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Great Recession and news shocks: evidence based on an estimated DSGE model

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Abstract

This paper examines whether productivity news shocks were among the drivers of the Great Recession. To do this, the Smets and Wouters (Am Econ Rev 97(3):586–606, 2007. https://doi.org/10.1257/aer.97.3.586) model is extended by a generalized preference specification which allows for scaling wealth effects on the labor supply. The resulting model is estimated using Bayesian methods which draw upon the US data from the period 1965Q2 to 2014Q3. There are four main results: (i) Estimation of the model is inconclusive regarding the degree of wealth elasticity of the labor supply. As a result, two complementary versions of the model prevail, each of which has differing implications for the transmission and the quantitative importance of exogenous shocks. (ii) When the degree of wealth elasticity of the labor supply is low, news shocks replace risk premium shocks, suggesting that news shocks are one possible reason for fluctuations in US business cycles. (iii) When the Great Recession period is analyzed through the lenses of the two complementary versions of the model, two explanations emerge as potential reasons behind the deepening of the crisis: worsening credit conditions as well as the collapse of over-optimistic expectations regarding future productivity. (iv) For both model specifications, general developments in productivity are estimated to be positive. Therefore, productivity slowdown is not considered to be among the reasons for the emergence or persistence of the Great Recession.

Keywords Business cycles · News shocks · DSGE · Bayesian Estimation · GHH Preferences

JEL Classification E32

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1 Introduction

The Great Recession was the most severe and extended recession ever experienced in the post-war USA. Since this crisis occurred, economists have been trying to disentangle the real or financial shocks that may have triggered the recession as well as trying to quantify the contribution of those shocks in relation to the collapse of economic activity. In the literature, the consensus is that the recession originated in the financial sector. However, the origin and relative importance of alternative disturbances, which amplified the crisis, are still open to debate. In this literature, there has been a recent discussion revolving around the fact that productivity slowdown may have been either a cause or a consequence of the Great Recession. Gust et al. (2017) and Christiano et al. (2015) claim that low productivity growth was among the origins of the crisis. On the contrary, Lindé et al. (2016) show that productivity shocks were positive during the recession and weak productivity growth was not a key contributing factor to the crisis. However, this debate misses an important aspect regarding productivity shocks. In addition to current productivity developments, as has recently been shown in the literature, news about future productivity was seen to be an important driver of business cycles (Beaudry and Portier 2006; Schmitt-Grohé and Uribe 2012; Fujiwara et al. 2011). In this paper, I address this gap by formally estimating a dynamic stochastic general equilibrium (DSGE) model extended with productivity news shocks. I aim to contribute to this strand of research in two ways: (i) by estimating the productivity process before and during the recession and (ii) by investigating whether expectation-driven waves of optimism and pessimism, regarding future productivity, contributed to the emergence and the deepening of the crisis.

As is suggested by Barro and King (1984) and Cochrane (1994), and more recently by Beaudry and Portier (2007), it is not easy to accommodate news shocks in the standard neoclassical growth model or in many of its variants. The transmission of news shocks in a standard real business cycle model is as follows: Agents expecting higher future productivity feel wealthier, so they increase their consumption and leisure. Since the output level is determined by labor supply and predetermined capital, this decline in the labor supply leads to a fall in output and investment. That is, the good news about future productivity move hours and consumption in opposite directions, thus leading to a recession. As this narrative shows, the capacity of a model to generate news-driven business cycles depends on its labor market structure. Nebioglu (2017) shows that to account for news shocks, the labor market structure of the standard neoclassical growth model can be modified. In particular, internal habit formation in consumption, preferences with low wealth elasticity of labor supply, and labor adjustment costs can be used to modify the labor supply schedule, whereas investment adjustment costs, variable capacity utilization, and wage and price rigidities can be used to alter the labor demand schedule. In the literature, Jaimovich and Rebelo (2009) use a generalized utility function which allows for varying degrees of wealth elasticity of the labor supply, variable capital utilization costs and investment adjustment costs, Christiano et al. (2008) assume habit formation in consumption, investment adjustment costs as well as both wage and price rigidities, and Kobayashi and Nutahara (2010) assume price rigidity and investment adjustment costs to generate news-driven business cycles.[1]

In this paper, I use the model developed by Smets and Wouters (2007) as the benchmark, since it features standard real and nominal frictions proposed in the news shock literature and has proven to be successful in accounting for unanticipated shocks. Furthermore, it fits the US data well. In addition, to facilitate the operation of news shocks, I extend this model by using a modified version of the generalized preference structure offered by Jaimovich and Rebelo (2009). Jaimovich and Rebelo (2009) preferences nest (King et al. 1988) and (Greenwood et al. 1988) preferences as extreme cases and allow for scaling wealth effects on the labor supply. King et al. (1988) preferences refer to the standard neoclassical preference structure with strong wealth effects on labor supply, as in the original (Smets and Wouters 2007) formulation, while (Greenwood et al. 1988) preferences show that the magnitude of wealth effects on the labor supply is zero. I use the generalized preference structure as the empirical evidence based on estimated DSGE models regarding the magnitude of wealth effects on labor supply is limited and mixed. Within news shock literature, using (Jaimovich and Rebelo 2009) preferences and the RBC framework, Schmitt-Grohé and Uribe (2012) estimate the parameter governing the wealth effect on the labor supply as close to zero. On the contrary, Khan and Tsoukalas (2012) estimate a relatively important wealth effect on the labor supply using a New Keynesian model. On the other hand, Galí et al. (2011) show that in a standard DSGE model, adding unemployment to the set of observable variables leads to a dramatic change in the estimate of this parameter.

This paper also makes a methodological contribution to the DSGE literature by offering a different specification for news shock. Instead of modeling news shock as an innovation to productivity level that hit the economy at a future date, this paper specifies news shock as a current innovation to the economy's growth potential. Similar to the news shocks literature, this framework aims to identify the expected increase in future productivity as a source of aggregate fluctuations. A positive innovation in the growth rate of TFP means a gradual increase in the level of productivity; hence, it can be used to model optimistic expectations about future productivity levels, i.e., following this shock, agents observing the increase in productivity expect it will continue to increase in the future. Modeling news shocks in this fashion is consistent with the original formulation of Beaudry and Portier (2006) and with the findings of Barsky et al. (2014). Both studies show that news shocks have the character of anticipated growth shocks. In particular, they show that productivity displays a smooth increase over a number of quarters following a news shock.

In this paper, Bayesian methodology is employed for estimations along with quarterly US data over the period 1965Q2–2014Q3 for seven key macroeconomic variables which are the log difference of real GDP; real consumption; real investment; real wages; log hours worked; the log difference of the GDP deflator; and the federal funds rate. Throughout the paper, I discuss the results from three different estimations. First, I estimate the (Smets and Wouters 2007) model extended by the generalized preference structure offered by Jaimovich and Rebelo (2009). The results from this estimation

[1] Interested reader can refer to Beaudry and Portier (2014) for an extensive review of the empirical and theoretical literature about news shocks.

show that with different starting values, optimization of the posterior density delivers two extreme values for the parameter that governs the wealth elasticity of the labor supply, implying standard (King et al. 1988) preferences at one extreme and (Greenwood et al. 1988) preferences at the other. In addition, two complementary versions of the model prevail with different implications for transmission mechanisms and the quantitative importance of exogenous shocks. Considering the mixed empirical evidence in the literature regarding the magnitude of wealth elasticity parameters, two additional estimations are made by fixing this parameter to the extreme values prior to estimation. Hereafter, the model with King et al. (1988) preferences will be referred to as the KPR model and the model with Greenwood et al. (1988) preferences will be referred to as the GHH model. For both the KPR and GHH models, the Metropolis–Hastings algorithm is used to estimate the posterior distribution of the parameters and the shock processes.

All in all, the results from these estimation exercises are fourfold: (i) For the KPR model, parameter estimates are very similar to Smets and Wouters (2007) and productivity news shocks are not chosen by the data; (ii) for the GHH model, the risk premium shock is replaced by the productivity news shock, and the dynamics and the quantitative implications of the model are quite different from Smets and Wouters (2007) model; (iii) although the two models have different explanations for the business cycles, they interpret the crisis period rather similarly. For both models, investment-specific technology shocks and monetary policy shocks are the main causes of the recession, while productivity shocks contribute positively to the output growth over most of the crisis period; and (iv) two models interpret the most acute phase of the crisis differently whereby there was a substantial drop in output during the quarter after the fall of Lehman Brothers. The KPR model attributes most of the role to risk premium shocks while the GHH model points to the collapse of over-optimistic expectations (followed by a negative news shock) as the main cause. Therefore, in line with the results of Lindé et al. (2016), I find that the productivity slowdown itself is not among the causes of the Great Recession, as it had already started to decline years before the recession. I do, however, find that agents did not recognize this decline in time and the collapse of over-optimistic expectations following the fall of Lehman Brothers contributed to the deepening of the recession.

The outline of the paper is as follows: Sect. 2 presents the model economy while Sect. 3 presents the loglinearized model. Section 4 explains the data and econometric methodology. Section 5 discusses the estimation results. Section 6 presents forecast error variance decompositions and Sect. 7 analyzes the causes the Great Recession with the help of the models considered in this paper. Concluding remarks are presented in Sect. 8.

2 The model

This section outlines my model of the US business cycles. It is a medium-scale DSGE model in the spirit of Smets and Wouters (2007) (SW henceforth) with several real and nominal frictions. The economy is populated by six agents: households; labor unions; labor packers; final good producers; intermediate good producers; and the government. In the following subsections, I give a detailed description of the model economy.

2.1 Households

There is a continuum of households indexed by $\tau \in (0, 1)$. Each household τ chooses consumption (C_t^τ), hours worked (L_t^τ), bond holdings (B_t^τ), investment (I_t^τ) and capital utilization (z_t^τ). I adopt the preference structure suggested by Jaimovich and Rebelo (2009) (JR, henceforth) which nests two special cases, which I describe later. I modify this preference structure to include external habit formation in consumption, therefore, utility depends positively on consumption C_t^τ relative to the aggregate consumption of the previous period, C_{t-1} and negatively on the labor supply, L_t^τ.[2]

The utility function of the household τ is

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left[(C_t^\tau - hC_{t-1}) - \psi \left(L_t^\tau\right)^\theta X_t\right]^{1-\sigma} - 1}{1-\sigma}, \tag{1}$$

where X_t is a geometric average of current and past habit-adjusted consumption levels as given by: $X_t = \left(C_t^\tau - hC_{t-1}\right)^\omega X_{t-1}^{1-\omega}$. $\beta \in (0, 1)$ denotes the subjective discount factor, $h \in [0, 1)$ governs the degree of external habit formation, $\sigma > 0$ is the coefficient of relative risk aversion, and $\theta > 1$ determines the elasticity of labor supply in the special case $\omega = 0$. The parameter $\omega \in [0, 1]$ governs the wealth elasticity of labor supply. When $\omega = 0$, there are no wealth effects on labor supply as in Greenwood et al. (1988) and with $\omega = 1$ the preference structure boils down to standard (King et al. 1988) preferences with strong wealth effects on labor supply. For intermediate values of ω, there are no wealth effects on the labor supply in the short run, however, they eventually start to build up as time passes. The magnitude of ω determines the horizon in which wealth effects start to kick in.

The budget constraint expressed in real terms is

$$C_t^\tau + I_t^\tau + b_t \frac{B_t^\tau}{\epsilon_t^b P_t} = \frac{B_{t-1}^\tau}{P_t} + \frac{W_t^h}{P_t} L_t^\tau + r_t^k z_t^\tau K_{t-1}^\tau + Div_t - T_t, \tag{2}$$

and the capital accumulation equation is:

$$K_t = [1 - \Psi(z_t)] K_{t-1} + \epsilon_t^I \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) I_t. \tag{3}$$

Household's total income consists of labor income, $\frac{W_t^h}{P_t} L_t^\tau$, return on the real capital stock, $r_t^k z_t^\tau K_{t-1}^\tau$ and dividend payments, Div_t, from labor unions. T_t is lump

[2] In their sensitivity analysis, SW show that reducing habit formation in consumption is quite costly in terms of likelihood, therefore JR preferences are modified to include external habit formation in consumption to keep the preference structure similar to SW.

sum tax paid to the government. The capital income depends not only on the capital accumulated last period but also on its utilization rate, z_t^τ.

The function $S(.)$ introduces investment adjustment costs of the form proposed by Christiano et al. (2005) with $S(\gamma) = S'(\gamma) = 0$, $S''(.) > 0$. ϵ_t^I is the shock to the price of investment relative to consumption goods and assumed to follow an AR(1) process: $\log(\epsilon_t^I) = (1 - \rho_I)\log(\epsilon^I) + \rho_I \log(\epsilon_{t-1}^I) + \eta_t^I$ where η_t^I is IID-Normal investment specific technology shock.

Households own the capital stock and decide how much capital to rent to intermediate good producers at a given rate, r_t^k. They can increase their supply of capital services either by investing in additional capital, I_t or by increasing the utilization rate of already installed capital, z_t. Increasing the intensity of capital accumulation entails a cost in the form of a faster depreciation as in Greenwood et al. (1988). $\Psi(z_t)$ is the depreciation function that is convex in utilization with $\Psi'(z_t) > 0$, $\Psi''(z_t) \geq 0$. The depreciation is constant and equals to Ψ in steady state.

Finally, households hold their financial wealth in the form of bonds, B_t. Bonds are one period securities with price b_t. ϵ_t^b is an exogenous premium in the return to bonds, which accounts for the inefficiencies in the financial sector leading to some premium on the deposit rate versus the risk-free rate set by the central bank, or a risk premium that households require to hold the one period bond and it is assumed to follow AR(1) process: $\log(\epsilon_t^b) = (1 - \rho_b)\log(\epsilon^b) + \rho_b \log(\epsilon_{t-1}^b) + \eta_t^b$ where η_t^b is an IID-Normal risk premium shock.

In equilibrium, households will make the same choices for consumption, hours worked, bonds, investment, and capital utilization. Therefore, for the rest of this section, I will drop τ index for those variables.

First order conditions for consumption/saving choice imply:

$$E_t\left[\beta \frac{\lambda_{t+1}}{\lambda_t}\frac{\epsilon_t^b R_t}{\Pi_{t+1}}\right] = 1 \tag{4}$$

where R_t is the gross nominal return on bonds. ($R_t = 1 + i_t = 1/b_t$) and λ_t is marginal utility of consumption which is given by:

$$\lambda_t = \left(C_t - hC_{t-1} - \psi L_t^\theta X_t\right)^{-\sigma}\left(1 - \omega\psi L_t^\theta\left(C_t - hC_{t-1}\right)^{\omega-1} X_t^{1-\omega}\right). \tag{5}$$

Households supply their homogeneous labor in a competitive market. First-order conditions regarding leisure/consumption trade-off give the following labor supply function for the case of flexible wages:

$$w_t^h = \frac{W_t^h}{P_t} = \frac{\psi\theta L_t^{\theta-1} X_t}{1 - \omega\psi L_t^\theta\left(C_t - hC_{t-1}\right)^{\omega-1} X_t^{1-\omega}}. \tag{6}$$

w_t^h is the real wage desired by the households and reflects the marginal rate of substitution between leisure and consumption. Note that when $\omega = 0$, the labor supply decision depends only on real wages, in this extreme case, there is no wealth effect on the labor supply.

The first-order conditions for capital, investment and utilization result in the following equations for real value of capital, investment, and the rate of utilization:

$$Q_t = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left\{ r^k_{t+1} z^\tau_{t+1} + Q_{t+1} \left(1 - \delta(z_{t+1})\right) \right\} \right], \tag{7}$$

$$\begin{aligned} 1 &= Q_t \epsilon^I_t \left(1 - S' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} - S \left(\frac{I_t}{I_{t-1}} \right) \right) \\ &\quad + E_t \left[Q_{t+1} \frac{\lambda_{t+1}}{\lambda_t} \epsilon^I_{t+1} \beta S' \left(\frac{I_{t+1}}{I_t} \right) \frac{I_{t+1}}{I_t^2} I_{t+1} \right], \end{aligned} \tag{8}$$

$$r^k_t = Q_t \Psi'(z_t). \tag{9}$$

Q_t is Tobin's Q and is defined as $Q_t = \mu_t / \lambda_t$ where μ_t and λ_t are Lagrange multipliers associated with the capital accumulation equation and the budget constraint, respectively.

According to Eq. (7), the value of installed capital depends on the expected future value of capital taking into account the depreciation rate and the expected future return to capital.

Equation (8) is the investment Euler equation and determines the dynamics of investment as a function of the real value of the capital and the investment adjustment costs.

The first-order condition for the utilization rate given by Equation (9) equates the cost of higher capital utilization with the rental price of capital services. The cost function $\Psi'(.)$ is multiplied by Q_t to convert it to a unit for consumption goods. An increase in the rental rate provides an incentive to increase utilization up to the point where extra benefit equals extra cost, as long as Q_t does not move in the same direction.

2.2 Firms

The country produces a single homogeneous final good and a continuum of intermediate goods. The final good is traded in a perfectly competitive market and is used by households for consumption and investment. There is monopolistic competition in the intermediate goods sector, and each household is a producer of a specialized intermediate good. The agents in the labor market are the intermediate labor union and labor packers. The intermediate labor union rents homogeneous labor from households and differentiates and sells it to labor packers. Labor packers combine differentiated labor and sell it to intermediate good producers as a homogeneous labor input. Wages for differentiated labor and prices for differentiated goods are adjusted following (Calvo 1983) model and wages and prices that are not re-optimized are partially indexed to past inflation rates.

2.2.1 Labor market

Households supply their homogeneous labor, L_t to an intermediate labor union which then differentiates the labor services as L^j_t where $j \in [0, 1]$ and resells them to labor packers. The intermediate union has market power in its negotiations with labor packers and sets wages following the (Calvo 1983) model. In turn, labor packers package labor composite L_t and sell it to intermediate good producing firms in a perfectly competitive environment.

Labor packers use the following technology to convert the differentiated labor into composite L_t

$$L_t = \left[\int_0^1 \left(L_t^j \right)^{\frac{1}{1+\lambda_{w,t}}} \mathrm{d}j \right]^{1+\lambda_{w,t}}. \tag{10}$$

As a result, the labor demand for differentiated labor services is given by the equation below:

$$L_t^j = \left(\frac{W_t^j}{W_t} \right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} L_t. \tag{11}$$

$\lambda_{w,t}$ is a stochastic parameter that determines the time varying wage markup in the labor market and it is assumed to follow an ARMA(1,1) process: $\log \lambda_{w,t} = (1 - \rho_w) \log \lambda_w + \rho_w \log \lambda_{w,t-1} + \theta_w \epsilon_{t-1}^w + \epsilon_t^w$ where ϵ_t^w is IID-Normal wage mark-up shock.

The price of the labor package given by $W_t = \left[\int_0^1 \left(W_t^l \right)^{\frac{1}{\lambda_{w,t}}} \mathrm{d}j \right]^{\lambda_{w,t}}$ becomes the wage cost of the intermediate good producers.

The real wage desired by the households, w_t^h, reflects the marginal rate of substitution between leisure and consumption. The labor union takes this marginal rate of substitution as the cost of labor services in negotiations with labor packers. The markup over the marginal disutility is distributed to households as dividends. The union has market power in its negotiations with labor packers. It can choose the wage rate for differentiated labor, W_t^j subject to the labor demand given by Equation (11). However, due to wage-setting à la (Calvo 1983), it can adjust the wages with a probability of 1-ξ^w in each period. In addition, wages which cannot be adjusted are changed at the deterministic growth rate γ and the weighted average of the steady state inflation and the inflation of the last period. Therefore, the union sets wages considering that they may not be adjusted for a long period and chooses $\tilde{W}_t^j$ for each $j \in [0, 1]$ to maximize the following objective function:

$$E_t \sum_{s=0}^{\infty} (\xi^w)^s \left[\frac{\beta^s \lambda_{t+s}/P_{t+s}}{\lambda_t/P_t} \right] \left[W_{t+s}^j - W_{t+s}^h \right] L_{t+s}^j$$

subject to

$$L_{t+s}^j = \left(\frac{W_{t+s}^j}{W_{t+s}} \right)^{-\frac{1+\lambda_{w,t+s}}{\lambda_{w,t+s}}} L_{t+s}$$

and

$$W^j_{t+s} = \tilde{W}^j_t \left(\prod_{l=1}^{s} \gamma \pi^{\gamma_w}_{t+l-1} \pi_*^{1-\gamma_w} \right) \text{ for } s = 1, 2, \ldots, \infty.$$

This maximization problem results in the following markup equation for the re-optimized wage:

$$E_t \sum_{s=0}^{\infty} (\xi^w)^s \left[\frac{\beta^s \lambda_{t+s}/P_{t+s}}{\lambda_t/P_t} \right] L^j_{t+s} \frac{1}{\lambda_{w,t+s}} \left[1 + \lambda_{w,t+s}) W^h_{t+s} - \Xi_{t,s} \tilde{W}^j_t \right] = 0 \quad (12)$$

where

$$\Xi_{t,s} = \begin{cases} 1, & \text{for s=0} \\ \prod_{l=1}^{s} \gamma \pi^{\gamma_w}_{t+l-1} \pi_*^{1-\gamma_w} & \text{for } s = 1, 2, \ldots, \infty. \end{cases}$$

The aggregate wage expression is given by $W_t = \left[(1 - \xi^w) \tilde{W}_{t+s}^{\frac{1}{\lambda_{w,t}}} + \xi_w \left(\gamma \pi^{\gamma_w}_{t-1} \pi_*^{1-\gamma_w} W_{t-1} \right)^{\frac{1}{\lambda_{w,t}}} \right]^{\lambda_{w,t}}$.

2.2.2 Final good producers

The final good Y_t is a composite made of a continuum of intermediate goods Y^i_t as in Kimball (1995). The final good producers buy intermediate goods on the market, package the final good Y_t, and resell it to consumers, investors, and the government in a perfectly competitive market.

The final good producers choose Y_t and Y^j_t to maximize profits. Their problem is formulated as follows:

$$\max P_t Y_t - \int_0^1 P^i_t Y^i_t \mathrm{d}i$$

subject to

$$\int_0^1 G\left(\frac{Y^i_t}{Y_t}; \lambda_{p,t} \right) \mathrm{d}i = 1$$

where P_t and P^i_t are the price of the final and intermediate goods, respectively, and G is a strictly concave and increasing function defined by $G(1) = 1$. $\lambda_{p,t}$ is the markup disturbance assumed to follow an ARMA(1,1) process : $\log \lambda_{p,t} = (1 - \rho_p) \log \lambda_p + \rho_p \log \lambda_{p,t-1} + \theta_p \epsilon^p_{t-1} + \epsilon^p_t$ where ϵ^p_t is IID-Normal price mark-up shock.

The optimization results in the following first-order conditions :

$$P_t = \frac{\mu_t^p}{Y_t} \int_0^1 G'\left(\frac{Y_t^i}{Y_t}\right) \frac{Y_t^i}{Y_t} \mathrm{d}i, \tag{13}$$

$$P_t^i = \mu_t^p G'\left(\frac{Y_t^i}{Y_t}\right) \frac{1}{Y_t}. \tag{14}$$

Here, $\lambda_{p,t}$'s argument is left out when considering the optimization problem, as it is exogenous. μ_t^p stands for Lagrange multiplier, which is constant for all i. As suggested in Kimball (1995), Equation (14) allows one to generate any desired shape of demand curve facing the individual firm.

Combining the above FOCs gives:

$$Y_t^i = \frac{1}{G'\left(\frac{Y_t^i}{Y_t}\right)} Y_t \left[\frac{P_t^i}{P_t} \int_0^1 G'\left(\frac{Y_t^i}{Y_t}\right) \frac{Y_t^i}{Y_t} \mathrm{d}i\right].$$

The assumptions on $G(.)$ imply that the demand for input Y_t^i is decreasing in its relative price and the elasticity of demand is an increasing function of the relative price.

2.2.3 Intermediate good producers

Intermediate good producer $i \in [0, 1]$ uses the following technology:

$$Y_t^i = \epsilon_t^a \left(z_t K_{t-1}\right)^\alpha \left(\gamma^t L_t\right)^{1-\alpha} - \gamma^t \epsilon_t^a \Phi. \tag{15}$$

The capital that is used in production is determined by the capital accumulated during the previous period (K_{t-1}) as well as the utilization rate chosen by the household (z_t). γ represents the labor augmenting deterministic growth rate in the economy, Φ represents the fixed costs in production, α represents the elasticity of output with respect to capital. ϵ_t^a is the total factor productivity which is assumed to follow an AR(1) process: $\log \epsilon_t^a = (1 - \rho_a) \log \epsilon^a + \rho_a \log \epsilon_{t-1}^a + \log \epsilon_t^{ga} + \eta_t^a$. Here, η_t^a is IID-Normal neutral productivity shock and ϵ_t^{ga} is the stochastic growth rate of TFP which is assumed to follow an AR(1) process: $\log \epsilon_t^{ga} = (1 - \rho_{ga}) \log \epsilon^{ga} + \rho_{ga} \log \epsilon_{t-1}^{ga} + \eta_t^{ga}$ where η_t^{ga} is IID-Normal productivity growth rate shock. A positive neutral productivity shock (η_t^a) increases the total factor productivity on impact, after which the effect slowly decays. This way of modeling neutral productivity shock is standard in business cycle literature. On the other hand, the effect of a positive productivity growth rate shock (η_t^{ga}) on total factor productivity is small on impact; however, it slowly builds up over time. An agent who observes a positive innovation to ϵ_t^{ga} expects that the total factor productivity will be higher in the future. Therefore, this specification is used to model news shock in this paper. Modeling news shocks in this fashion is consistent with the original formulation of Beaudry and Portier (2006) and with the findings of Barsky et al. (2014). Both studies show that news shocks have the character of anticipated growth shocks; in particular, they show that productivity displays a smooth increase over a number of quarters following the news shock.

Intermediate firm chooses capital and labor to minimize their cost stream which is given by following equation subject to the production function:

$$E_t \sum_{i=0}^{\infty} \frac{1}{\prod_{k=0}^{i-1} R_{t+k}} \left[W_{t+i} L_{t+i} + r^k_{t+i} \tilde{K}_{t+i}) \right]. \tag{16}$$

Combining first-order conditions of the firm gives the marginal cost function and the labor demand function:

$$MC_t = \frac{1}{\gamma^{t(1-\alpha)} \varepsilon^a_t} (1-\alpha)^{-(1-\alpha)} \alpha^{-\alpha} r_t^{k\alpha} W_t^{1-\alpha}, \tag{17}$$

$$W_t = \frac{1-\alpha}{\alpha} \frac{K^s_t}{L_t} r^k_t. \tag{18}$$

As in Calvo (1983), in each period, a fraction $1 - \xi_p$ of firms can set their prices. Those who cannot set their prices index their prices to an average of the inflation of the past period and the inflation target. Therefore, the firm maximizes his profit thinking that he may not re-optimize in the future by choosing $\tilde{P}^i_t$:

$$E_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \frac{\lambda_{t+s}/P_{t+s}}{\lambda_t/P_t} \left[\tilde{P}^i_t \left(\prod_{l=1}^{s} \pi_{t+l-1}^{\gamma_p} \pi_*^{1-\gamma_p} \right) - MC_{t+s} \right] Y^i_{t+s}$$

subject to

$$Y^i_{t+s} = \frac{1}{G'\left(\frac{Y^i_{t+s}}{Y_{t+s}}\right)} Y_t \left[\frac{P^i_t \Xi_{t,s}}{P_{t+s}} \int_0^1 G'\left(\frac{Y^i_{t+s}}{Y_{t+s}}\right) \frac{Y^i_{t+s}}{Y_{t+s}} \mathrm{d}i \right].$$

$\beta^s \frac{\lambda_{t+s}/P_{t+s}}{\lambda_t/P_t}$ is the nominal discount factor for firms which equals the discount factor of households that are the final owners of the firm and $\Xi_{t,s}$ is given by the following expression:

$$\Xi_{t,s} = \begin{cases} 1 & \text{for s=0} \\ \prod_{l=1}^{s} \pi_{t+l-1}^{\gamma_p} \pi_*^{1-\gamma_p} & \text{for } s = 1, 2, \ldots, \infty. \end{cases}$$

The first-order condition is given by:

$$E_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \frac{\lambda_{t+s}/P_{t+s}}{\lambda_t/P_t} Y^i_{t+s} \left[\tilde{P}^i_t X_{t,s} + \left(\tilde{P}^i_t X_{t,s} - MC_{t+s} \right) \frac{1}{G'^{-1}(z_{t+s})} \frac{G'(x_{t+s})}{G''(x_{t+s})} \right] = 0$$

where $x_t = \frac{1}{G'(\frac{P_t^i}{P_t}\int_0^1 G'\left(\frac{Y_t^i}{Y_t}\right)\frac{Y_t^i}{Y_t}\mathrm{d}i)}$.

The aggregate price index is given by:

$$P_t = (1-\xi_p)P_t^i \frac{1}{G'(\frac{P_t^i}{P_t}\int_0^1 G'\left(\frac{Y_t^i}{Y_t}\right)\frac{Y_t^i}{Y_t}\mathrm{d}i)} + \xi_p \pi_{t-1}^{\gamma_p}\pi_*^{1-\gamma_p} P_{t-1}\frac{1}{G'(\frac{P_{t-1}\pi_{t-1}^{\gamma_p}\pi_*^{1-\gamma_p}}{P_t}\int_0^1 G'\left(\frac{Y_t^i}{Y_t}\right)\frac{Y_t^i}{Y_t}\mathrm{d}i)}.$$

2.3 Government policies

The central bank follows a nominal interest rate rule by adjusting its instrument in response to deviations of inflation and output from their respective target levels:

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{r_r}\left[\left(\frac{\pi_t}{\pi^*}\right)^{r_\pi}\left(\frac{Y_t}{Y_t^*}\right)^{r_y}\right]^{1-r_r}\left(\frac{Y_t/Y_{t-1}}{Y_t^*/Y_{t-1}^*}\right)^{r_{\Delta y}}\epsilon_t^m \tag{19}$$

where R^* is the steady-state nominal gross interest rate, π_t^* is the inflation target, and Y_t^* is the natural output. The natural output level is defined as the output level that would prevail in the absence of nominal rigidities and wage and price markup shocks.

The parameter r_r determines the degree of interest rate smoothing. ϵ_t^m is the monetary policy shock which assumed to follow an AR(1) with an IID-Normal error term: $\log\epsilon_t^m = (1-\rho_m)\log(\epsilon^m) + \rho_m\log\epsilon_{t-1}^m + \eta_t^m$.

The government budget constraint is of the form

$$P_tG_t + B_{t-1} = T_t + \frac{B_t}{R_t}$$

where T_t are nominal lump sum taxes that also appear in household's budget constraint. Government spending relative to the steady state output path, $g_t = G_t/(Y\gamma^t)$ is assumed to follow the process: $\log g_t = (1-\rho_g)\log g + \rho_g\log g_{t-1} + \rho_{gy}(\log\epsilon_t^a - \log\epsilon_{t-1}^a) + \eta_t^g$ where η_t^g is IID-Normal government spending shock. As in SW, the government spending is allowed to respond to the total factor productivity process.

2.4 Market equilibrium

The final goods market is in equilibrium if production equals aggregate demand consisting of households' consumption, investment, and government expenditures.

$$Y_t = C_t + I_t + G_t \tag{20}$$

The capital market is in equilibrium when the demand for capital by the intermediate goods producers equals the supply by the households. The labor market is in equilibrium if firms' demand for labor equals labor supply at the wage level set by the households.

The interest rate is determined by the reaction function that describes monetary policy decisions. In the bond market, equilibrium means that government debt is held by domestic investors at the market interest rate R_t.

3 Loglinearized model

As the model features a deterministic trend, it needs to be detrended in order to make it stationary. Lower case variables represent detrended real variables which can be considered as stationary processes that have a well-defined steady state. Then, the resulting equations are linearized around the nonstochastic steady state for the empirical analysis of Sect. 4. The hat (^) above a variable denotes its log deviation from its steady state. This section summarizes the resulting linearized equations.

The aggregate resource constraint is given by

$$\hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{i}{y}\hat{i}_t + \hat{g}_t \tag{21}$$

where $\frac{c}{y}$ and $\frac{i}{y}$ are the steady-state consumption–output ratio and investment–output ratio, respectively.

The dynamics of consumption are determined by the consumption Euler equation and is given by:

$$\begin{aligned} \hat{c}_t =& \frac{1}{c_1}(\hat{r}_t - E_t\hat{\pi}_{t+1} + \hat{\epsilon}_t^b) + \frac{c_2}{c_1}\hat{c}_{t-1} + \frac{c_3}{c_1}E_t\hat{c}_{t+1} \\ &+ \frac{c_4}{c_1}\left(E_t\hat{L}_{t+1} - \hat{L}_t\right) + \frac{c_5}{c_1}\hat{x}_{t-1} \end{aligned} \tag{22}$$

for which the coefficients are given by

$$\begin{aligned} c_1 &= \frac{1+\bar{h}}{1-\bar{h}}\left[-\frac{\sigma}{1-\bar{\delta}} + \frac{\omega\bar{\delta}}{1-\omega\bar{\delta}}\right] + \bar{\delta}\left[\frac{\sigma}{1-\bar{\delta}} - \frac{\omega}{1-\omega\bar{\delta}}\right]\frac{\omega}{1-\bar{h}}\left(\omega+\bar{h}\right), \\ c_2 &= \frac{\bar{h}}{1-\bar{h}}\left[-\frac{\sigma}{1-\bar{\delta}} + \frac{\omega\bar{\delta}}{1-\omega\bar{\delta}}\right] + \bar{\delta}\left[\frac{\sigma}{1-\bar{\delta}} - \frac{\omega}{1-\omega\bar{\delta}}\right]\left(\frac{\omega^2\bar{h}}{1-\bar{h}}\right), \\ c_3 &= \frac{1}{1-\bar{h}}\left[-\frac{\sigma}{1-\bar{\delta}} + \frac{\omega\bar{\delta}}{1-\omega\bar{\delta}}\right] + \bar{\delta}\left[\frac{\sigma}{1-\bar{\delta}} - \frac{\omega}{1-\omega\bar{\delta}}\right]\frac{\omega}{1-\bar{h}}, \\ c_4 &= \theta\bar{\delta}\left[\frac{\sigma}{1-\bar{\delta}} - \frac{\omega}{1-\omega\bar{\delta}}\right], \\ c_5 &= -\bar{\delta}\left[\frac{\sigma}{1-\bar{\delta}} - \frac{\omega}{1-\omega\bar{\delta}}\right]\omega(1-\omega). \end{aligned}$$

The dynamics of $\hat{x}_t$ are determined by:

$$\hat{x}_t = \frac{\omega}{1-\bar{h}}(\hat{c}_t - \bar{h}\hat{c}_{t-1}) + (1-\omega)\hat{x}_{t-1}. \tag{23}$$

Current consumption depends positively on future and past consumption levels and negatively on the expected real interest rate. A positive innovation to shock $\hat{\epsilon}^b$ means that households require a higher interest rate to hold government bonds.

The dynamics of investment come from the investment Euler equation and are given by:

$$\hat{i}_t = \frac{1}{1+\bar{\beta}\gamma}\hat{i}_{t-1} + \frac{\bar{\beta}\gamma}{(1+\bar{\beta}\gamma)}E_t\hat{i}_{t+1} + \frac{1}{\gamma^2 S''(1+\bar{\beta}\gamma)}\hat{q}_t + \hat{\epsilon}_t^I. \tag{24}$$

Current investment depends on past and future investment levels due to the investment adjustment cost and the elasticity of investment with respect to the price of capital depends negatively on the investment adjustment cost parameter. $\hat{\epsilon}_t^I$ follows an AR(1) process with normally distributed i.i.d. errors and innovation to this shock means a reduction in the price of capital; furthermore, it temporarily increases investment.

The real value of capital is given by:

$$\hat{q}_t = -(\hat{r}_t - E_t\hat{\pi}_{t+1} + \hat{\epsilon}_t^b) + (1-\bar{\beta}(1-\tau))E_t\hat{r}_{t+1}^k + \bar{\beta}(1-\tau)E_t\hat{q}_{t+1}. \tag{25}$$

This equation shows that the price of capital depends negatively on the real interest rate and positively on the rental rate of capital and the future price of investment. As $\hat{\epsilon}_t^b$ reflects the risk premium demanded by households for holding bonds, it also shows up in this arbitrage equation.

On the supply side, the aggregate production function is given by:

$$\hat{y}_t = \left(1 + \frac{\Phi}{y}\right)\left[\alpha(\hat{k}_t + \hat{z}_t) + (1-\alpha)\hat{L}_t + \hat{\epsilon}_t^a\right] \tag{26}$$

where the utilization rate is determined by:

$$\hat{z}_t = \frac{\Psi'}{\Psi''}\left(\hat{r}_t^k - \hat{q}_t\right). \tag{27}$$

The utilization rate depends positively on the rental rate of capital and negatively on the real value of the capital.

The capital accumulation equation is given by:

$$\hat{k}_{t+1} = \frac{1}{\gamma}\left[(1-\tau)\,\hat{k}_t + \frac{i}{k}\hat{i}_t - r^k\hat{z}_t\right]. \tag{28}$$

As the variable capital utilization cost is defined in terms of capital goods, it shows up as a negative term in this equation.

The marginal cost is given by

$$\hat{mc}_t = (1-\alpha)\,\hat{w}_t + \alpha\hat{r}_t^k - \hat{\epsilon}_t^a. \tag{29}$$

The pricing decision results in the following inflation equation:

$$\begin{aligned}\hat{\pi}_t = &\frac{\iota_p}{1+\beta\iota_p}\hat{\pi}_{t-1} + \frac{\beta}{1+\beta\iota_p}E_t\hat{\pi}_{t+1}\\ &-\frac{1}{1+\beta\iota_p}\frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p}((\phi_p-1)\epsilon_p+1)\hat{\mu}_t^p.\end{aligned} \tag{30}$$

Current inflation depends on past inflation as well as on future inflation, and the time-varying price markup shock. Due to the existence of price rigidities, prices cannot immediately adjust to desired markup levels.

Profit maximization of the intermediate good producers results in the following labor demand equation:

$$\hat{w}_t = \hat{k}_t + \hat{z}_t - \hat{L}_t + \hat{r}_t^k. \tag{31}$$

The wage-setting equation is given by:

$$\begin{aligned}\hat{w}_t = &\frac{1}{1+\bar{\beta}\gamma}\hat{w}_{t-1} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma}E_t\hat{w}_{t+1} + \frac{\iota_w}{1+\bar{\beta}\gamma}\hat{\pi}_t + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma}E_t\hat{\pi}_{t+1}\\ &+\frac{(1-\xi^w)(1-\bar{\beta}\gamma)\xi^w}{(1+\bar{\beta}\gamma)\xi^w}\frac{1}{(\lambda_w-1)\epsilon_w+1}(\hat{w}_t^h-\hat{w}_t)+\hat{\epsilon}_t^w\end{aligned} \tag{32}$$

where $\hat{w}_t^h$ stands for the real wage desired by the household and is given by the following equation:

$$\begin{aligned}\hat{w}_t^h = &\left(\theta-1+\frac{\omega\kappa}{1-\bar{h}}\right)\hat{L}_t + \frac{\kappa\omega^2+(\theta(1-\bar{h})-\kappa)\omega}{\theta(1-\bar{h})^2}(\hat{c}_t-\bar{h}\hat{c}_{t-1})\\ &+\left(\frac{\omega(1-\omega)\kappa}{\theta(1-\bar{h})}+1-\omega\right)\hat{x}_{t-1}.\end{aligned} \tag{33}$$

Finally, the model is closed with the following monetary reaction function of the central bank:

$$\begin{aligned}\hat{r}_t = &r_r\hat{r}_{t-1} + (1-r_r)\left[r_\pi\hat{\pi}_t + r_y\left(\hat{y}_t-\hat{y}_t^*\right)\right]\\ &+r_{\Delta y}\left[\left(\hat{y}_t-\hat{y}_t^*\right)-\left(\hat{y}_{t-1}-\hat{y}_{t-1}^*\right)\right]+\hat{\epsilon}_t^m.\end{aligned} \tag{34}$$

Equations (21)–(34) determine 14 endogenous variables: $\hat{y}_t$, $\hat{c}_t$, $\hat{i}_t$, $\hat{l}_t$, $\hat{k}_t$, $\hat{z}_t$, $\hat{r}_t$, $\hat{\pi}_t$, $\hat{q}_t$, $\hat{w}_t$, $\hat{w}_t^h$, $\hat{r}_t^k$, $\hat{x}_t$, $\hat{mc}_t$ of the model. The stochastic behavior of the system of linear rational expectations equations is driven by 8 exogenous shock variables: three shocks arising from technological changes $\hat{\epsilon}_t^a$, $\hat{\epsilon}_t^{ga}$, $\hat{\epsilon}_t^I$, a risk premium shock, $\hat{\epsilon}_t^b$, two markup shocks, $\hat{\epsilon}_t^w$, $\hat{\epsilon}_t^p$ and two policy shocks, $\hat{\epsilon}_t^g$ and $\hat{\epsilon}_t^m$. Markup shocks follow an ARMA(1,1) process, while all other shocks follow an AR(1) process.

4 Data and econometric methodology

This paper uses quarterly data over the period 1965Q2–2014Q3 on seven key macroeconomic variables for the USA, including the log difference of real GDP; real consumption; real investment; real wages; log hours worked; inflation; and interest rate. The dataset is assembled from various sources. Real GDP, consumption, and investment data come from the US Bureau of Economic Analysis database. Real GDP is measured in 1996 dollars. Data on the nominal wage and hours worked come from the US Department of Labor database. The nominal wage is measured as nonfarm business hourly compensation, while hours worked is calculated as the product of the average duration of nonfarm business weekly hours and civilian employment. Inflation is measured as the log difference of the GDP deflator taken from the US Bureau of Economic Analysis database. All nominal variables are converted to real variables using the GDP deflator. The data measuring output, real consumption, real investment, and hours worked are divided by the civilian noninstitutional population index. Finally, the federal funds rate is taken from the Board of Governors of the Federal Reserve System. A full description of the data used is given in the Data Appendix.

The measurement equations that link the observables to the model variables are given below:

$$
\begin{aligned}
100 * \text{dlog}(\text{GDP}_t) &= \bar{\gamma} + \hat{y}_t - \hat{y}_{t-1} \\
100 * \text{dlog}(C_t) &= \bar{\gamma} + \hat{c}_t - \hat{c}_{t-1} \\
100 * \text{dlog}(I_t) &= \bar{\gamma} + \hat{i}_t - \hat{i}_{t-1} \\
100 * \text{dlog}(W_t) &= \bar{\gamma} + \hat{w}_t - \hat{w}_{t-1} \\
100 * \log(\text{Hours}_t) &= \bar{l} + \hat{l}_t \\
100 * \text{dlog}(\text{GDPDef}_t) &= \bar{\pi} + \hat{\pi}_t \\
\text{FFR}_t &= \bar{r} + \hat{r}_t
\end{aligned}
$$

where dlog stands for the log difference of the corresponding observable variable. $\bar{\gamma} = 100(\gamma - 1)$ is the common quarterly trend growth rate to real GDP, consumption, investment and wages; $\bar{\pi} = 100(\Pi_* - 1)$ is the quarterly steady state inflation rate and $\bar{r} = 100(\frac{\gamma^{\sigma_c}}{\beta}\Pi_* - 1)$ is the steady-state nominal interest rate. Finally, $\bar{l}$ is the steady-state hours worked which is normalized to be equal to zero. Lower case variables with a hat stand for percentage deviations model variables corresponding to observables from their steady state values.

The model presented in the previous section is estimated by using Bayesian estimation techniques. All estimations are done with the Dynare program created by Adjemian et al. (2011).

The loglinearized model developed in this paper is an extended version of Smets and Wouters (2007). Their approach is therefore used to choose calibrated parameters prior to estimation. The depreciation rate is fixed at 0.025 (quarterly), the exogenous spending-GDP ratio g/y is set at 18%, the steady-state mark-up in the labor market (λ_w) is set at 1.5, and the curvature parameters of the Kimball aggregators in the goods and the labor market (ϵ_p and ϵ_w) are both set at 10.

The priors on the stochastic processes are harmonized as much as possible. The standard errors of the innovations are assumed to follow an inverse-gamma distribution with a mean of 0.1 and a standard deviation of 2 and the persistence of the AR(1) processes and MA parameters are beta distributed with a mean of 0.5 and a standard deviation of 0.2. The Calvo probabilities are assumed to be around 0.5 for both prices and wages with a standard error of 0.1 and the prior mean of the degree of indexation to past inflation is also set at 0.5 with a standard error of 0.15 in both the goods and labor markets, as in SW.

The prior on the adjustment cost parameter for investment is set at around 8 with a standard error of 3, while the capacity utilization elasticity is set at 0.5 with a standard error of 0.25. The mean and standard deviation of the adjustment cost parameter are increased relative to the ones in SW, as the estimated modes of these parameters tend to hit the boundary, with the prior used in SW. Similarly, the standard deviation of the capacity utilization elasticity is increased from 0.15 to 0.25 to allow for the possibility of extreme values.

There are two additional structural parameters to SW parameters due to JR preference specification: θ and ω. θ is assumed to be normally distributed with a mean of 1.4 and a standard deviation of 0.75 and, as ω is between 0 and 1, is assumed to be beta distributed with a mean of 0.5 and a standard deviation of 0.25

Table 1 gives an overview of the assumptions regarding the prior distribution of the estimated parameters.

5 Estimation results

This section discusses the results from three estimated models: (i) the generalized model (model with generalized preference structure offered by Jaimovich and Rebelo (2009)), (ii) the KPR model (the parameter for the wealth elasticity of the labor supply, ω, is calibrated to one prior to estimation), (iii) the GHH model (the parameter for the wealth elasticity of the labor supply, ω, is calibrated to close to zero prior to estimation).

The results from the estimation of the generalized model suggest that with different starting values, the optimization of the posterior density delivers two extreme parameter values for the parameter that governs the wealth elasticity of the labor supply, ω. More precisely, given the initial value of this parameter, the numerical optimization routine results in a different extreme for this parameter (either close to 0 or close to 1). This result suggests that the data prefer preferences either with a very low degree of wealth elasticity of labor supply as in Greenwood et al. (1988) or with a strong wealth elasticity of labor supply as in King et al. (1988). To understand whether the likelihood surface is bimodal or flat with respect to the wealth elasticity parameter ω, the generalized model is re-estimated when this parameter is fixed prior to the

Table 1 Prior distributions of structural parameters and shock processes

	Parameter	Dist.	Mean	SD
σ_a	SD of productivity shock	I.Gamma	0.1	2
σ_{ga}	SD of productivity growth rate shock	I.Gamma	0.1	2
σ_b	SD of risk premium shock	I.Gamma	0.1	2
σ_g	SD of government spending shock	I.Gamma	0.1	2
σ_I	SD of investment shock	I.Gamma	0.1	2
σ_m	SD of monetary policy shock	I.Gamma	0.1	2
σ_p	SD of price markup shock	I.Gamma	0.1	2
σ_w	SD of wage premium shock	I.Gamma	0.1	2
ρ_a	Persistency of productivity shock	Beta	0.5	0.2
ρ_{ga}	Persistency of productivity growth rate shock	Beta	0.5	0.2
ρ_b	Persistency of risk premium shock	Beta	0.5	0.2
ρ_g	Persistency of government spending shock	Beta	0.5	0.2
ρ_I	Persistency of investment shock	Beta	0.5	0.2
ρ_r	Persistency of monetary policy shock	Beta	0.5	0.2
ρ_p	Persistency of price markup shock	Beta	0.5	0.2
ρ_w	Persistency of wage markup shock	Beta	0.5	0.2
μ_p	MA parameter for the price markup shock	Beta	0.5	0.2
μ_w	MA parameter for the wage markup shock	Beta	0.5	0.2
ϕ	Investment adjustment cost parameter	Normal	8	3
σ	The coefficient of relative risk aversion	Normal	1.5	0.375
h	Habit formation parameter	Beta	0.7	0.1
ξ_w	Wage rigidity parameter	Beta	0.5	0.1
ξ_p	Price rigidity parameter	Beta	0.5	0.1
ι_w	Wage indexation parameter	Beta	0.5	0.15
ι_p	Price indexation parameter	Beta	0.5	0.15
Ψ	Variable capital utilization cost parameter	Beta	0.5	0.25
$1 + \Phi/y$	One plus the share of fixed costs in production	Normal	1.25	0.125
r_π	The coefficient on inflation in monetary reaction function	Normal	1.5	0.25
r_r	Interest rate smoothing parameter in monetary reaction function	Beta	0.75	0.1
r_y	The coefficient on output gap in monetary reaction function	Normal	0.125	0.05
$r_{\Delta y}$	The coefficient on output gap growth in monetary reaction function	Normal	0.125	0.05
$\overline{\pi}$	Quarterly steady state inflation rate	Gamma	0.625	0.1
$100(\beta^{-1} - 1)$	Discount factor	Gamma	0.25	0.1
$\bar{l}$	Steady state hours worked	Normal	0.0	2.0
$\overline{\gamma}$	Quarterly trend growth rate	Normal	0.4	0.1
ρ_{gy}	The reaction of government spending to productivity shocks	Normal	0.5	0.25
α	Share of capital in production	Normal	0.3	0.05
θ	Exponent of labor in the utility function	Normal	1.4	0.75
ω	Wealth elasticity parameter	Beta	0.5	0.25

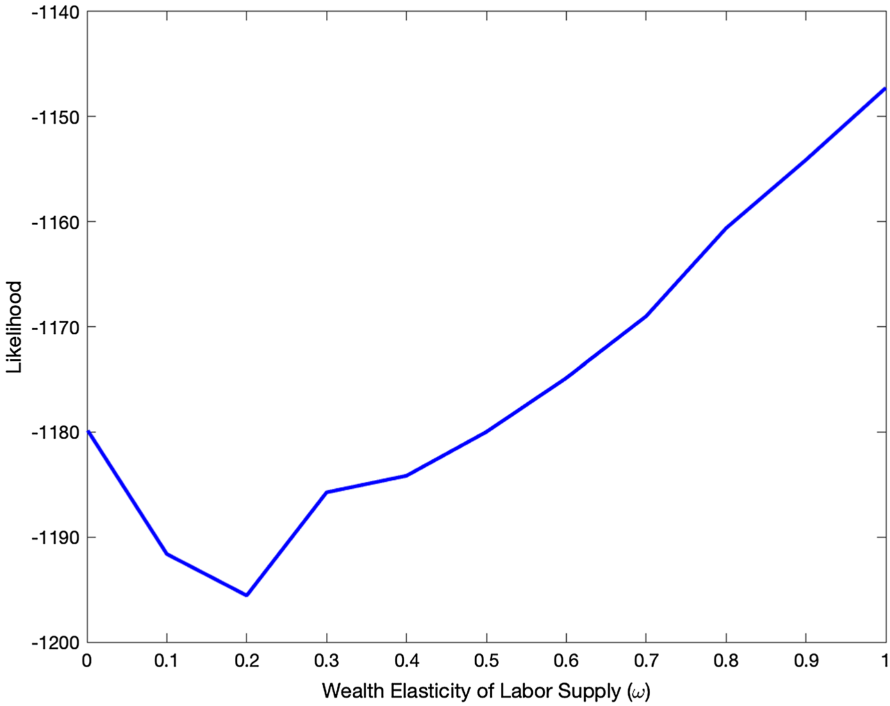

Fig. 1 Variation of the marginal likelihood implied by the variations of ω

estimation.[3] Figure 1 shows how the likelihood varies with respect to this parameter. This exercise confirms that the likelihood surface is bimodal for the wealth elasticity parameter and shows why the optimization of the posterior density converges to one of the extreme outcomes depending on the starting values.

Another observation coming from the first estimation is that two different estimates for the wealth elasticity parameter bring about two different combinations of estimated structural parameters and shocks processes, each with different implications for the transmission mechanisms and the quantitative importance of exogenous shocks. When ω is close to 1, the productivity growth rate shocks are not chosen by the data and the quantitative importance and the transmission mechanisms of other shocks are very similar to SW. On the other hand, when ω is close to 0, the productivity growth rate shocks replace the risk premium shocks in SW, and the dynamics and the quantitative implications of the model change substantially. The similarity of the model with $\omega = 1$ extreme to SW means that the model specification is fine-tuned in favor of this extreme. This manifests itself in the marginal likelihood difference across two extremes. A specification search for the model with $\omega = 0$ extreme could improve the marginal likelihood of this extreme; however, this is left as a future exercise. Instead, to explore the quantitative implications of these two preference structures, two additional estimations are conducted by fixing the parameter ω to the extremes prior to estima-

[3] The grid for ω is chosen as [0.001 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1].

tion. In addition, for these estimations, irrelevant shocks are excluded for each model specification (i.e., the risk premium shock for the GHH model and the productivity growth rate shock for the KPR model).

Table 2 presents parameter estimates for the GHH model and the KPR model, respectively. The posterior mode is obtained by maximizing the log posterior function, while the posterior mean, five and ninety-five percentiles of the posterior distribution are obtained through the Metropolis–Hastings algorithm. The results for the GHH model are based on two million draws (20% of the draws are kept as burn-in draws), while the results for the KPR model are based on four hundred thousand draws (30% of the draws are kept as burn-in draws).[4]

The difference between the two models is mainly in the labor supply conditions due to the difference in the preference structures. For the GHH version of the model, the magnitude of wealth effects on the labor supply is zero in the short run and, as a result, the labor supply moves procyclically in response to most shocks. Therefore, lower nominal rigidities or lower elasticity of investment is needed to ensure a procyclical response of labor to demand shocks. On the other hand, the procyclical response of labor limits the increase in wages in response to demand shocks and, hence, helps to stabilize the marginal cost and inflation. Focusing on the parameters that are important for explaining the persistency of wages and inflation, a number of findings are worth emphasizing. First, the estimated degree of wage stickiness is somewhat similar across the two models (0.78 for GHH vs 0.80 for KPR), while the estimated degree of wage indexation for the GHH model is higher than for the KPR model (0.67 vs 0.58). On the other hand, the estimated degree of price rigidity parameter is lower for the GHH model compared to the KPR model (0.75 vs 0.83). Similarly, the price indexation parameter is lower for the GHH model (0.24 vs 0.34). Second, the AR and MA coefficients of the wage markup shock are estimated to be lower for the GHH version (AR coefficient: 0.98 vs. 0.65 and MA coefficient: 0.96 vs. 0.62), while the estimated standard deviation remains the same. These differences in the parameters are consistent with the implications of different degrees of wealth elasticity on labor supply. For the GHH preferences, lower variation in the wage variable in the model results in lower persistency of wage markup shocks, and procyclicality of labor supply is ensured with lower price indexation.

Turning to the monetary reaction function parameters, for the GHH specification, the monetary policy is estimated to be less responsive to inflation (1.47 vs 1.82) and to output gap growth (0.13 vs 0.28). This result might be explained by the lower persistency of prices due to fallen price stickiness and persistency of wage markup shocks. In addition, less persistent markup shocks result in lower volatility of the output gap; hence, this might explain the estimated decrease in the response of monetary policy to output and the output gap growth.

[4] For each of the specifications, I run two chains of the Metropolis–Hastings algorithm. In order to assess the convergence of the chains, univariate and multivariate diagnostics by Brooks and Gelman (1998) are used. For both models, I find that despite different initializations, the chains converged as the number of draws increased. For GHH model, to achieve convergence for parameters of the ARMA wage process, higher number of draws were needed. This explains the difference in the number of draws across two models. MCMC diagnostics as well as plots of priors and posterior distribution of parameter estimates under all specifications are available upon request.

Table 2 Parameter estimates for the GHH and KPR models

		GHH Model ($\omega = 0.000001$)			KPR Model ($\omega = 1$)		
		Posterior mean	5%	95%	Posterior mean	5%	95%
ρ_a	Persistency of productivity shock	0.98	0.98	0.99	0.98	0.97	0.998
ρ_{ga}	Persistency of productivity growth rate shock	0.88	0.84	0.93	0.84	0.77	0.91
ρ_g	Persistency of government spending shock	0.99	0.99	1.00	0.97	0.96	0.99
ρ_I	Persistency of investment specific technology shock	0.80	0.74	0.87	0.81	0.71	0.90
ρ_r	Persistency of monetary policy shock	0.11	0.03	0.18	0.14	0.05	0.23
ρ_p	Persistency of price markup shock	0.93	0.89	0.97	0.87	0.80	0.94
ρ_w	Persistency of wage markup shock	0.65	0.37	0.94	0.98	0.96	0.99
μ_p	MA parameter for the price markup shock	0.82	0.74	0.92	0.96	0.94	0.99
μ_w	MA parameter for the wage markup shock	0.62	0.35	0.89	0.96	0.93	0.98
ϕ	Investment adjustment cost parameter	9.50	6.01	13.00	3.62	2.01	4.96
σ	The coefficient of relative risk aversion	1.93	1.49	2.38	1.32	1.04	1.58
h	Habit formation parameter	0.40	0.35	0.46	0.51	0.42	0.60
ξ_w	Wage rigidity parameter	0.78	0.69	0.88	0.80	0.74	0.87
ξ_p	Price rigidity parameter	0.75	0.70	0.80	0.83	0.78	0.88
ι_w	Wage indexation parameter	0.67	0.47	0.87	0.58	0.37	0.79
ι_p	Price indexation parameter	0.24	0.11	0.38	0.34	0.18	0.49
Ψ	Variable capital utilization cost parameter	0.80	0.71	0.90	0.90	0.80	0.999
$1 + \Phi/y$	One plus the share of fixed costs in production	1.61	1.50	1.72	1.49	1.36	1.61

Table 2 continued

		GHH Model ($\omega = 0.000001$)			KPR Model ($\omega = 1$)		
		Posterior mean	5%	95%	Posterior mean	5%	95%
r_π	The coefficient on inflation in monetary reaction function	1.47	1.29	1.65	1.82	1.55	2.09
r_r	Interest rate smoothing parameter in monetary reaction function	0.82	0.78	0.86	0.84	0.81	0.88
r_y	The coefficient on output gap in monetary reaction function	0.05	0.03	0.07	0.11	0.07	0.15
$r_{\Delta y}$	The coefficient on output gap growth in monetary reaction function	0.13	0.10	0.16	0.28	0.24	0.33
$\overline{\pi}$	Quarterly steady state inflation rate	0.65	0.48	0.82	0.76	0.59	0.93
$100(\beta^{-1} - 1)$	Discount factor	0.19	0.08	0.30	0.15	0.06	0.24
$\bar{l}$	Steady state hours worked	-1.38	-3.57	0.81	0.43	-1.49	2.36
$\overline{\gamma}$	Quarterly trend growth rate	0.36	0.34	0.39	0.38	0.32	0.43
ρ_{gy}	The reaction of government spending to productivity shocks	0.47	0.35	0.60	0.50	0.38	0.62
α	Share of capital in production	0.17	0.14	0.20	0.19	0.16	0.22
θ	Exponent of labor in the utility function	1.99	1.64	2.33	1.01	0.25	1.65
σ_a	SD of productivity shock	0.47	0.42	0.51	0.48	0.43	0.52
σ_g	SD of government spending shock	0.50	0.45	0.54	0.49	0.45	0.53
σ_I	SD of investment specific technology shock	0.37	0.31	0.42	0.38	0.32	0.44
σ_m	SD of monetary policy shock	0.22	0.20	0.24	0.23	0.21	0.25
σ_p	SD of price markup shock	0.12	0.10	0.14	0.20	0.17	0.22
σ_w	SD of wage premium shock	0.38	0.33	0.42	0.37	0.33	0.40
σ_b	SD of risk premium shock	*	*	*	0.42	0.30	0.53
σ_{ga}	SD of productivity growth rate shock	0.05	0.03	0.07	*	*	*
Log data density (Posterior Distribution)		1168.59		1150.74			

A star (*) indicates that the parameter does not belong to the corresponding model

Focusing on the real rigidities, there are two major differences between the two versions of the model. First, for the GHH model, the investment adjustment cost parameter increases substantially from 3.62 to 9.5, which implies that the elasticity of investment with respect to the price of capital is almost tripled. This means a gradual response of investment to all shocks and, in the case of the productivity growth rate shock, prevents the drop in investment on impact. Second, the variable capital utilization parameter falls from 0.9 to 0.8, which implies that elasticity of utilization with respect to $(r^k - Q)$ increases to 0.25 from 0.11. So, for the GHH model of the model, the utilization channel is more operative and helps to smooth the response of the rental rate of capital and therefore the marginal cost to the shocks. In summary, the changes in the real rigidity parameters for the GHH model help to offset the loss of persistency of the model variables due to fallen price rigidity and the persistency of wage markup shocks.

6 Quantitative importance of news shocks

The first condition for a shock to be a candidate to explain a significant proportion of business cycle fluctuations is that, given the model structure, it should be able to create a positive correlation between output, consumption, investment, and hours present in the data. The two variants of the model imply different transmission mechanisms for the exogenous disturbances; therefore, for each model, a different set of shocks is elicited to explain the sources of business cycle fluctuations. Having alternative explanations in macroeconomics is not uncommon, as it can be seen from the famous citation from Cochrane (1994): "What shocks are responsible for economic fluctuations? Despite at least 200 years in which economists observed fluctuations in economic activity, we are still not sure." Therefore, I aim to offer two complementary explanations based on the two different model specifications that I estimate. I do not aim to propose one single model that explains the variations in the economy. To assess the quantitative importance of shocks considered for each model, I present unconditional (average) forecast error variance decompositions in Table 3.[5]

For the GHH model, three productivity shocks: Neutral productivity shock, productivity growth rate shock, and investment shock explain most of the short-run and long-run variations in the real variables. The short-run movements in real GDP and consumption are primarily driven by technology shocks, productivity growth rate shocks, investment shocks, and productivity shocks. Together, they account for 81% and 84% of the unconditional forecast error variance of real GDP growth and consumption growth, respectively. In the long run, the same set of shocks explain most of the variance in output and consumption level. However, the share of productivity growth rate shocks and productivity shocks rises, while the share of investment shocks drops. Other shocks play only small roles in accounting for both the short-run and the long-run variance in output and consumption. Investment shocks dominate all other shocks with a share of 87% in accounting for the unconditional variation of

[5] The conditional forecast error variance decompositions for forecast horizons 12, 24, 36 and 48 are presented in the online appendix.

Table 3 Unconditional forecast error variance decomposition (in percent)

	Output growth	Consumption growth	Investment growth	Output	Consumption	Investment	Hours	Inflation	Interest rate
Productivity shock									
GHH	19	13	6	42	29	32	30	25	27
KPR	22	12	2	50	43	15	3	2	3
Government spending shock									
GHH	9	4	0	2	16	5	2	8	9
KPR	19	4	0	3	6	1	9	1	2
Investment shock									
GHH	42	33	87	14	11	27	27	17	23
KPR	10	3	67	9	5	46	11	0	8
Monetary policy shock									
GHH	5	7	2	1	1	1	2	1	4
KPR	13	21	8	5	5	7	11	2	7
Price markup shock									
GHH	4	5	3	3	3	3	7	16	5
KPR	4	6	4	5	4	11	9	37	3
Wage markup shock									
GHH	1	1	0	0	0	0	1	3	1
KPR	1	4	2	16	27	5	33	52	23
Productivity growth rate shock									
GHH	20	39	2	39	41	31	31	31	32
Risk premium shock									
KPR	30	50	17	12	11	15	24	5	54

investment growth. In the long run, productivity and productivity growth rate shocks become dominant with 32% and 31% share in variation in investment level, respectively. Finally, the GHH model attributes most of the variation in hours to productivity shocks and productivity growth rate shocks.

For the KPR model, fluctuations in output growth are mainly due to risk premium shocks (30%), productivity shocks (22%), and, to a lesser extent, government spending shocks (19%). On the other hand, productivity shocks (50%), risk premium shocks (12%), and wage markup shocks (16%) are dominant reasons for the variations in the level of output. Risk premium shocks are important for the short-run variation in consumption (50%), while productivity shocks (43%) and wage markup shocks (27%) become dominant for the long-run variation in this variable.

Investment is mainly driven by investment-specific technology shocks both in the short run and in the long run (67% and 46%, respectively). Finally, wage markup shocks (33%) and risk premium shocks (25%) are dominant drivers for the variation of hours in the KPR model. These results are in line with that of SW.

Similar to the GHH specification, Justiniano et al. (2010) attribute a large share of output fluctuations to investment shocks both in the short run and in the long run. On the other hand, similar to the KPR version, they find a small role for these shocks in accounting for variations in consumption and they rely on productivity shocks and preference shocks to explain the variation in consumption.[6] This difference in explaining variations in consumption is due to the modifications in the transmission mechanisms of the models. For the GHH specification, consumption responds procyclically to investment shocks, whereas in the KPR specification and Justiniano et al. (2010), its response is negative. Similarly, Khan and Tsoukalas (2011) show that creating a model featuring the procyclical response of consumption to investment shocks increase the quantitative importance of investment shocks in accounting for variations in real variables. Justiniano et al. (2010) explain the difference of their results relative to SW regarding the quantitative importance of investment shocks by the fact that they use different definitions of investment and consumption in their estimation.[7] On the contrary, this paper uses the dataset of SW and in the GHH model, investment shocks are found to be very important in explaining fluctuations in output, consumption, and investment due to convenient internal propagation mechanisms existing in the model for investment shocks.

For the GHH model, although productivity growth rate shocks are important for output and consumption fluctuations, its share is negligible for the short-run variation in investment. This is due to the weak short-run response of investment to those shocks. The emergence of productivity growth rate shocks as one of the major determinants of output and consumption fluctuations for the GHH model relies, in part, on the identification of investment shocks as the most quantitatively important shock. In the KPR model (also in SW), the risk premium shock helps to explain the co-movement

[6] Preference shock is defined as a shock to discount factor as in Smets and Wouters (2003) which affects only the inter-temporal consumption Euler equation. In the KPR model, instead of discount factor shock, risk premium shock is utilized to generate co-movement among consumption and investment.

[7] In SW, inventory changes are not included in investment; however, they are included in output. Durable consumption is included in consumption. Justiniano et al. (2010) include both of these into investment; hence, the investment series used by them is more pro-cyclical and volatile.

of consumption and investment. In the GHH version, this co-movement is generated by investment shock; hence, productivity growth rate shock is identified to account for the remaining variation in output, consumption, and hours.

7 Understanding the great recession

There is a recent discussion in the literature that seeks to understand if productivity slowdown contributed to the crisis. Christiano et al. (2015) estimate a DSGE model using pre-2008 data and then use the estimated model to run simulations to analyze Great Recession period. For their simulations, they adopt an unobserved components representation for the growth rate of neutral technology. To be more explicit, in their model, when there is a shock to productivity, agents do not know whether it is transitory or permanent and they solve a signal extraction problem when they adjust their forecast of future values of productivity in response to an unanticipated move in current productivity. Using this setup, they suggest that the TFP was persistently low during the Great Recession and the slowdown in productivity contributed to the drop in consumption, investment, and output while creating positive effects on employment and labor force participation. Similarly, Gust et al. (2017) show that the TFP was low during the beginning of the recession and that it only recovered in 2010. On the contrary, Lindé et al. (2016) re-estimate SW using pre-recession and recession data, and they show that their estimation procedure filters out a sequence of positive technology shocks during the recession. They also claim that weak TFP growth was not a key driver of the crisis. Contributing to this line of research, this section aims to understand the roles of productivity and expectations about future productivity in the emergence and deepening of the Great Recession.

The Bureau of Labor Statistics, FRED Economic Data (Federal Reserve Bank of St. Louis), and OECD publish annual measurements of productivity for the USA. In addition, Fernald (2012) propose a quarterly measurement for raw and utilization-adjusted total factor productivity for the business sector. I present different measures in three different diagrams. First, Fig. 2 presents the percentage growth rate of the annual multi-factor and labor productivity series for both the private business and manufacturing sectors, published by the Bureau of Labor Statistics between the years 1987 and 2014. Second, the upper panel of Fig. 3 presents the annual percentage growth rate of the total factor productivity between the years 1964 and 2011, published by the FRED Economic Database, while the lower panel presents the annual percentage growth rate of multi-factor and labor productivity measures of the OECD productivity database. Finally, Fig. 4 shows the annualized quarterly growth rate of raw and utilization-adjusted total factor productivity for the business sector for 1965Q2–2014Q3, proposed by Fernald (2012). Two common patterns are worth highlighting in all of these four measurements of productivity. First, there was an upsurge in productivity growth in the late nineties; subsequently, the productivity slowdown began prior to the 2001 recession. Second, a similar acceleration of the productivity growth and following slowdown occurred prior to the Great Recession. In particular, the productivity growth started to decline as early as 2003, years before the start of the recession. Fernald (2014) shows that the mid-1990s surge in the productivity growth ended prior

Fig. 2 Bureau of Labor Statistics measures of multi-factor productivity and labor productivity (% growth). Shaded regions indicate recessions dated by NBER

to the Great Recession; however, as of 2003Q4, growth returned to its 1973–1995 pace. Complementary evidence is given by Kahn and Rich (2007), showing that by early 2005, the probability reached near unity that the economy was in a low-growth regime.

Therefore, when we look at this episode through the lens of today, we see that productivity was already low prior to the recession and it appears that it was not the unexpected slowdown of productivity that caused the crisis. However, there is a problem with the productivity data in that, typically, these data are only available with a considerable delay. Hence, economic agents cannot observe real-time data on productivity when making their decisions and, instead, try to forecast future fundamentals given the (imperfect) signals they receive. From this perspective, a wave of optimism might create an investment and consumption demand today which then turns into a crash if beliefs turn out to be overoptimistic. In what comes next, I explore this idea as a potential contributor to the Great Recession. Section 7.1 presents two narratives that suggest that economic agents were over-optimistic regarding the future path of productivity prior to the recession. Section 7.2 shows the implications of the two model specifications for the causes of the Great Recession.

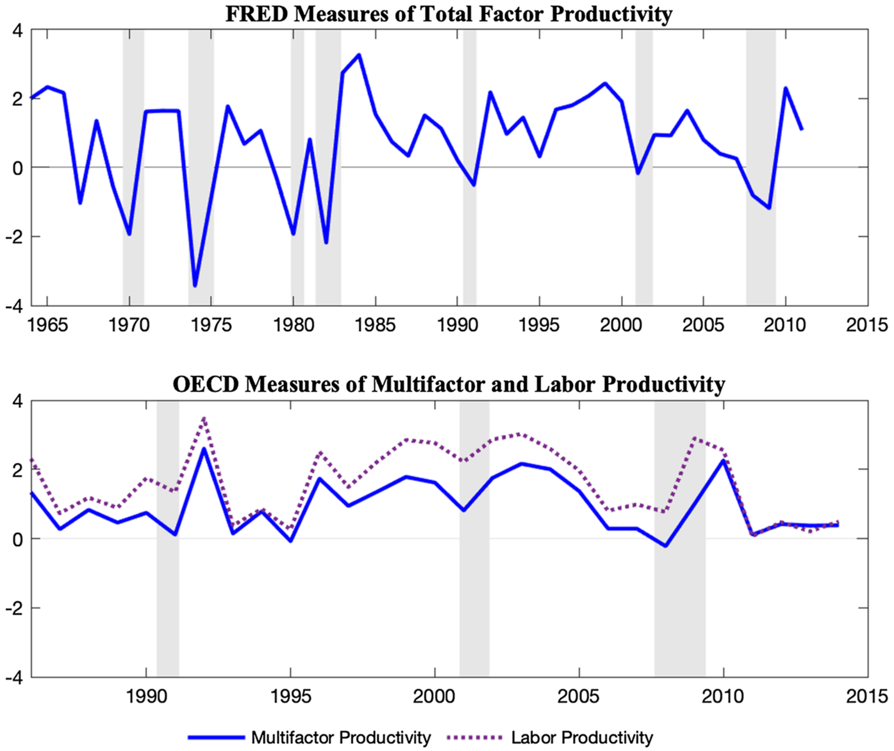

Fig. 3 OECD and FRED Economic Data measures of multi-factor productivity and labor productivity (% growth). Shaded regions indicate recessions dated by NBER

7.1 Bad prospects but optimistic expectations

This section presents the estimated time series for productivity levels for all model specifications[8] and compares them to the other estimates in the literature. Figure 5 shows that the estimated productivity series for the GHH model displays similar patterns relative to the one for the KPR model. The discrepancy in the level is due to the presence of growth rate shock in the productivity process for the GHH model. It can be seen in the first panel in Fig. 5 that the estimated series for all specifications can replicate some well-established historical patterns, such as the productivity slowdown in the 1970s and the productivity surge in the late 1990s. This is consistent with the findings of Fernald (2014) and Kahn and Rich (2007)(with its updated reports), in which productivity starts to slow down around 2005, taking off again toward the end of the recession. The second panel in Fig. 5 shows the smoothed series for the productivity growth rate shock. The positive (negative) values can be interpreted as periods in which agents are optimistic (pessimistic) about future productivity.[9] It can

[8] The estimate is the smoothed series derived with simple Kalman filter.

[9] Here, optimistic/pessimistic expectations do not refer to subjective feelings about future productivity. Instead, estimated growth rate shocks are realized shocks and agents' expectations about future productivity

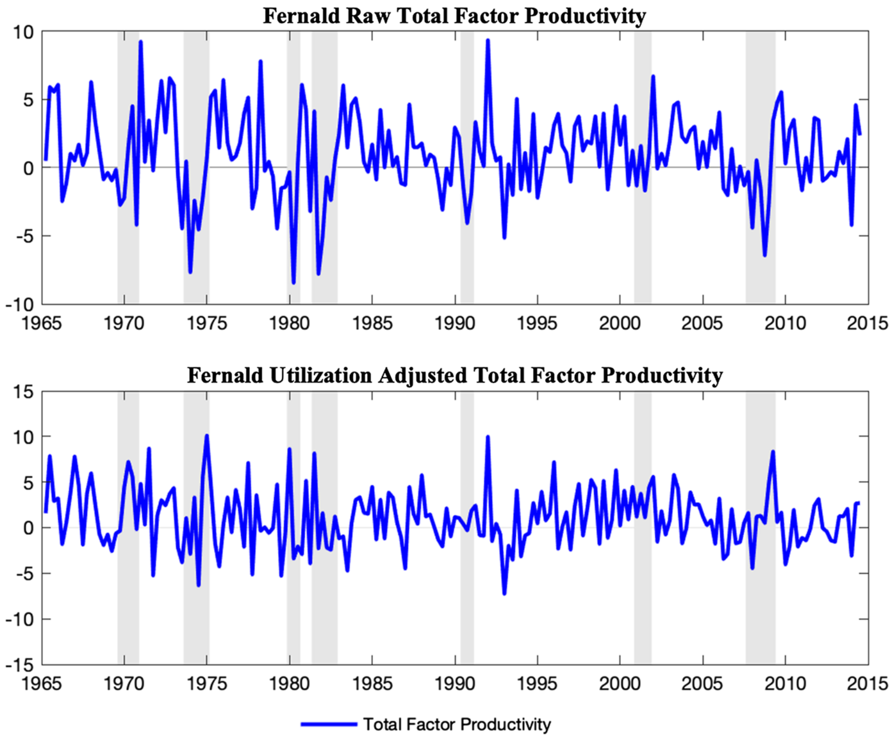

Fig. 4 Fernald's measures of total factor productivity and utilization adjusted total factor productivity (annualized % growth). Shaded regions indicate recessions dated by NBER

be seen that the productivity growth rate series show a continuous increase prior to the recession despite the drop in productivity level and it continues to rise until the middle of the recession. This shows that despite the slowdown in productivity, agents expected higher growth between 2005 and 2009 and did not recognize deteriorating productivity trends on time. In what follows, I present two narratives consistent with this conjecture.

The first narrative comes from estimates of the potential output of the Congressional Budget Office. One of their reports, published in 2014, examines how their estimate of potential output for 2017 changed between January 2007 and February 2014.[10] In the report, it is documented that from the earlier projection to the later one, the Congressional Budget Office reduced its projection for 2017 by 7.3% and it is suggested that about two-thirds of this revision is due to a reassessment of economic trends that were in process before the recession began. In the report, it is stated that after the National

are rational given the information available to them. However, since a positive shock to the growth rate of productivity means an expectation of a gradual and continuous increase in future productivity, which may or may not be confirmed later on, I interpret these shocks as optimistic expectations about future productivity. (Opposite is true for negative shocks.)

10 The report is called "Revisions to CBO's Projection of Potential Output Since 2007" and can be accessed through the following URL: https://www.cbo.gov/publication/45150.

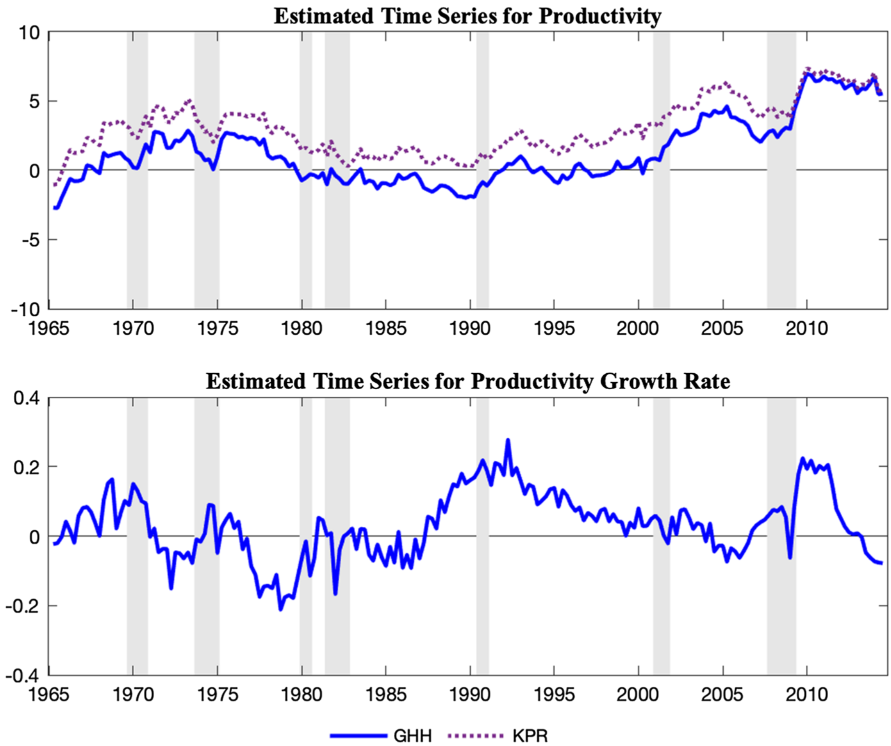

Fig. 5 Estimated productivity and productivity growth rate series. Shaded regions indicate recessions dated by NBER

Bureau of Economic Research designated the fourth quarter of 2007 as the peak of the business cycle, the agency concluded that the trend rates of growth in the 2000s had generally been lower than they were in the 1990s. In addition, they estimated new trends between business cycle peaks in 2001 and 2007.

The second narrative comes from the Survey of Professional Forecasters, which is a survey of macroeconomic forecasts for the US economy issued by the Federal Reserve Bank of Philadelphia. Figure 6 presents the first quarter average and median forecasts for the annual average rate of growth in productivity over the current and next 9 years in percentage points. It can be seen that both the mean and median forecasts in 2000s are above 2% and the mean forecast starts to decline by 2005, while the median forecast starts to decline by 2007. However, the substantial revision of expectations starts in the first quarter of 2007, just before the outbreak of the crisis.

Based on these narratives, we might conclude that there was some evidence of over-optimistic expectations about future fundamentals prior to the recession. However, to what extent did the revisions in the expectations contribute to the emergence and deepening of the crisis? The next section attempts to answer this question.

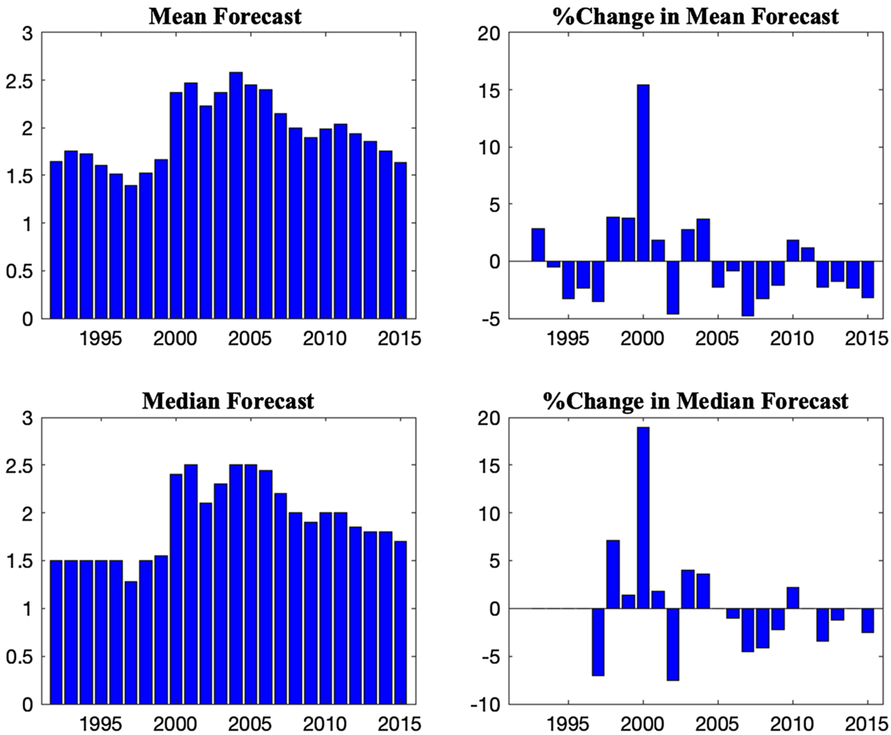

Fig. 6 Mean and median forecasts of Survey of Professional Forecasters for 10-year productivity growth

7.2 Which shocks caused the Great Recession?

In Sect. 6, I showed how the quantitative importance of shocks considered in this paper differs across two model specifications; GHH and KPR. In this section, I use these variants of the model to interpret the Great Recession period.

Figure 7 presents the historical decomposition of output, consumption, investment, and hours worked for the KPR model. It can be seen that the early phase of the recession is mainly explained by negative risk premium shocks and investment-specific technology shocks. As the Federal Reserve cuts the Fed Funds Rate to near zero by the end of 2008, the negative effect of the zero lower bound starts to kick in by 2009Q1, which is the worst quarter during the recession period. In addition, the largest impact of the negative risk premium shock occurs during this quarter. 2009Q2 is designated as the trough of the recession period by the National Bureau of Economic Research. As of this date, risk premium shocks start to contribute positively to output and consumption growth, whereas investment shock and monetary policy shock continue to affect the economy negatively. During the recession period and the recovery, productivity shocks contribute positively to the economy except for small declines in 2008Q2 and 2009Q1. To sum up, the KPR model interprets this period as a series of negative risk premium shocks together with a series of negative investment-specific technology shocks. Both shocks can be regarded as proxies to the financial market disturbances. The investment-

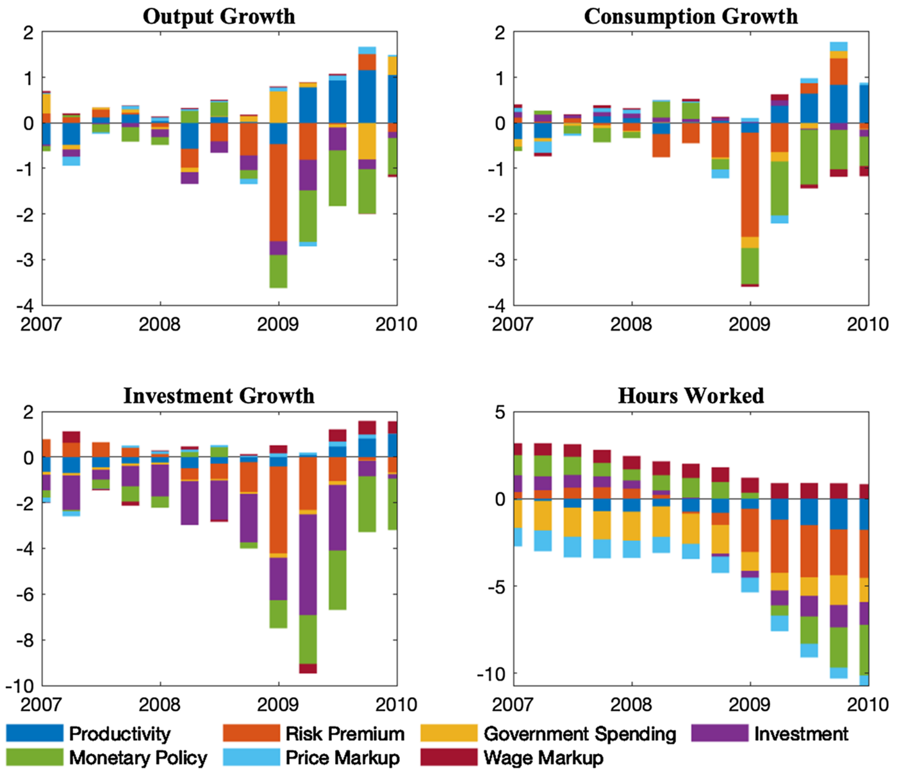

Fig. 7 Historical decomposition for the KPR Model

specific technology shock affects the production of installed capital from investment goods and can be considered as a proxy to the disturbances to the intermediation ability of the financial sector. Justiniano et al. (2011) show that these shocks correlate strongly with interest rate spreads. On the other hand, risk premium shocks can be regarded as a proxy for net worth shocks, as suggested by SW or as a proxy for shocks to the demand for safe assets as in Fisher (2015). Therefore, one can say that the KPR model points to financial market disruptions as the main driver of the recession.

As mentioned in previous sections, with the GHH version of the model, data filter out productivity growth rate shocks instead of risk premium shocks. Figure 8 presents historical decompositions for this model. It can be seen that productivity growth rate shocks remain positive until the most acute phase of the recession, only creating a large negative effect on output and consumption growth in 2009Q1. The date of the negative shift of expectations coincides with the fall of Lehman Brothers, which occurred in September 2008.[11] Similar to the KPR model, during the early phase of the recession, investment shocks are the dominant factor that lead to the fall in output and consumption, and the zero lower bound starts to be active as of 2009Q2. It can

[11] The evolution of smoothed innovations for the two versions of the model is presented in the online appendix.

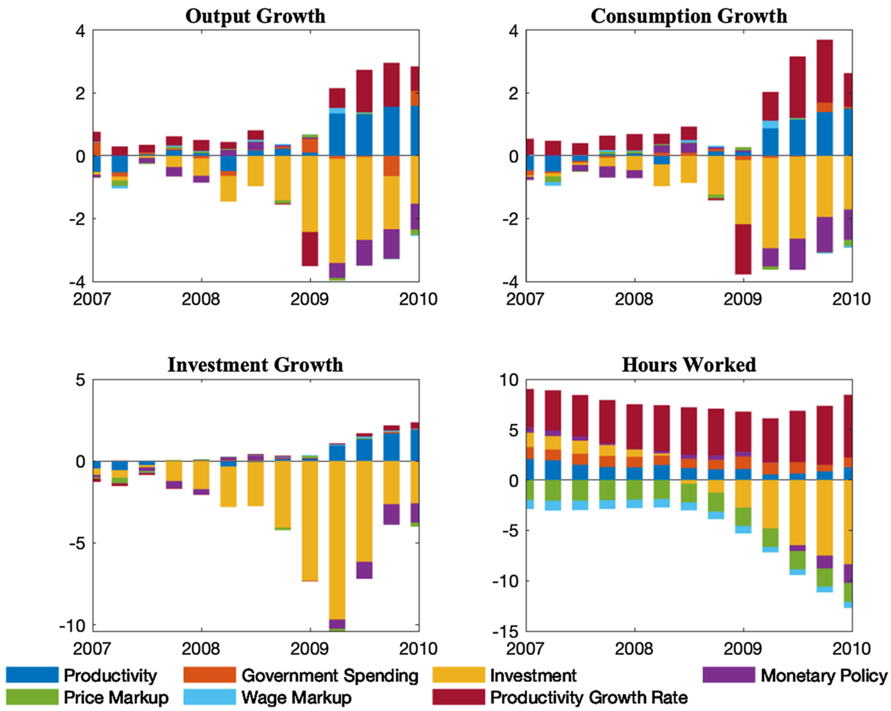

Fig. 8 Historical decomposition for the GHH Model

be seen that after this date, productivity shocks and productivity growth rate shocks contribute positively to the output and consumption growth.

Before the fall of Lehman Brothers, there was widespread optimism regarding the future growth of the economy. Economic agents were forecasting very strong figures for both productivity and output growth and these expectations caused the expected income to rise. As a result, households increased their demand for goods and services. Specifically, high demand increased house prices in the economy and reinforced wealth effects on homeowners, inducing them to further increase their consumption. With the fall of Lehman Brothers, the growth expectations underlying the boom temporarily crashed and households significantly decreased their consumption due to the falling growth prospects for that quarter. However, the negative effect of pessimistic expectations did not persist, as the monetary policy managed to affect the growth expectations positively with alternative expansionary monetary policy tools starting from 2009Q2. Moreover, the positive trend in productivity growth contributed to the formation of optimistic expectations about the future starting from the middle of the recession. Finally, output and consumption growth remained weak after the recession, for both models, due to enduring financial system problems manifesting themselves as investment-specific technology shocks.

These results suggest the data are quite informative and both models attribute most of the role to investment shocks and monetary policy shocks for the big drop of the output and consumption during the recession and their slow recovery afterward. However, the two models interpret the quarter after the fall of Lehman Brothers (the most acute quarter of the recession) quite differently: For this quarter, according to the GHH model, a decline in growth expectations contributed significantly to negative growth while risk premium shocks were in effect according to the KPR model. Finally, for both versions of the model, productivity followed an increasing path and weak productivity growth was not responsible for the emergence and the persistence of the crisis. On the contrary, they contributed positively to the recovery.

8 Conclusion

The idea of expectation-driven business cycles is worth analyzing because it is an intuitive and plausible explanation for economic fluctuations and it offers a plausible theory for recessions for the class of technology-driven business cycle models. For instance, the economy might enter a bust period, even in periods of technological growth, if the growth in TFP is less than expected. In this paper, I aimed to assess the quantitative importance of news shocks in the presence of other shocks that are commonly used in the literature. To this end, I modified the (Smets and Wouters 2007) model with the preference structure offered in Jaimovich and Rebelo (2009). In addition, to specify news shock, I considered productivity growth rate shocks instead of jump specification, which is commonly used in the literature. This way of modeling news shock has two advantages. First, the data decide on the trajectory of TFP following an i.i.d. shock to the productivity growth rate, and there is no need to set an arbitrary date for the realization of the shock. Second, for all possible trajectories of TFP, this specification implies a smooth and continuous change in TFP and other variables. This is a desired property for the fit of the model considering the persistency of macroeconomic variables.

The maximization of the posterior density of the generalized model shows that the parameter that governs the wealth elasticity of the labor supply is not identified by the data: The data prefer preferences either with a very low degree of wealth elasticity of the labor supply, as in Greenwood et al. (1988), or with a strong wealth elasticity of the labor supply, as in King et al. (1988). Moreover, for the two preference specifications, the quantitative implications of the estimated model change substantially. For the model with King et al. (1988) preferences (the KPR model), risk premium, wage markup shocks and productivity shocks are quantitatively important. On the other hand, for the model with Greenwood et al. (1988) preferences (the GHH model), three productivity shocks explain most of the variation in real variables. In particular, for the GHH model, news shocks replace risk premium shocks in the KPR model and they are identified as an important driver of business cycle fluctuations.

To obtain the posterior distribution of parameters, using the Metropolis–Hastings algorithm, I run two additional estimations by fixing the wealth elasticity parameter to close to zero and to one prior to estimation. Two results emerge from these estimations: (i) I find that the parameter estimates and quantitative importance of the shocks are very similar to their counterparts from the posterior density maximization; (ii) among the two models considered, the KPR model outperforms the GHH model in terms of likelihood. The second result seems to favor strong wealth effects on the labor supply. However, the difference in likelihoods is not surprising, as the KPR model is very similar to SW and the model specification is fine-tuned in favor of this model. Considering that the existence of wealth effects on the labor supply is still an open question in the literature, I use both versions of the model to offer two complementary explanations for the US business cycles.

Modifying the model to achieve a better fit for the GHH version might improve the likelihood of this version. For example, the substitution of the risk premium shock in the KPR model with the productivity growth rate shock in the GHH model is consistent with empirical findings in the literature regarding the information content of interest rate spreads. Pessimistic expectations about future productivity are frequently associated with expanding credit spreads and it is difficult to differentiate between risk premium shocks and expectation shocks. Therefore, extending the current model with the financial accelerator mechanism to allow for the endogenous determination of credit spreads seems to be a promising path in order to explain the relationship between risk premium and growth rate shocks and to improve the fit of the model.

Finally, in addition to providing a general explanation for business cycles, I use the two versions of the model to analyze the Great Recession period. I find that although the two models offer very different explanations to business cycles, they interpret the Great Recession period rather similarly, except for the worst quarter of the crisis. The GHH model attributes the deepening of the crisis to the collapse of over-optimistic expectations while the KPR model attributes most of the role to worsening credit conditions. For both model specifications, general developments in productivity are estimated to be positive. Therefore, productivity slowdown is not among the reasons for the emergence or persistence of the Great Recession. Using the GHH model, I show that the productivity trends started to slow down prior to the recession, as early as the year 2005; however, agents continued to expect stronger growth until the middle of the recession period. In addition, the collapse of these over-optimistic expectations contributed to the deepening of the recession in 2009Q1. In real life, the data for productivity are available with a delay and agents forecast the future fundamentals using these weak signals. Therefore, extending the current model to allow for a learning mechanism might be a promising way to understand how waves of optimism and pessimism affect the real economy.

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Availability of data and materials(data transparency) Data are available upon request.
Code availability Dynare codes are available upon request.

Declarations

Conflict of interest The author has no conflicts of interest to declare that are relevant to the content of this article.

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