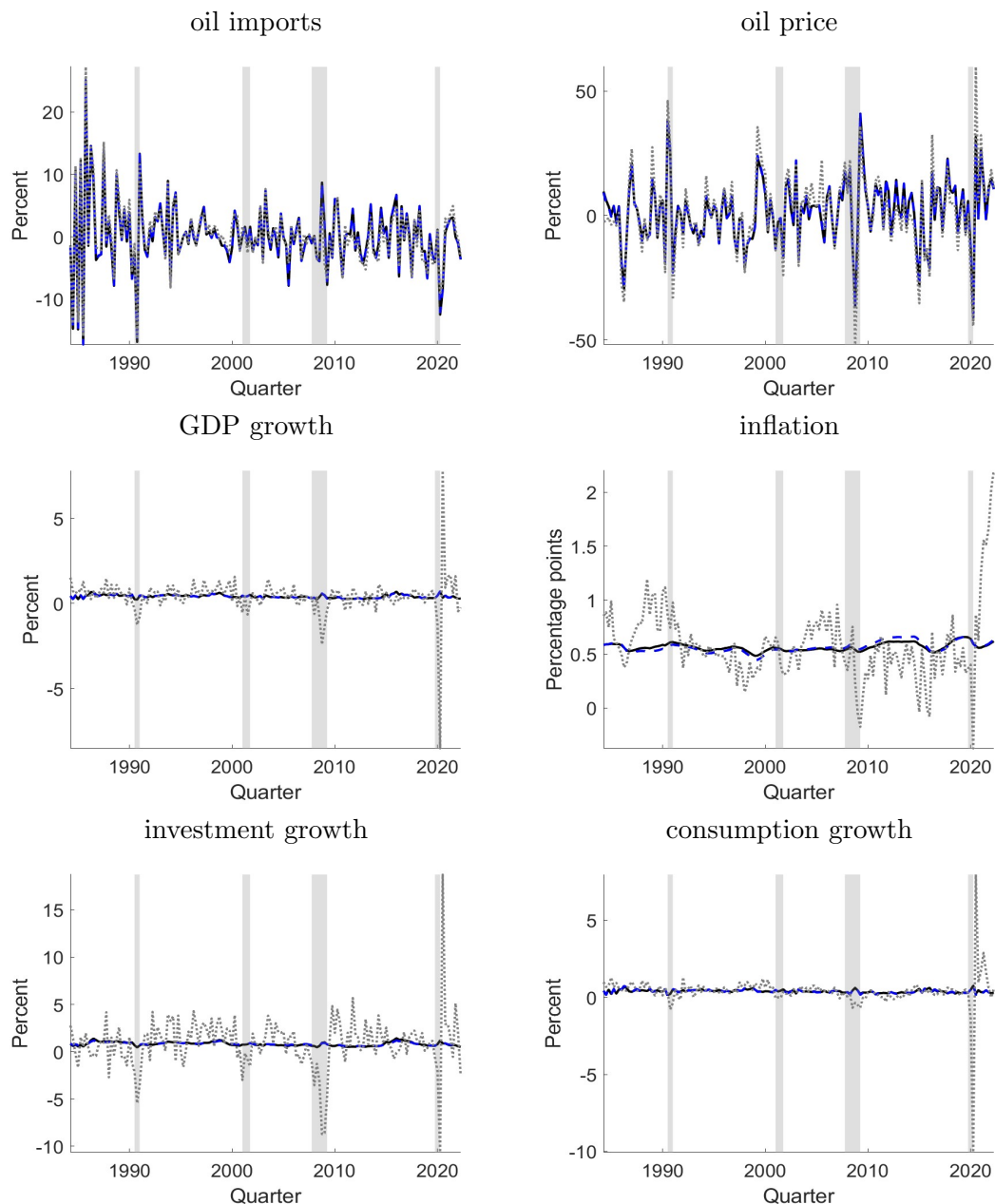
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Appendix A Figures

Figure 6: Historical contribution of oil market shocks



Notes: The solid black line represents the historical decomposition for the CEE–Oil model, the dashed blue line for the CMR–Oil model, and the dotted gray line the observed data. Shaded areas represent National Bureau of Economic Research recessions as reported on <https://www.nber.org/cycles.html>.

Sources: Own computation, Federal Reserve Bank of St. Louis, US Energy Information Administration.

Appendix B Tables

Table 4: Classification of shock groups

Group	Shocks
anticipated risk	η^{ξ^i} for $i \in \{1, \dots, 8\}$
unanticipated risk	η^σ
risk	anticipated and unanticipated risk
financial	η^γ, η^{term}
investment	$\eta^{\zeta^i}, \eta^{\mu^r}$
monetary policy (M.P.)	η^{x^p}
fiscal policy	η^g
policy	fiscal policy and monetary policy
markup	η^{ϵ^p}
demand	η^{ζ^c}
domestic oil supply	$\eta^{\zeta^{o,d}}$
export oil supply	$\eta^{\zeta^{o,ex}}$
oil demand	η^{ϵ^o}
foreign oil supply	$\eta^{\zeta^{o,im}}$
oil supply	domestic and foreign oil supply
oil	oil supply and oil demand

Table 5: Endogenous variables

Variable		Description
stationary	non-stationary	
	z_t	long-run unit root technology shock
$\epsilon^{k,o}$		temporary productivity shock capital and oil
p^m	P^m	price of composite good
m	M	composite good
o	O	oil consumption
$o^{d,ex,im}$	$O^{d,ex,im}$	oil domestic production, exports and imports
p^o	P^O	oil price
$\zeta^{o,im,o,ex}$		domestic, imports and exports oil productivity shock
o^{obs}		observational variable for oil consumption growth rate
$p^{o,obs}$		observational variable for relative price of oil growth rate
$o^{d,obs}$		observational variable for domestic oil production growth rate
$o^{im,obs}$		observational variable for oil imports growth rate
$o^{ex,obs}$		observational variable for oil exports growth rate
R^L		long-run interest rate
R^k		return on capital
n	N	net worth
$\bar{\omega}$		threshold for idiosyncratic risk
σ		risk
γ		fraction of entrepreneurs not leaving the market
$F(\bar{\omega})$		risk of bankruptcy
$G(\bar{\omega})$		expected value of ω for bankrupt entrepreneurs
$dcost(\bar{\omega})$		monitoring cost
ξ^s		news to risk s periods ahead
ζ_{term}		term structure
b^{obs}		observational variable for credit
$R^k - R^{L,obs}$		observational variable for relative price of risk premium
$S^{1,obs}$		observational variable for spread
n^{obs}		observational variable for net worth
c	C	consumption
g	G	government expenditure
i	I	investment
q	Q	price of raw capital
λ^z		marginal utility of consumption
y^z	Y	net output
ϕ		fix costs
h		hours worked
\bar{k}	\bar{K}	raw capital
u		utilization rate of raw capital
r^k	\tilde{r}^k	rental rate of capital
w	W	wage
s	S	real marginal cost
μ^z		long-run technology growth rate
μ^Y		long-run investment growth rate
R		risk free interest rate
F^p		auxiliary variable for optimal price
K^p		auxiliary variable for optimal price
F^w		auxiliary variable for optimal wage
K^w		auxiliary variable for optimal wage
w^*		wage dispersion index
p^*		price distortion index
π		gross inflation
$\tilde{\pi}$		gross inflation of non-optimizing firms
$\tilde{\pi}^w$		gross wage inflation of non-optimizing unions
π^w		gross wage inflation
ϵ		temporary TFP shock
ϵ^h		temporary productivity shocks for hours worked
$\zeta^{i,c,h}$		investment adjustment cost, preference shock consumption and labour supply
$\epsilon^{w,p}$		wage and price mark up shock
y^{obs}		observational variable for GDP growth
h^{obs}		observational variable for hours worked
i^{obs}		investment observation
w^{obs}		observational variable for wages
c^{obs}		observational variable for consumption
$p^{i,obs}$		observational variable for relative price of investment
π^{obs}		inflation observation
R^{obs}		observational variable for risk free interest rate

Table 6: Exogenous variables

Shock	Description
η^{ϵ^K}	productivity shock for capital
η^{ϵ^O}	productivity shock for oil
η^{ζ^o}	exogenous temporary oil cost shock
$\eta^{\zeta^{o,im}}$	exogenous temporary oil import shock
$\eta^{\zeta^{o,ex}}$	exogenous temporary oil export shock
η^{τ^o}	exogenous temporary oil tax shock
η^γ	survival rate of entrepreneurs
η^σ	unanticipated risk
η^{ζ^s}	news to risk s periods ahead
η^{term}	term structure shock
η^n	measurement error net worth
η^{gamma}	survival rate of entrepreneurs
η^{x^p}	exogenous monetary policy shock
η^{ϵ^w}	exogenous temporary shock wage markup
η^{ϵ^p}	exogenous temporary shock price markup
η^{μ^Υ}	exogenous long-run investment shock
η^{μ^z}	exogenous long-run TFP shock
η^ϵ	exogenous temporary TFP shock
η^{ϵ^h}	exogenous temporary productivity shock hours
η^{ζ^h}	labour supply preference shock
η^{ζ^c}	consumption preference shock
η^{ζ^i}	marginal efficiency of investment shock
η^g	exogenous shock to government expenditure

Table 7: Structural Parameters

Parameter	Description
$\tilde{a}_{\Delta p^o}$	weight on oil inflation in Taylor rule
α^O	distribution parameter for oil
α^M	distribution parameter for composite good
γ^o	oil extraction cost parameter
$\gamma^{o^e x}$	oil exports extraction cost parameter
$\gamma^{o^{im}}$	oil imports extraction cost parameter
η^O	inverse demand price elasticity for oil consumption
σ^O	inverse supply price elasticity for oil production
τ^o	tax on oil production
Θ	share of consumed remaining assets of leaving entrepreneurs
μ	monitoring cost
ω^e	transfers to entrepreneurs from households
α^K	distribution parameter capital
α^N	distribution parameter labour
λ^f	elasticity of substitution for intermediate products
λ^w	elasticity of substitution for different labour types
η^M	elasticity of substitution between energy-capital composite good and labour
β	discount factor
δ	depreciation rate of capital
ψ^L	weight on disutility on labour
$\sigma^{a(u)}$	curvature of utilization cost
ξ^p	Calvo parameter prices
ξ^w	Calvo parameter wages
$\tilde{\rho}$	AR(1) coefficient for risk free interest rate
\tilde{a}_π	weight on inflation in Taylor rule
$\tilde{a}_{\Delta y}$	weight on output growth in Taylor rule
$\bar{\pi}$	steady-state inflation
ι	price indexing weight of inflation target
ι^{μ^z}	wage indexing weight on persistent technology growth
ι^w	wage indexing weight on inflation target
b	habit formation parameter
τ^c	consumption tax rate
τ^K	capital income tax rate
τ^l	labour income tax rate
S''	curvature of investment adjustment cost
σ^L	curvature for the disutility to labour
v	mean growth rate for capital
v^o	mean growth rate for oil consumption
τ^o	oil tax rate

Table 8: Shock Distribution Parameters

Parameter	Description
σ^{ϵ^K}	standard deviation capital technology shock
σ^{ϵ^O}	standard deviation oil productivity
σ^{μ^o}	standard deviation productivity of oil
σ^{p^o}	standard deviation measurement error refinery acquisition price
σ^{ζ^o}	standard deviation oil supply shock
$\sigma^{\zeta^{o,im}}$	standard deviation oil imports shock
$\sigma^{\zeta^{o,ex}}$	standard deviation oil exports shock
σ^{τ^o}	standard deviation oil tax shock
σ^σ	standard deviation unanticipated risk shock
σ^ξ	standard deviation anticipated shock
$\sigma(\xi_t, \xi_{t-1})$	signal correlation
σ^{term}	standard deviation term structure shock
σ^γ	standard deviation survival rate entrepreneurs
σ^n	standard deviation measurement error net worth
ρ^{ϵ^K}	AR(1) coefficient for capital technology shock
$\rho^{\zeta^{o,im}}$	AR(1) coefficient for oil imports shocks
$\rho^{\zeta^{o,ex}}$	AR(1) coefficient for oil exports shocks
ρ^{τ^o}	AR(1) coefficient for oil tax shocks
ρ^γ	AR(1) coefficient for survival rate of entrepreneurs
ρ^σ	AR(1) coefficient for σ
ρ^{term}	AR(1) coefficient for term structure
ρ^{ϵ^O}	AR(1) coefficient for oil productivity
ρ^{μ^o}	AR(1) coefficient for oil productivity shocks
ρ^{ζ^o}	AR(1) coefficient for oil cost shocks
ρ^ϵ	AR(1) coefficient for TFP shocks
ρ^{ϵ^h}	AR(1) coefficient for hours shocks
ρ^{ϵ^p}	AR(1) coefficient for price markup shock
ρ^{ϵ^w}	AR(1) coefficient for wage markup shock
ρ^{μ^z}	AR(1) coefficient for μ^z
ρ^{μ^γ}	AR(1) coefficient for μ^γ
ρ^{ζ^c}	AR(1) coefficient for ζ^c
ρ^{ζ^i}	AR(1) coefficient for ζ^i
ρ^{ζ^h}	AR(1) coefficient for ζ^h
ρ^g	AR(1) coefficient for government expenditure
ρ^s	AR(1) coefficient for marginal cost

Table 9: Steady-state Parameters

Parameter	Description
ϵ^K	steady-state capital technology shock
ϵ^O	steady-state oil productivity
$\bar{\epsilon}$	steady-state technology shock
ϵ^h	steady-state labour productivity shock
ϵ^w	steady-state wage markup shock
$\bar{\mu}^z$	steady-state growth rate
$\bar{\mu}^I$	steady-state investment growth rate
ϵ^o	long-run value of oil productivity shock
$\frac{o}{y}$	long-run oil output ratio
$\frac{o^d}{o^{im}}$	long-run oil domestic output to oil consumption ratio
$\frac{o^e}{o^d}$	long-run oil imports to oil consumption ratio
$\frac{o^e}{o^d}$	long-run oil exports to oil domestic ratio
$o^{ex,trend,obs}$	trend in net oil exports observation
$o^{im,trend,obs}$	trend in oil imports observation
$o^{d,trend,obs}$	trend in oil domestic production observation
$o^{trend,obs}$	trend in oil consumption observation
$p^{o,trend,obs}$	trend in oil price observation
$F(\bar{\omega})$	steady-state bankruptcy rate
$\bar{\gamma}$	steady-state survival rate of entrepreneurs
$\frac{\bar{n}}{\bar{k}}$	steady-state equity to asset ratio
$R^L - R$	steady-state term structure
$\bar{\sigma}$	steady-state risk level
$credit^{trend,obs}$	trend in consumption observation
$n^{trend,obs}$	trend in net worth observation
$premium^{trend,obs}$	trend in premium observation
$Spread1^{trend,1,obs}$	trend in spread 1 observation
ϕ^G	steady-state share of government expenditure on output
ϕ^O	steady-state share of oil on output
ϕ^K	steady-state share of capital on output
r^k	steady-state rental rate on capital services
\bar{R}	steady-state interest rate
$c^{trend,obs}$	trend in consumption observation
$gdp^{trend,obs}$	trend in GDP observation
$h^{trend,obs}$	trend in hours observation
$i^{trend,obs}$	trend in investment observation
$w^{trend,obs}$	trend in wage observation
$p^{i,trend,obs}$	trend in relative price of investment observation
$R^{trend,obs}$	trend in interest rate observation
$\pi^{trend,obs}$	trend in inflation observation

Table 10: Prior information (parameters)

Parameter	Distribution	CEE		CEE–Oil		CMR–Oil	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
S''	Gaussian	5	3	12.8413	2.0768	12.8413	2.0768
$\sigma^{a(u)}$	Gaussian	1	0.1	0.9515	0.1021	0.9515	0.1021
$\tilde{a}_{\Delta y}$	Gaussian	0.3	0.05	0.2745	0.0452	0.2745	0.0452
ξ^w	Beta	0.5	0.1	0.7019	0.0555	0.7019	0.0555
ξ^p	Beta	0.5	0.1	0.8894	0.012	0.8894	0.012
$\tilde{\rho}$	Beta	0.75	0.1	0.8637	0.0133	0.8637	0.0133
σ^ϵ	Inv. Gamma	0.1	2	0.0096	0.0006	0.0096	0.0006
σ^{μ^z}	Inv. Gamma	0.1	2	0.0121	0.0007	0.0121	0.0007
σ^{μ^r}	Inv. Gamma	0.1	2	0.0073	0.0004	0.0073	0.0004
σ^{ζ^i}	Inv. Gamma	0.1	2	0.0354	0.0026	0.0354	0.0026
σ^{ζ^c}	Inv. Gamma	0.1	2	0.0246	0.0032	0.0246	0.0032
σ^g	Inv. Gamma	0.1	2	0.0222	0.0013	0.0222	0.0013
σ^{x^p}	Inv. Gamma	0.1	2	0.0085	0.0005	0.0085	0.0005
σ^{ϵ^p}	Inv. Gamma	0.1	2	0.2019	0.0431	0.2019	0.0431
ρ^ϵ	Beta	0.5	0.2	0.9151	0.0242	0.9151	0.0242
ρ^{μ^z}	Beta	0.5	0.2	0.069	0.0364	0.069	0.0364
ρ^{μ^r}	Beta	0.5	0.2	0.4363	0.139	0.4363	0.139
ρ^{ζ^i}	Beta	0.5	0.2	0.415	0.0498	0.415	0.0498
ρ^{ζ^c}	Beta	0.5	0.2	0.9189	0.0337	0.9189	0.0337
ρ^g	Beta	0.5	0.2	0.9582	0.0147	0.9582	0.0147
ρ^{ϵ^p}	Beta	0.5	0.2	0.089	0.0512	0.089	0.0512
oil market							
η^M	Gamma			1	0.2000	1	0.2000
η^O	Gamma			0.1000	0.0500	0.1000	0.0500
σ^O	Gamma			10.0000	2.0000	10.0000	2.0000
σ^{ζ^o}	Inv. Gamma			0.1000	2.0000	0.1000	2.0000
$\sigma^{\zeta^{o,im}}$	Inv. Gamma			0.1000	2.0000	0.1000	2.0000
$\sigma^{\zeta^{o,ex}}$	Inv. Gamma			0.1000	2.0000	0.1000	2.0000
ρ^{ζ^o}	Beta			0.5000	0.2000	0.5000	0.2000
$\rho^{\zeta^{o,ex}}$	Beta			0.5000	0.2000	0.5000	0.2000
$\rho^{\zeta^{o,im}}$	Beta			0.5000	0.2000	0.5000	0.2000
ρ^{ϵ^o}	Beta			0.5000	0.2000	0.5000	0.2000
financial accelerator							
σ^γ	Inv. Gamma					0.1	2
σ^ξ	Inv. Gamma					0.1	2
σ^σ	Inv. Gamma					0.1	2
σ^{term}	Inv. Gamma					0.1	2
σ^n	Inv. Gamma					0.1	2
$\sigma(\xi_t, \xi_{t-1})$	Beta					0.5	0.1
ρ^γ	Beta					0.5	0.1
ρ^σ	Beta					0.5	0.1
ρ^{term}	Beta					0.5	0.1

Appendix C Model equations

C.1 CEE model equations

The CEE model consists of equations (25) to (48), which describe the behaviour of endogenous variables. Here the stationary version of the model is reported. The derivation of all model equations is provided in the Online Appendix. Shocks are described by (49) to (57).

C.1.1 Households

This block contains model equations describing the behaviour of representative households in the model.

$$\begin{aligned} \mathcal{S} \left(\frac{\mu^z_t \Upsilon \zeta^i_t i_t}{i_{t-1}} \right) &= \left(\exp \left(\sqrt{\frac{\mathcal{S}''}{2}} \left(\frac{\mu^z_t \Upsilon \zeta^i_t i_t}{i_{t-1}} - \Upsilon \bar{\mu}^z \right) \right) \right. \\ &\quad \left. + \exp \left(-\sqrt{\frac{\mathcal{S}''}{2}} \left(\frac{\mu^z_t \Upsilon \zeta^i_t i_t}{i_{t-1}} - \Upsilon \bar{\mu}^z \right) \right) - 2 \right). \end{aligned} \quad (25)$$

$$\bar{k}_t = \frac{(1-\delta)}{\mu^z_t \Upsilon} \bar{k}_{t-1} + \left(1 - S \left(\frac{\mu^z_t \Upsilon \zeta^i_t i_t}{i_{t-1}} \right) \right) i_t. \quad (26)$$

$$\lambda^z_t (1 + \tau^c) = \frac{\mu^z_t \zeta^c_t}{\mu^z_t c_t - b c_{t-1}} - \frac{\beta b \zeta^c_{t+1}}{c_{t+1} \mu^z_{t+1} - b c_t}. \quad (27)$$

$$\begin{aligned} 0 &= \frac{(-\lambda^z_t)}{\mu^{\Upsilon}_t} + \lambda^z_t q_t \left(1 - S \left(\frac{\mu^z_t \Upsilon \zeta^i_t i_t}{i_{t-1}} \right) - \frac{\partial S \left(\frac{\mu^z_t \Upsilon \zeta^i_t i_t}{i_{t-1}} \right)}{\partial \frac{i_t}{\Upsilon}} \right) \\ &\quad + \frac{\beta \lambda^z_{t+1}}{\Upsilon \mu^z_{t+1}} q_{t+1} \frac{\partial S \left(\frac{\mu^z_{t+1} \Upsilon \zeta^i_{t+1} i_{t+1}}{i_t} \right)}{\partial \frac{i_t}{\Upsilon}} \left(\frac{\Upsilon \mu^z_{t+1} \zeta^i_{t+1} i_{t+1}}{i_t} \right)^2. \end{aligned} \quad (28)$$

$$r_t^k = \bar{r}^k \exp \left(\sigma^{a(u)} (u_t - 1) \right). \quad (29)$$

$$0 = \beta \frac{\lambda_{t+1}^z}{\mu_{t+1}^z \pi_{t+1}} r_{t+1}^k u_{t+1} (1 - \tau^K) - q_t \lambda_t^z + (1 - \delta) \beta q_{t+1} \lambda_{t+1}^z. \quad (30)$$

$$0 = (1 + R_t) \frac{\beta \lambda_{t+1}^z}{\pi_{t+1} \mu_{t+1}^z} - \lambda_t^z. \quad (31)$$

C.1.2 Production

The standard NK-DSGE model introduces a two-layer production process of final goods. Therefore total final output y_t is given by

$$y_t = p_t^* \frac{\lambda^f}{\lambda^{f-1}} \epsilon_t \left(\frac{u_t \bar{k}_{t-1}}{\mu_t^z \Upsilon} \right)^{\alpha^K} \left(\epsilon_t^h h_t w_t^* \frac{\lambda^w}{\lambda^{w-1}} \right)^{\alpha^N} - \phi_t. \quad (32)$$

$$\phi_t = \frac{1 - \frac{1}{\lambda^f}}{\frac{1}{\lambda^f}} y_{t-4}. \quad (33)$$

$$\frac{r_t^k}{s_t} = \alpha^K \left(\frac{\phi_t + y_t p_t^* \frac{\lambda^f}{1 - \lambda^f}}{\frac{u_t \bar{k}_{t-1}}{\mu_t^z \Upsilon}} \right). \quad (34)$$

$$\frac{w_t}{s_t} = \alpha^N \left(\frac{\phi_t + y_t p_t^* \frac{\lambda^f}{1 - \lambda^f}}{h_t w_t^* \frac{\lambda^w}{\lambda^{w-1}}} \right). \quad (35)$$

C.1.3 Price setting

Intermediate goods-producing firms minimize costs associated with their primary production factors.

$$\tilde{\pi}_t = \pi_{t-1}^{1-\iota} \bar{\pi}^\iota. \quad (36)$$

$$F_t^p = y_t \lambda_t^z + \left(\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}} \right)^{\frac{1}{1-\lambda^f}} \beta \xi^p F_{t+1}^p. \quad (37)$$

$$K_t^p = s_t y_t \lambda^z \lambda^f \epsilon_t^p + \beta \xi^p \left(\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}} \right)^{\frac{\lambda^f}{1-\lambda^f}} K_{t+1}^p. \quad (38)$$

$$K_t^p = F_t^p \left(\frac{1 - \xi^p \left(\frac{\tilde{\pi}_t}{\pi_t} \right)^{\frac{1}{1-\lambda^f}}}{1 - \xi^p} \right)^{1-\lambda^f}. \quad (39)$$

$$p_t^* = \left((1 - \xi^p) \left(\frac{K_t^p}{F_t^p} \right)^{\frac{\lambda^f}{1-\lambda^f}} + \xi^p \left(\frac{\tilde{\pi}_t}{\pi_t} p_{t-1}^* \right)^{\frac{\lambda^f}{1-\lambda^f}} \right)^{\frac{1-\lambda^f}{\lambda^f}}. \quad (40)$$

C.1.4 Wage setting

Households provide different labour types $h_{j_h, j_l, t}$. Unions represent these labour types. Unions negotiate wages for each type of labour. Labour contractors use the different types of labour to provide homogenous labour l_t .

$$\tilde{\pi}_t^w = \pi_{t-1}^{1-l^w} \bar{\pi}^{l^w} \bar{\mu}^{z(1-l^w)} \mu_t^z l^{\mu^z}. \quad (41)$$

$$\pi_t^w = \mu_t^z \pi_t. \quad (42)$$

$$w_t^* = \left((1 - \xi^w) \left(\frac{1 - \xi^w \left(\frac{\tilde{\pi}_t^w w_{t-1}}{\pi_t^w w_t} \right)^{\frac{1}{1-\lambda^w}}}{1 - \xi^w} \right)^{\lambda^w} + \xi^w \left(\frac{\tilde{\pi}_t^w w_{t-1}}{\pi_t^w w_t} w_{t-1}^* \right)^{\frac{\lambda^w}{1-\lambda^w}} \right)^{\frac{1}{1-\lambda^w}}. \quad (43)$$

$$F_t^w = \frac{h_t w_t^* \lambda^{\frac{\lambda^w}{1-\lambda^w}} \lambda^z (1 - \tau^l)}{\lambda^w \epsilon_t^w} + \beta \xi^w \left(\frac{\tilde{\pi}_{t+1}^w}{\pi_{t+1}^w} \right)^{\frac{1}{1-\lambda^w}} \left(\frac{w_t}{w_{t+1}} \right)^{\frac{\lambda^w}{1-\lambda^w}} F_{t+1}^w. \quad (44)$$

$$K_t^w = \left(h_t w_t^* t^{\frac{\lambda^w}{\lambda^w - 1}} \right)^{1 + \sigma^L} + \beta \xi^w \left(\frac{w_t \frac{\tilde{\pi}_{t+1}^w}{\bar{\pi}_{t+1}^w}}{w_{t+1}} \right)^{\frac{\lambda^w (1 + \sigma^L)}{1 - \lambda^w}} K_{t+1}^w. \quad (45)$$

$$K_t^w = \frac{F^w t w_t \left(\frac{1 - \xi^w \left(\frac{\tilde{\pi}_{t-1}^w w_{t-1}}{\bar{\pi}_{t-1}^w w_t} \right)^{\frac{1}{1 - \lambda^w}}}{1 - \xi^w} \right)^{1 - \lambda^w (1 + \sigma^L)}}{\zeta_t^h \psi^L}. \quad (46)$$

C.1.5 Monetary policy and resource constraint

$$\frac{1 + R_t}{1 + \bar{R}} = \left(\frac{1 + R_{t-1}}{1 + \bar{R}} \right)^{\bar{\rho}} \left\{ \left(\frac{\pi_{t-1}}{\bar{\pi}} \right)^{1 + \bar{a}_\pi} \left(\frac{\mu_{t-1}^z}{\bar{\mu}^z} \frac{c_{t-1} + \frac{i_{t-1}}{\bar{\mu}_{t-1}^\Upsilon} + g_{t-1}}{c_{t-2} + \frac{i_{t-2}}{\bar{\mu}_{t-2}^\Upsilon} + g_{t-2}} \right)^{\bar{a}_{\Delta y}} \right\}^{1 - \bar{\rho}} + \frac{\sigma^{x^p}}{4} x_t^p. \quad (47)$$

$$y_t = c_t + \frac{i_t}{\bar{\mu}_t^\Upsilon} + g_t + \frac{\bar{k}_{t-1}}{\bar{\mu}_t^z \bar{\Upsilon}} a(u_t). \quad (48)$$

C.1.6 Shocks

Shocks in the CEE model are responsible for fluctuations of the endogenous variables around the balanced growth path. These variables do not depend on the development of endogenous variables.

$$\log \left(\frac{g_t}{\bar{g}} \right) = \rho^g \log \left(\frac{g_{t-1}}{\bar{g}} \right) + \sigma^g \eta_t^g. \quad (49)$$

$$\log \left(\frac{\epsilon_t}{\bar{\epsilon}} \right) = \rho^\epsilon \log \left(\frac{\epsilon_{t-1}}{\bar{\epsilon}} \right) + \sigma^\epsilon \eta_t^\epsilon. \quad (50)$$

$$\log \left(\frac{\epsilon_t^h}{\bar{\epsilon}^h} \right) = \rho^{\epsilon^h} \log \left(\frac{\epsilon_{t-1}^h}{\bar{\epsilon}^h} \right) + \sigma^{\epsilon^h} \eta_t^{\epsilon^h}. \quad (51)$$

$$\log \left(\frac{\epsilon^p_t}{\bar{\epsilon}^p} \right) = \rho^{\epsilon^p} \log \left(\frac{\epsilon^p_{t-1}}{\bar{\epsilon}^p} \right) + \sigma^{\epsilon^p} \eta^{\epsilon^p}_t. \quad (52)$$

$$\log \left(\frac{\epsilon^w_t}{\bar{\epsilon}^w} \right) = \rho^{\epsilon^w} \log \left(\frac{\epsilon^w_{t-1}}{\bar{\epsilon}^w} \right) + \sigma^{\epsilon^w} \eta^{\epsilon^w}_t. \quad (53)$$

$$\log \left(\frac{\mu^z_t}{\bar{\mu}^z} \right) = \rho^{\mu^z} \log \left(\frac{\mu^z_{t-1}}{\bar{\mu}^z} \right) + \sigma^{\mu^z} \eta^{\mu^z}_t. \quad (54)$$

$$\log \left(\frac{\mu^{\Upsilon}_t}{\bar{\mu}^{\Upsilon}} \right) = \rho^{\mu^{\Upsilon}} \log \left(\frac{\mu^{\Upsilon}_{t-1}}{\bar{\mu}^{\Upsilon}} \right) + \sigma^{\mu^{\Upsilon}} \eta^{\mu^{\Upsilon}}_t. \quad (55)$$

$$\log \left(\frac{\zeta^c_t}{\bar{\zeta}^c} \right) = \rho^{\zeta^c} \log \left(\frac{\zeta^c_{t-1}}{\bar{\zeta}^c} \right) + \sigma^{\zeta^c} \eta^{\zeta^c}_t. \quad (56)$$

$$\log \left(\frac{\zeta^i_t}{\bar{\zeta}^i} \right) = \rho^{\zeta^i} \log \left(\frac{\zeta^i_{t-1}}{\bar{\zeta}^i} \right) + \sigma^{\zeta^i} \eta^{\zeta^i}_t. \quad (57)$$

C.1.7 Observational Equations

$$c_t^{obs} = \bar{c}^{obs} \frac{\mu^z_t c_t}{\mu^z c_{t-1}}, \quad (58)$$

$$y_t^{obs} = \bar{y}^{obs} \frac{\mu^z_t \left(c_t + \frac{i_t}{\mu^{\Upsilon}_t} + g_t \right)}{\bar{\mu}^z \left(c_{t-1} + \frac{i_{t-1}}{\mu^{\Upsilon}_{t-1}} + g_{t-1} \right)}, \quad (59)$$

$$h_t^{obs} = \bar{h}^{obs} \frac{h_t}{(\bar{h})}, \quad (60)$$

$$i_t^{obs} = \bar{i}^{obs} \frac{\mu^z_t i_t}{\mu^z i_{t-1}}, \quad (61)$$

$$w_t^{obs} = \bar{w}^{obs} \frac{\mu^z_t w_t}{\mu^z w_{t-1}}, \quad (62)$$

$$p_t^{i,obs} = \bar{p}^{i,obs} \frac{\mu^{\Upsilon}}{\mu^{\Upsilon}_t}, \quad (63)$$

$$\pi_t^{obs} = \bar{\pi}^{obs} \frac{\pi_t}{\bar{\pi}}, \quad (64)$$

$$R_t^{obs} = \bar{R}^{obs} \exp(R_t - \bar{R}). \quad (65)$$

C.2 CMR model equations

The CMR model uses (25) to (47). Including the financial accelerator leads to modifications of the resource constraint. Further, (66), (68), (69), (70), (71), (72) are additional model equations. These equations describe the behaviour of entrepreneurs and mutual funds. The new resource constraint is now (73) and replaces (48). Further, the financial accelerator model will introduce new shocks to the model. These shocks drive the dispersion in the idiosyncratic productivity of entrepreneurs.

C.2.1 Entrepreneurs

$$F(\bar{\omega}_t) = \Phi \left(\frac{\log(\bar{\omega}_t) + \frac{\sigma_{t-1}^2}{2}}{\sigma_{t-1}} \right). \quad (66)$$

$$G(\bar{\omega}_t) = \Phi \left(\frac{\log(\bar{\omega}_t) + \frac{\sigma_{t-1}^2}{2}}{\sigma_{t-1}} - \sigma_{t-1} \right). \quad (67)$$

$$1 + R_t^k = \frac{\pi_t \left((1 - \tau^k) (u_t r_t^k - a(u_t)) + (1 - \delta) q_t \right)}{\Upsilon q_{t-1}} + \delta \tau^k. \quad (68)$$

$$0 = 1 + \frac{(1 + R_t^k) \frac{\bar{k}_{t-1} q_{t-1}}{n_{t-1}} (G(\bar{\omega}_t) (1 - \mu) + \bar{\omega}_t (1 - F(\bar{\omega}_t)))}{1 + R_{t-1}} - \frac{\bar{k}_{t-1} q_{t-1}}{n_{t-1}}. \quad (69)$$

$$0 = \frac{(1 - (\bar{\omega}_{t+1} (1 - F(\bar{\omega}_{t+1})) + G(\bar{\omega}_{t+1}))) (1 + R_{t+1}^k)}{1 + R_t} \quad (70)$$

$$+ \frac{1 - F(\bar{\omega}_{t+1})}{1 - F(\bar{\omega}_{t+1}) - \mu \Phi\left(\frac{\log(\bar{\omega}_{t+1}) + \frac{\sigma_t^2}{2}}{\sigma_t}\right) \sigma_t} \left(\frac{1 + R_{t+1}^k}{1 + R_t} (\bar{\omega}_{t+1} (1 - F(\bar{\omega}_{t+1})) \dots \right.$$

$$\left. + (1 - \mu) G(\bar{\omega}_{t+1}) \right) - 1 \Bigg).$$

$$n_t = q_{t-1} \bar{k}_{t-1} \frac{\gamma_t}{\mu^{z_t} \pi_t} \left(R_t^k - R_{t-1} - (1 + R_t^k) \dots \right. \quad (71)$$

$$\left. (G(\bar{\omega}_t) + \bar{\omega}_t (1 - F(\bar{\omega}_t)) - (G(\bar{\omega})_t (1 - \mu) + \bar{\omega}_t (1 - F(\bar{\omega})_t))) \right) + \omega^e + \frac{n_{t-1} (1 + R_{t-1}) \gamma_t}{\mu^{z_t} \pi_t}.$$

$$dcost(\bar{\omega})_t = \frac{\bar{k}_{t-1} q_{t-1} (1 + R_t^k) G(\bar{\omega})_t \mu}{\mu^{z_t} \pi_t}. \quad (72)$$

$$y_t = dcost(\bar{\omega}_t) + c_t + \frac{i_t}{\mu \Upsilon_t} + g_t + \frac{\bar{k}_{t-1}}{\mu^{z_t} \Upsilon} a(u_t) + \frac{\Theta (1 - \gamma_t) (n_t - \omega^e)}{\gamma_t}. \quad (73)$$

C.2.2 Shocks

$$\log\left(\frac{\sigma_t}{\bar{\sigma}}\right) = \rho^{\pi^*} \log\left(\frac{\sigma_{t-1}}{\bar{\sigma}}\right) + \sigma^\sigma \eta_t^\sigma + \sum_{s=1}^S \log(\xi_{t-s}^s). \quad (74)$$

$$\log(\xi_t^s) = \begin{cases} \sigma^\xi \eta_t^{\xi^s} + (2\sigma(\xi_t^s, \xi_t^{s+1}) - 1) \log(\xi_t^{s+1}) & \text{if } s < S, \\ \sigma^\xi \eta_t^{\xi^s} & \text{if } s = S. \end{cases} \quad (75)$$

$$\log \left(\frac{\gamma_t}{\bar{\gamma}} \right) = \rho^\gamma \log \left(\frac{\gamma_{t-1}}{\bar{\gamma}} \right) + \sigma^\gamma \eta^\gamma_t. \quad (76)$$

$$\log \left(\frac{\zeta_t^{term}}{\bar{\zeta}^{term}} \right) = \rho^{term} \log \left(\frac{\zeta_{t-1}^{term}}{\bar{\zeta}^{term}} \right) + \sigma^{term} \eta^{term}_t. \quad (77)$$

C.2.3 Observational Equations

$$\frac{b_t^{obs}}{\bar{b}^{obs}} = \frac{q_t \bar{k}_t - n_t}{q_{t-1} \bar{k}_{t-1} - n_{t-1}} \frac{\mu_t^z}{\mu^z}, \quad (78)$$

$$\frac{n_t^{obs}}{\bar{n}^{obs}} = \frac{n_t}{n_{t-1}} \frac{\mu_t^z}{\mu^z}, \quad (79)$$

$$\frac{premium_t^{obs}}{premium^{obs}} = \exp \left\{ \mu G_{t-1}(\bar{\omega}_t) \frac{q_{t-1} \bar{k}_t}{q_{t-1} \bar{k}_t - n_t} - \mu G(\bar{\omega}) \frac{q \bar{k}}{q \bar{k} - n} \right\}, \quad (80)$$

$$\frac{S_t^{1,obs}}{\bar{S}^{1,obs}} = 1 + R_t^L - R_t. \quad (81)$$

C.3 CMR/CEE–Oil model equations

To include oil as production factor I replace equations (32), (34), and (35) with equations (82), (83), (84), (85), (87) and (88). These equations describe the production process. It is also necessary to describe the behaviour of oil-supplying firms. The behaviour of oil supplying firms is described by (89), (90), (91), and (92). It is necessary to modify the resource constraint to include oil as reported in (86). Oil market shocks are introduced with (93), (94), (95), (96), and (97). A shock for capital productivity is introduced as well (98).

C.3.1 Production

$$y_t = \begin{cases} p^*_t \frac{\lambda^f}{\lambda^{f-1}} \epsilon_t \left(\alpha^M \frac{1}{\eta^M} m_t \frac{\eta^{M-1}}{\eta^M} + \alpha^N \frac{1}{\eta^M} \left(\epsilon^h_t h_t w^*_t \frac{\lambda^w}{\lambda^{w-1}} \right) \frac{\eta^{M-1}}{\eta^M} \right)^{\frac{\eta^M}{\eta^{M-1}}} - \phi_t, & \text{if } \eta^M \neq 1, \\ p^*_t \frac{\lambda^f}{\lambda^{f-1}} \epsilon_t m_t \alpha^M \left(\epsilon^h_t h_t w^*_t \frac{\lambda^w}{\lambda^{w-1}} \right)^{\alpha^N} - \phi_t, & \text{if } \eta^M = 1. \end{cases} \quad (82)$$

$$m_t = \begin{cases} \left(\alpha^{K \frac{1}{\eta^O}} \left(\epsilon^m_t \frac{u_t \bar{k}_{t-1}}{\mu^z_t \Upsilon} \right)^{\frac{\eta^O-1}{\eta^O}} + \alpha^{O \frac{1}{\eta^O}} (\epsilon^o_t o_t)^{\frac{\eta^O-1}{\eta^O}} \right)^{\frac{\eta^O}{\eta^O-1}}, & \text{if } \eta^O \neq 1, \\ \left(\epsilon^m_t \frac{u_t \bar{k}_{t-1}}{\mu^z_t \Upsilon} \right)^{\alpha^K} (\epsilon^o_t o_t)^{\alpha^O}, & \text{if } \eta^O = 1. \end{cases} \quad (83)$$

$$\frac{p^m_t}{s_t} = \alpha^{M \frac{1}{\eta^M}} \epsilon_t^{\frac{\eta^M-1}{\eta^M}} \left(\frac{m_t}{\phi_t + y_t p_t^* \frac{\lambda^f}{1-\lambda^f-1}} \right)^{\frac{(-1)}{\eta^M}}. \quad (84)$$

$$\frac{w_t}{s_t} = \alpha^{N \frac{1}{\eta^M}} \epsilon_t^{\frac{\eta^M-1}{\eta^M}} \epsilon^h_t \left(\frac{h_t w_t^* \frac{\lambda^w}{1-\lambda^w-1}}{\phi_t + y_t p_t^* \frac{\lambda^f}{1-\lambda^f-1}} \right)^{\frac{(-1)}{\eta^M}}. \quad (85)$$

$$y_t = c_t + \frac{i_t}{\mu_t^z \Upsilon} + g_t + \frac{\bar{k}_{t-1} a(u_t)}{\mu_t^z \Upsilon} - p_t^o (o^{ex}_t - o^f_t) \quad (86)$$

$$\begin{cases} + dcost(\bar{\omega})_t + \frac{\Theta(1-\gamma_t)(n_t - \omega^e)}{\gamma_t}, & \text{for CMR-Oil model,} \\ & \text{for CEE-Oil model.} \end{cases}$$

C.3.2 Oil market

$$\frac{p_t^o}{p^m_t} = \alpha^{O \frac{1}{\eta^O}} \epsilon^o_t \left(\frac{o_t}{m_t} \right)^{\frac{(-1)}{\eta^O}}. \quad (87)$$

$$\frac{r^k_t}{p^m_t} = \alpha^{K \frac{1}{\eta^O}} \epsilon^m_t \left(\frac{u_t \bar{k}_{t-1}}{\mu^z_t \Upsilon} \right)^{\frac{(-1)}{\eta^O}}. \quad (88)$$

$$p_t^o (1 - \tau^O) = \left(\frac{\zeta^o_t}{\gamma^o} \right)^{1+\sigma^O} o_t^{d \sigma^O}. \quad (89)$$

$$p_t^o (1 - \tau^O) = \left(\frac{\zeta^{o,im}_t}{\gamma^{o,im}} \right)^{1+\sigma^O} o_t^{im \sigma^O}. \quad (90)$$

$$o_t^{ex} = o_t^d \zeta^{o,ex}_t. \quad (91)$$

$$o_t + o_t^{ex} = o_t^d + o_t^{im}. \quad (92)$$

C.3.3 Shocks

$$\log \left(\frac{\zeta_t^o}{\zeta^o} \right) = \rho^{\zeta^o} \log \left(\frac{\zeta_{t-1}^o}{\zeta^o} \right) + \sigma^{\zeta^o} \eta^{\zeta^o}_t. \quad (93)$$

$$\log \left(\frac{\zeta_t^{o,im}}{\zeta^{o,im}} \right) = \rho^{\zeta^{o,im}} \log \left(\frac{\zeta_{t-1}^{o,im}}{\zeta^{o,im}} \right) + \sigma^{\zeta^{o,im}} \eta^{\zeta^{o,im}}_t. \quad (94)$$

$$\log \left(\frac{\zeta_t^{o,ex}}{\zeta^{o,ex}} \right) = \rho^{\zeta^{o,ex}} \log \left(\frac{\zeta_{t-1}^{o,ex}}{\zeta^{o,ex}} \right) + \sigma^{\zeta^{o,ex}} \eta^{\zeta^{o,ex}}_t. \quad (95)$$

$$\log \left(\frac{\tau_t^o}{\tau^o} \right) = \rho^{\tau^o} \log \left(\frac{\tau_{t-1}^o}{\tau^o} \right) + \sigma^{\tau^o} \eta^{\tau^o}_t. \quad (96)$$

$$\log \left(\frac{\epsilon_t^o}{\epsilon^o} \right) = \rho^{\epsilon^o} \log \left(\frac{\epsilon_{t-1}^o}{\epsilon^o} \right) + \sigma^{\epsilon^o} \eta^{\epsilon^o}_t. \quad (97)$$

$$\log \left(\frac{\epsilon_t^k}{\epsilon^k} \right) = \rho^{\epsilon^k} \log \left(\frac{\epsilon_{t-1}^k}{\epsilon^k} \right) + \sigma^{\epsilon^k} \eta^{\epsilon^k}_t. \quad (98)$$

C.3.4 Observational Equations

$$o_t^{obs} = \frac{\mu_t^z}{\bar{\mu}^z} \frac{O_t}{O_{t-1}} \bar{o}^{obs}, \quad (99)$$

$$o_t^{d,obs} = \frac{\mu_t^z}{\bar{\mu}^z} \frac{O_t^d}{O_{t-1}^d} \bar{o}^{d,obs}, \quad (100)$$

$$o_t^{im,obs} = \frac{\mu_t^z}{\bar{\mu}^z} \frac{O_t^{im}}{O_{t-1}^{im}} \bar{o}^{im,obs}, \quad (101)$$

$$o_t^{ex,obs} = \frac{\mu_t^z}{\bar{\mu}^z} \frac{O_t^{ex}}{O_{t-1}^{ex}} \bar{o}^{ex,obs}, \quad (102)$$

$$p_t^{o,obs} = \bar{p}^{o,obs} \frac{p_t^o}{p_{t-1}^o}. \quad (103)$$

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