A Possible Explanation of the Missing Deflation Puzzle

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Abstract

During the Great Recession, despite the large fall in output, the fall in inflation was modest. This is known as the missing deflation puzzle. In this paper, we develop and estimate a New Keynesian model to provide an explanation for the puzzle. The new model allows for time-varying volatility in cross-sectional idiosyncratic uncertainty and accounts for changes in intermediate goods prices. We show that inflation did not fall much because intermediate goods prices were increasing during the Great Recession.

Keywords: Price Mark-up Shocks; Great Recession; Inflation; DSGE; Intermediate Inputs.

JEL Classification Numbers: E52, E58.

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1 Introduction

New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models have become an important tool for monetary policy analysis and forecasting at central banks and other policy institutions around the world. However, the failure of these models to forecast the behaviour of inflation and other key macroeconomic variables during the Great Recession has been interpreted as evidence against this class of models. Two important papers in this regard are Ball and Mazumder (2011) and Hall (2011). Ball and Mazumder make their point by forecasting inflation during Great Recession using the New Keynesian Phillips Curve (NKPC), which determines inflation in the models. They find that the NKPC estimated from 1960 to 2007 cannot forecast inflation during the Great Recession. Hall criticises the NKPC on the basis that it fails to provide an explanation for the "missing deflation" puzzle. Missing deflation is characterised as higher levels of actual inflation during the Great Recession than the NKPC predicts. The NKPC relates inflation and economic activity. Given the depth and duration of the recession caused by the 2008 financial crisis, the NKPC would predict severe deflation. However, this did not happen and inflation remained positive.

This paper offers an explanation for the missing deflation puzzle. We argue that the reason for stable inflation was the increasing intermediate materials prices during the Great Recession. When we plot intermediate materials price inflation and Personal Consumption Expenditure (PCE) inflation for goods, both the series track each other very closely (see Figure 1). The correlation between the two series is 0.8. Moreover, the co-movement between intermediate materials price inflation and

PCE goods price inflation is stable for the entire period: before and after the Great Recession. Both the series experienced a sharp fall at the start of the crisis which was followed by a simultaneous recovery.

To test our argument, we use a modified version of the Smets and Wouters (2007) (henceforth SW) model. Specifically, we reformulate the SW model to include the financial frictions mechanism in Bernanke et al. (1999) (henceforth BGG) and to account for the changes in intermediate materials prices. Further, we remove the price mark-up shocks in the model and following Aoki (2001), De Walque et al. (2006) and Huang and Liu (2005), consider supply-side shocks that arise from changes in relative intermediate materials prices. Let us briefly explain these additions to the SW model.

To incorporate intermediate prices in the SW model, we divide production into two sectors. In one of the sectors intermediate materials are produced and in the other finished goods. We assume that intermediate materials are used as a factor input for the production of finished goods, while a small proportion of the intermediate materials is also needed to convert finished goods into final consumption goods. Prices in both sectors are set according to Calvo (1983) pricing. Inflation in both the sectors depend on sector-specific current and future marginal costs. We further assume that prices in the intermediate materials sector are also subject to a sector-specific shock. This shock is meant to capture exogenous factors affecting intermediate prices (e.g. Arab Spring). As a result, inflation in the intermediate goods sector depends on future marginal cost and the sector specific shock.

Turning to the second addition, as is well-known (see, e.g., Christiano et al.

(2014), henceforth CMR), the BGG mechanism models the idiosyncratic uncertainty faced by entrepreneurs. The common assumption is that the volatility of cross-sectional idiosyncratic uncertainty fluctuates over time. This measure of volatility is referred to as risk. In line with CMR, we assume that the risk shock process has both unanticipated (or stochastic) and anticipated (or news) components. Several recent papers (e.g. CMR and Schmitt-Grohe and Uribe (2012)) show that accounting for the anticipated component improves the empirical performance of the model significantly. The rest of the model is exactly the same as that in SW.

Next, we estimate the new model for US data using Bayesian techniques. Finally, we compare the dynamics of inflation, output and marginal cost from our model with and without the intermediate input shocks over the period of the Great Recession. Our results suggest that intermediate materials prices played an important role in keeping inflation stable during most of the Great Recession. Importantly, our model achieves this in a way that is consistent with the micro-evidence on prices.

The intuition behind these results is straightforward. In our model, since intermediate materials are an input in production, marginal cost depends also on intermediate materials prices. During the Great Recession, intermediate prices were increasing. As a result, during the Great Recession, the marginal cost in our model remains significantly high. Stable marginal costs, relative to that suggested by the SW, helps the model in explaining stable inflation dynamics without requiring large degree of price rigidities. To put it differently, the new model suggests that the increase in intermediate prices during the Great Recession offset most of the decrease in marginal cost due to decreased economic activity.

Turning to the role of BGG mechanism in model, the BGG mechanism plays a crucial role in explaining the output dynamics in the model. It helps to capture the drop in output at the beginning of the crisis. We find that both components of the risk shock process, anticipated and unanticipated, are important for capturing the fall in output. The intuitive explanation for the importance of anticipated component is straightforward. Anticipating that future uncertainty will increase, banks increase the interest rate on loans more. An increased interest rate depresses investment further, leading to a larger fall in output and, consequently in inflation.[1] However, the fall in inflation is offset by the increase in intermediate materials prices.

This paper is closely related to earlier papers by Coibion and Gorodnichenko (2013) and Del Negro et al. (2015) (henceforth NGS). Coibion and Gorodnichenko (2013) show that 'missing deflation' is a one-off event in response to rising oil prices. However, in our model, accounting for oil prices alone does not have a significant impact on inflation, as, at around 1%, the share of oil in production is very small. Nevertheless, we reach similar conclusions using intermediate materials prices. The volatility in the prices of intermediate materials closely tracks the volatility in energy prices. The correlation between the two data series is as high as 0.84, suggesting that the factors driving changes in energy prices may be the same as those underlying changes in intermediate materials prices. Our paper differs further from Coibion and Gorodnichenko in its modelling approach. While their analysis is based on the expectations−augumented Phillips curve proposed by Friedman (1968), ours is

[1] In the previous version of this paper, we also find the anticipated component of the risk shock to play an important role in correctly forecasting observed contraction in output growth at the start of the crisis.

carried out in a New Keynesian general equilibrium framework in which the Phillips curve is micro-founded. However, this paper further strengthens their conclusion by showing that their finding of missing deflation being a one-off event has a wider applicability and holds also in a New Keynesian general equilibrium model.

NGS, on the other hand, argue, using a New Keynesian model with BGG-type financial frictions, that the near stability of inflation during the Great Recession was due to anchored expectations. Their results depend on having a large degree of price stickiness and therefore a very flat NKPC. At 8 quarters, average age of price contracts in NGS is twice that in micro evidence on prices (Klenow and Malin (2011)). NGS suggest that since inflation expectations of the households remained anchored, prices were not revised downwards substantially despite sharp contraction in output.

Another possible explanation for the stability of inflation during the Great Recession is forwarded by Gilchrist et al. (2016). Gilchrist et al. note that financially constrained firms raise their prices following adverse financial shocks. This is because, since financially constained firms find it difficult to access external finance, they face a higher risk of default. As a result, they raise their prices to maintain internal liquidity even at the cost of a decrease in firm's market share. On the other hand, firms, which are not financially constrained, cut their prices in response to decrease in demand for their products. The explanation in Gilchrist et al. and the one provided in this paper has important implications for firms' mark-ups. In Gilchrist et al., since financially contrained firms raise their prices in order to maintain internal liquidity, mark-ups increase. Whereas, the explanation in this paper implies increasing mark-ups for intermediate goods producing firms and decreasing mark-ups for finished goods producing firms.

The implication for finished goods firms' mark-up in this paper is in line with the explanation for missing deflation suggested in Christiano et al. (2015). Christiano et al. propose that inflation did not fall due to increase in firms' marginal costs. However, the reason for increasing marginal costs is different in Christiano et al. than in this paper. At the start of the crisis, borrowing costs increased substantially. Therefore, financially constrained firms, which were previously financing their operating costs (e.g. wage bills) through borrowing, experienced an increase in their financing costs during the crisis. This increased firms' marginal costs and, therefore, kept inflation stable.

The rest of the paper is organised as follows. Section 2 describes the model. Section 3 explains the estimation strategy. Section 4 presents the estimation results. Section 5 analyses the dynamics of inflation with and without the intermediate shocks. Finally, section 6 concludes.

2 The Model

The framework in this paper builds on the model in SW to allow for input-output linkages between intermediate materials and finished goods. The framework also accounts for the idiosyncratic uncertainty faced by entrepreneurs. While the production of intermediate materials requires labour and capital as inputs, the production of finished goods requires labour, capital and intermediate materials as inputs. Finished goods and a fraction of intermediate materials are combined to produce the final consumption goods that are consumed by households. The two sectors also face the financial accelerator mechanism of BGG where financial market frictions arising through information asymmetry and agency costs affect the real side of the economy. In this we follow the work of NGS and CMR. Finally, the modelling of households and the monetary policy are standard New Keynesian.

In the rest of the section, we describe the behaviour of firms followed by the description for the behaviour of households and monetary policy. The model is detrended using a deterministic trend and nominal variables are replaced with their real counterparts. Finally, the model is linearised around the stationary steady state of the detrended variables.

2.1 Intermediate and Finished Goods

There is a continuum of firms $f \in [0, 1]$. We divide the unit interval into two sub-intervals representing each sector: a finished goods sector (s) and an intermediate sector (m). Firms in both sectors produce under an imperfectly competitive market and have monopoly power over a differentiated good. Each firm within the two sectors produces a single differentiated good, $Y^s(f)$ and $Y^m(f)$, which are combined to produce a final good in each sector, Y^s and Y^m, respectively. The share of intermediate sector in total production in the economy is given by (1-μ^u), while the share of the finished goods sector is μ^u. Total intermediate production is denoted by Y^m. A fraction of intermediate goods is used as an input in the production of finished goods. The remaining fraction, not used in production, is combined with the finished goods to produce the final consumption good, C_t.[2] C_t enters the utility function of the representative household. The aggregation is done according to a Dixit-Stiglitz aggregator. Total consumption is given by:

$$C_t = \left((1-\bar{\alpha})(Y_t^s)^{\frac{1}{1+\rho}} + \bar{\alpha}(Y_t^m)^{\frac{1}{1+\rho}}\right)^{1+\rho} \tag{1}$$

where $\frac{1+\rho}{\rho}$ is the elasticity of substitution between finished goods and intermediate goods. Y_t^s and Y_t^m are given by:

$$Y_t^s = \left[\int_0^{\mu^u} (Y_{ft})^{1/(1+\rho)} df\right]^{1+\rho} \tag{2}$$

$$Y_t^m = \left[\int_{\mu^u}^1 (Y_{ft})^{1/(1+\rho)} df\right]^{1+\rho} \tag{3}$$

The corresponding price index is:

$$P_t = \left((1-\bar{\alpha})^{\frac{1+\rho}{\rho}} (P_t^s)^{-\frac{1}{\rho}} + \bar{\alpha}^{\frac{1+\rho}{\rho}} (P_t^m)^{-\frac{1}{\rho}}\right)^{-\rho} \tag{4}$$

where P_t is the general price index, P_t^m is the price of intermediate materials and P_t^s is the price level in the finished goods sector. In what follows, we will first describe the finished goods sector and then the intermediate sector. The demand for the finished goods sector and the intermediate goods sector is given by

$$Y_t^s = \left(\mu^u \frac{P_t}{P_t^s}\right)^{\frac{1+\rho}{\rho}} Y_t \tag{5}$$

$$Y_t^m = \left((1-\mu^u)\frac{P_t}{P_t^m}\right)^{\frac{1+\rho}{\rho}} Y_t \tag{6}$$

In the finished goods sector, with a constant returns to scale (CRS) technology, firms have a production function of the form:

$$Y_t^s(f) = \left[Y_t^m(f)\right]^{\mu} \left[A_t K_t^s(f)^{\alpha} \left[\gamma^t L_t^s(f)\right]^{1-\alpha}\right]^{1-\mu} - \gamma^t \Phi + E_t \tag{7}$$

[2] Such use of intermediate materials can be thought as packaging and transportation of the finished goods before they could be sold as final consumption goods.

where $Y_t^m(f)$ denotes intermediate sector goods used as input by firm f in the finished goods sector, $L_t^s(f)$ is a composite of labour input, $K_t^s(f)$ is capital services and Φ is the fixed cost. γ^t represents the labour-augmenting deterministic growth rate in the economy. α and μ are the share of capital and intermediate materials in production, respectively. A_t is the productivity shock which follows an AR(1) process with parameters ρ_a and σ_a. E_t is a stochastic shock process that is meant to capture changes in production that arise from external factors, such as unusually cold winters and rare disasters.[3]

To ensure that E_t is distinct from A_t and affects the output directly without affecting the marginal cost, it is assumed that E_t enters the production function additively. We assume that the shock affects the finished goods sector only. But it has an indirect effect on the intermediate goods sector. An unusually cold winter would cause a disruption in the production of the finished goods which will consequently reduce the demand for intermediate goods as well.[4] The log-linearised version of the production function in equation (7) is:

$$y_t^s = \phi_p(\mu y_t^m + (1-\mu)(\alpha k_t^s + (1-\alpha)L_t^s + a_t)) + e_t \tag{8}$$

where $e_t = \ln E_t$ and $a_t = \ln A_t$. Unlike the finished goods sector, firms in the intermediate sector have labor and capital as the only two factor inputs such that

[3]Another reason for including the E_t shock is a technical one. Since we include an additional data series on intermediate prices in our estimations, we need an additional shock to ensure that the number of observed variables are equal to the number of shocks. In any case, E_t does not play a significant role in driving model results. A variance decomposition analysis suggests that this shock explains only about 2% of the fluctuations in total output. We also model the E_t shock as a shock to capital as in Barro (2006) and Gourio (2012). Our main conclusions are robust to this alternate specification.

[4]In an alternative setting, we assume that the shock affects both the finished goods sector and the intermediate goods sector directly. Doing so does not change our main results significantly.

their production function is given by:

$$Y_t^m = A_t (K_t^m)^\alpha (\gamma^t L_t^m)^{1-\alpha} - \gamma^t \Phi \tag{9}$$

where $L_t^m(f)$ is a composite of labour input and $K_t^m(f)$ is capital services used in the intermediate sector. Log-linearising Equation (9) gives:

$$y_t^m = \phi_p(\alpha k_t^m + (1-\alpha) L_t^m + a_t) \tag{10}$$

Prices in both sectors are set according to Calvo pricing with no ad-hoc partial indexation. Log-linearisation of the aggregate price index in equation (4) is represented as:

$$0 = \bar{\alpha} \bar{p}_t^m + (1-\bar{\alpha}) \bar{p}_t^s \tag{11}$$

where $\bar{p}_t^s = p_t^s - p_t$ is the relative price level in the finished goods sector and $\bar{p}_t^m = p_t^m - p_t$ is the relative price level in the intermediate goods sector. Profit maximisation by the price-setting firms in the finished goods sector gives the following sectoral NKPC:

$$\pi_t^s = \beta \gamma^{1-\sigma_c} \pi_{t+1}^s + \kappa^s (\bar{mc}_t^s - \bar{p}_t^s) \tag{12}$$

where κ^s is the slope coefficient of the form:

$$\kappa^s = \frac{(1-\zeta_p \beta \gamma^{1-\sigma_c})(1-\zeta_p)}{\zeta_p} \tag{13}$$

and $\bar{mc}_t^s$ is the real marginal cost in the finished goods sector:

$$\bar{mc}_t^s = (1-\mu)(\alpha r_t^k + (1-\alpha) w_t - a_t) + \mu \bar{p}_t^m \tag{14}$$

ζ_p in equation (13) is the Calvo parameter for price stickiness. β is the discount factor. σ_c represents the elasticity of intertemporal substitution such that when it is above unity consumption and labor hours are complements. In equation (14) w_t is the real wage and r_t^k is the real rental rate of capital.

The NKPC in the intermediate sector is given by:

$$\pi_t^m = \beta\gamma^{1-\sigma_c}\pi_{t+1}^m + \kappa^m(\bar{mc}_t^m - \bar{p}_t^m) + \epsilon_t^{a^f} \tag{15}$$

where κ^m is the slope coefficient of the form:

$$\kappa^m = \frac{(1-\zeta_p^m\beta\gamma^{1-\sigma_c})(1-\zeta_p^m)}{\zeta_p^m} \tag{16}$$

where ζ_p^m is the Calvo parameter for price stickiness specific to the intermediate sector. $\bar{mc}_t^m$ is the real marginal cost in the intermediate sector:

$$\bar{mc}_t^m = \alpha r_t^k + (1-\alpha)w_t - a_t \tag{17}$$

$\epsilon_t^{a^f}$ in equation (15) is an exogenous shock to intermediate materials prices and follows an AR(2) process of the form in equation (18):

$$a_t^f = \rho_{a^f} a_{t-1}^f + \rho_{a^f}^2 a_{t-2}^f + \epsilon_t^{a^f} \tag{18}$$

The log-linearised aggregate output is given by

$$y_t = (1-\bar{\alpha})y_t^s + \bar{\alpha}y_t^m \tag{19}$$

When all of the intermediate materials are used by the finished goods producing firms (i.e. $\bar{\alpha} = 0$), the GDP equals finished sector output. The aggregate marginal cost is

$$mc_t = (1-\bar{\alpha})\bar{mc}_t^s + \bar{\alpha}\bar{mc}_t^m \tag{20}$$

The aggregate labour and capital in logs are given by

$$\begin{aligned} l_t &= \mu^u l_t^s + (1-\mu^u)l_t^m \\ k_t &= \mu^u k_t^s + (1-\mu^u)k_t^m \end{aligned} \tag{21}$$

In the next subsection, we will describe the financial accelerator mechanism which is identical to that in NGS.

2.2 The Financial Accelerator Mechanism and the Risk Shock

The introduction of financial frictions in the model alters the arbitrage equation. The arbitrage equation between the return on capital and the riskless rate in SW is replaced with an equation for capital returns and an equation for the spread between capital returns and the riskless rate. The equation determining the spread is:

$$E_t[\tilde{R}^k_{t+1} - R_t] = b_t + \zeta_{sp,b}(q^k_t + \bar{k}_t - n_t) + \tilde{\sigma}_{w,t} \tag{22}$$

Equation (22) has the SW arbitrage equation as a special case when the parameter, $\zeta_{sp,b}$, associated with the ratio of the value of installed capital to net worth, $\frac{Q^k_{t+i-1}\bar{K}_{t+i-1}}{N_{t+i-1}}$, is zero. q^k_t is the real value of the capital stock. $\tilde{\sigma}_{w,t}$ is the risk shock and $\tilde{R}^k_t$ denotes capital return to the entrepreneurs. $\tilde{R}^k_t$ can also be interpreted as required returns on capital, since entrepreneurs' borrowing cost within the model always equals $\tilde{R}^k_t$, given by:

$$\tilde{R}^k_t - \pi_t = \frac{r^k_*}{r^k_* + (1-\delta)} r^k_t + \frac{1-\delta}{r^k_* + (1-\delta)} q^k_t - q^k_{t-1} \tag{23}$$

n_t in equation (22) is the net worth of entrepreneurs expressed as:

$$n_t = \zeta_{n,\tilde{R}^k}(\tilde{R}^k_t - \pi_t) - \zeta_{n,R}(R_{t-1} - \pi_t) + \zeta_{n,q^k}(q^k_{t-1} + \bar{k}_{t-1}) + \zeta_{n,n} n_{t-1} \tag{24}$$

Following CMR and Fernandez-Villaverde et al. (2011), we assume the following process for the risk shock:

$$\tilde{\sigma}_{w,t} = \rho_{\tilde{\sigma}} \tilde{\sigma}_{w,t-1} + u_{\tilde{\sigma},t} \tag{25}$$

where

$$u_{\tilde{\sigma},t} = \rho_{\tilde{\sigma},n} u_{\tilde{\sigma},t-1} + \epsilon_{\tilde{\sigma},t} \tag{26}$$

After straightforward algebra, the last two equations can be rewritten as:

$$\tilde{\sigma}_{\omega,t+i} = \rho_{\tilde{\sigma}} \tilde{\sigma}_{\omega,t+i-1} + \rho^{i}_{\tilde{\sigma},n} \boldsymbol{\epsilon_{\tilde{\sigma},t}} + \rho^{i}_{\tilde{\sigma},n} \sum_{j=1}^{\infty} \rho^{j}_{\tilde{\sigma},n} \epsilon_{\tilde{\sigma},t-j} \tag{27}$$

where $0 < \rho_{\tilde{\sigma}}, \rho_{\tilde{\sigma},n} < 1$ and $\epsilon_{\tilde{\sigma},t}$ is i.i.d. (independent and identically distributed) and denotes the unanticipated component of risk, $\tilde{\sigma}_{\omega,t}$. Eq. (27) is an attempt to mimic the effect of the Lehman shock which increased both current and future risk in the economy. To see this more clearly, consider a financial shock, $\boldsymbol{\epsilon_{\tilde{\sigma},t}}$, in period '$t$'. $\boldsymbol{\epsilon_{\tilde{\sigma},t}}$ affects the economy in period 't' via two channels. First, $\boldsymbol{\epsilon_{\tilde{\sigma},t}}$ increases risk in period 't' ($\tilde{\sigma}_{\omega,t}$). Second, it also increases future risk ($\tilde{\sigma}_{\omega,t+i}$) and thus affects the current state of the economy through agents' intertemporal adjustment. $\boldsymbol{\epsilon_{\tilde{\sigma},t}}$ will receive less weight the further agents look into the future. $\rho^{i}_{\omega,n}$ is the weight on $\epsilon_{\tilde{\sigma},t}$ for risk in period '$t + i'$.

We call $\epsilon_{\tilde{\sigma},t-j}$ an anticipated component whose value was revealed in $t - j$. Thus, at time t the realisation of the risk $\tilde{\sigma}_{\omega,t}$ is influenced by the combined impact of both the unanticipated and the anticipated components. Furthermore, as Christiano et al. (2010) argue, such a generalised shock process helps to "tackle the deep-seated misspecification problems in DSGE models." The rest of the model equations are the same as in the SW model and are listed in the Appendix.

3 Estimation Strategy

This section starts with explaining the estimation methodology and macroeconomic data used for estimation purpose. We also present a brief overview of the prior distributions assumed for key parameters. Finally, the calibration of intermediate materials sector and the financial sector parameters is discussed.

We estimate the model in this paper (henceforth SW-BGG-I) for the period from 1981Q1 to 2013Q2. Following Smets and Wouters (2003), estimation is done using Bayesian estimation techniques.[5]

We use ten macroeconomic series at the quarterly frequency for the US economy. Seven of the data series are identical to SW: the log difference of real GDP, real consumption, real investment, real wage, log hours worked, log difference of the GDP deflator and the federal funds rate. Data for quarterly credit spread and 10-year inflation expectations are also included as in NGS. The credit spread is measured by the difference between the interest rate on BAA-rated corporate bonds and the 10 year US government bond rate. The Blue Chip Economic Indicators survey and the Survey of Professional Forecasters are used to obtain data for 10-year inflation expectations. Adding 10-year inflation expectations data is helpful since, as pointed out in Del Negro and Eusepi (2011) and Kiley (2008), inflation expectations contain information about people's beliefs regarding the Fed's inflation objectives. We further include data on the log difference of real intermediate materials prices. Seasonally adjusted intermediate price data are obtained from the St. Louis FED database[6]

[5]We ensure an acceptance rate of around 30% and allow for 250,000 replications for the Metropolis-Hastings algorithm. Estimation is done in Dynare 4.4.3.

[6]Producer Price Index by Commodity Intermediate Materials: Supplies & Components (PPI-

which are then deflated using the GDP deflator. The measurement equations relating the data to the model variables are:

$$
\begin{aligned}
OutputGrowth &= \gamma + 100(y_t - y_{t-1}) \\
ConsumptionGrowth &= \gamma + 100(c_t - c_{t-1}) \\
InvestmentGrowth &= \gamma + 100(i_t - i_{t-1}) \\
RealWageGrowth &= \gamma + 100(w_t - w_{t-1}) \\
HoursWorked &= \bar{l} + 100 l_t \\
Inflation &= \pi_* + 100\pi_t \\
FederalFundsRate &= R_* + 100 R_t \\
Spread &= SP_* + E_t[\tilde{R}^k_{t+1} - R_t] \\
10yrInflExp &= \pi_* + E_t[\frac{1}{40}\Sigma_{k=1}^{40}\pi_{t+k}] \\
IntermediateInflation &= \gamma + 100(\bar{p}^m_t - \bar{p}^m_{t-1})
\end{aligned} \tag{28}
$$

where $\bar{l}$, $\pi_* = 100(\Pi_* - 1)$ and $R_* = 100(\beta^{-1}\gamma^{\sigma_c}\Pi_* - 1)$ are the steady state of the quarterly hours worked, inflation and nominal interest rates, respectively. All the variables are expressed in percent.

Table 3 and Table 4 summarise the assumptions regarding prior distributions. Priors for most of the model parameters are similar to SW. In the SW-BGG-I, Calvo parameters for intermediate and finished goods sectors are specified a Beta prior distribution with standard deviation of 0.10. Klenow and Malin (2011) and Nakamura and Steinsson (2008) report that producer prices are more flexible than

ITM).

consumer prices. In line with this evidence, we assume that the prior mean for Calvo parameter is smaller in the intermediate sector than in the finished goods sector. Calvo parameter for the intermediate sector has a prior mean of 0.40. In contrast, Calvo parameter for the finished goods sector has a prior mean of 0.75. The price mechanism in the SW-BGG-I does not include price indexation.

The shock processes in the SW-BGG-I are similar to the SW for identical shocks. The risk shock follows a process that allows for anticipated signals as explained in equation (25). The price markup shock in the SW is replaced with the two supply side shocks. We interpret ϵ^{a^f} in equation (15) as shocks arising from changes in real intermediate prices. The persistence parameters of the two shocks follow a beta prior distribution with mean 0.50 and standard deviation 0.20. The standard deviation of the intermediate input shock, σ_{a^f}, has an Inverse Gamma prior distribution with mean 2.50 and standard deviation 2.0. σ_{ei} also follows an Inverse Gamma distribution with mean 0.10 and standard deviation 2.0.

Following Woodford (2003) and De Walque et al. (2006), the elasticity of substitution between the finished and the intermediate goods, $(1 + \rho)/\rho$, is assumed to equal 1. As a result, $\bar{\alpha}$ can be interpreted as the share of intermediate materials in final consumption good. We calibrate $\bar{\alpha}$ to equal 2%. Following Huang and Liu (2005), the share of intermediate materials in finished goods production, μ, is calibrated to equal 60%. We assume that the aggregation is done using a Dixit and Stiglitz aggregator and therefore ϵ_p equals 1. Table 1 reports the values for the parameters that are fixed in estimation.

Turning to the parameter values for the financial sector, following CMR, we

Table 1: **Exogenous parameter values**

Parameter	Definition	Values
β	Discount factor	0.9995
γ	Trend growth rate	1.004
δ	Depreciation rate	0.025
ϵ_w	Curvature of the Kimball labor market aggregator	10
g_y	Government spending-output ratio	0.18
μ	Share of intermediate materials in firms' production	0.60
$\bar{\alpha}$	Share of intermediate materials in consumption goods	0.02

calibrate the survival rate of entrepreneurs (τ) as 97.28% and the percentage of businesses going bankrupt ($F^*(\bar{\omega})$) as 1% annually. The rental rate of capital is assumed to be 0.045 to match the risk premium in the steady state. $Var(log\omega)$ is set at 0.24. Different from CMR, μ^e is endogenous in our model and has a steady-state value of 0.31, which is less than the value of 0.94 assumed in CMR. Parameters in the net worth equation are also endogenous and are derived in the model. All these numbers are summarised in Table 2.

Table 2: **Exogenous parameter values**

Entrepreneurs:		
$F^*(\bar{\omega})$	Percent of businesses that go into bankruptcy in a year	0.01
$Var(log\omega)$	Variance of the log-normally distributed i.i.d shock	0.24
τ	Fraction of entrepreneurs surviving to the next period	0.9728
μ^e	Monitoring costs	0.31
r^k	Rental rate of capital	0.045

We estimate the two financial sector parameters in equations (22) and (28), $\zeta_{sp,b}$ and SP_*, respectively. Priors for the financial sector parameters are set in line with NGS and are given in Table 4. SP_* follows a Gamma distribution with prior mean of 2 and standard deviation of 0.10. $\zeta_{sp,b}$ is assumed to follow a Beta distribution with mean of 0.05 and standard deviation of 0.005. The three parameters related to the risk shock are the persistence of the shock process ($\rho_{\bar{\sigma}}$), the standard deviation of the shock ($\sigma_{\bar{\sigma}}$) and the parameter on the anticipated components of the risk shock ($\rho_{\bar{\sigma},n}$). $\rho_{\bar{\sigma}}$ has a Beta prior distribution with mean 0.75 and standard deviation 0.15. $\sigma_{\bar{\sigma}}$ has mean 0.05 and standard deviation of 4 with an Inverse Gamma distribution. $\rho_{\bar{\sigma},n}$ also follows an Inverse Gamma prior distribution with mean 1 and standard deviation 2.

Prior distributions of the remaining parameters in the model are identical to those in SW.

4 Estimation Results

The estimated values for the structural parameters are reported in Table 3. Table 3 also includes the prior and posterior standard deviations for the corresponding parameters.

The posterior mean of the price stickiness parameter, ξ_p, in the finished goods sector is estimated at 0.78. This suggests an average age of the price contract of 4.5 quarters and is closer to the evidence reported in Klenow and Malin (2011). In contrast, when estimated over the sample period including Great Recession, NGS and SW models suggest an average age of the price contract of approximately 8 quarters. The estimated value of ξ_p^m is 0.71. In line with Klenow and Malin (2011), producer prices (i.e. intermediate sector prices) are more flexible than finished goods prices.[7]

[7] Posterior estimates for structural parameters imply the slope coefficient of finished goods sector

Table 3: **Prior and Posterior Estimates of Structural Parameters**

	Prior Distribution			Posterior Distribution SW-BGG-I	
	type	Mean	st. dev.	Mean	st. dev
structural parameters:					
φ	Normal	4.000	1.500	7.426	0.287
σ_c	Normal	1.500	0.375	1.126	0.072
h	Beta	0.700	0.100	0.590	0.065
ξ_w	Beta	0.500	0.100	0.947	0.003
σ_l	Normal	2.000	0.750	2.859	0.156
ξ_p^s	Beta	0.750	0.100	0.776	0.014
ξ_p^m	Beta	0.400	0.100	0.713	0.022
ι_w	Beta	0.500	0.150	0.117	0.029
ψ	Beta	0.500	0.150	0.301	0.029
ϕ_p	Normal	1.250	0.120	1.187	0.024
r_π	Normal	1.500	0.250	1.274	0.045
ρ_r	Beta	0.750	0.100	0.776	0.016
r_y	Normal	0.130	0.050	0.055	0.007
$r_{\triangle y}$	Normal	0.125	0.050	0.004	0.005
π_*	Gamma	0.625	0.100	0.962	0.024
$\bar{l}$	Normal	0.000	2.000	2.465	0.469
γ	Normal	0.400	0.100	0.286	0.023
α	Normal	0.300	0.050	0.248	0.015
SP_*	Beta	2.000	0.100	1.986	0.031
$\zeta_{sp,b}$	Beta	0.050	0.005	0.050	0.001

Most of the remaining parameters are inline with the estimation results in the SW. The two significant differences are with regards to the parameters governing the labour market and the monetary policy. Wages in the SW-BGG-I model are more

NKPC (i.e. κ^s) to equal 0.05. The NKPC for the intermediate sector is twice as steep as the finished goods sector with κ^m equal to 0.1. The corresponding value of κ in the SW model, estimated over the Great Recession period, is only 0.001. The estimation results in this paper, therefore, do not support the flattening of the NKPC after the Great Recession as suggested by models without intermediate materials. This difference is robust to including indexation in our model and as well for smaller share of intermediate materials in firms' production.

Table 4: **Prior and Posterior Estimates of Shock Processes**

	Prior Distribution			Posterior Distribution SW-BGG-I	
	type	Mean	st. dev.	Mean	st. dev
persistence of exogenous shocks:					
ρ_a	Beta	0.500	0.200	0.957	0.005
ρ_{a^f}	Beta	0.500	0.200	0.299	0.022
ρ_{ei}	Beta	0.500	0.200	0.029	0.043
ρ_{ei^1}	Beta	0.500	0.200	0.016	0.003
$\rho_{\bar{\sigma}}$	Beta	0.750	0.150	0.993	0.003
$\rho_{\bar{\sigma},\nu}$	Beta	0.750	0.150	0.533	0.083
ρ_b	Beta	0.500	0.200	0.987	0.003
ρ_g	Beta	0.500	0.200	0.991	0.006
ρ_μ	Beta	0.500	0.200	0.999	0.001
ρ_r	Beta	0.500	0.200	0.218	0.035
ρ_{π^*}	Beta	0.500	0.200	0.933	0.006
ρ_w	Beta	0.500	0.200	0.364	0.021
μ_w	Beta	0.500	0.200	0.759	0.012
ρ_{ga}	Normal	0.500	0.250	0.052	0.018
σ_a	Inv.Gamma	0.100	2.000	1.058	0.076
σ_{a^f}	Inv.Gamma	1.000	2.000	2.554	0.406
σ_{ei}	Inv.Gamma	0.100	2.000	1.317	0.099
$\sigma_{\bar{\sigma}}$	Inv.Gamma	0.050	4.000	0.064	0.006
σ_b	Inv.Gamma	0.100	2.000	0.037	0.009
σ_g	Inv.Gamma	0.010	2.000	0.497	0.034
σ_μ	Inv.Gamma	0.100	2.000	0.206	0.028
σ_r	Inv.Gamma	0.100	2.000	0.205	0.015
σ_{π^*}	Inv.Gamma	0.100	2.000	0.193	0.035
σ_w	Inv.Gamma	0.100	2.000	0.568	0.038

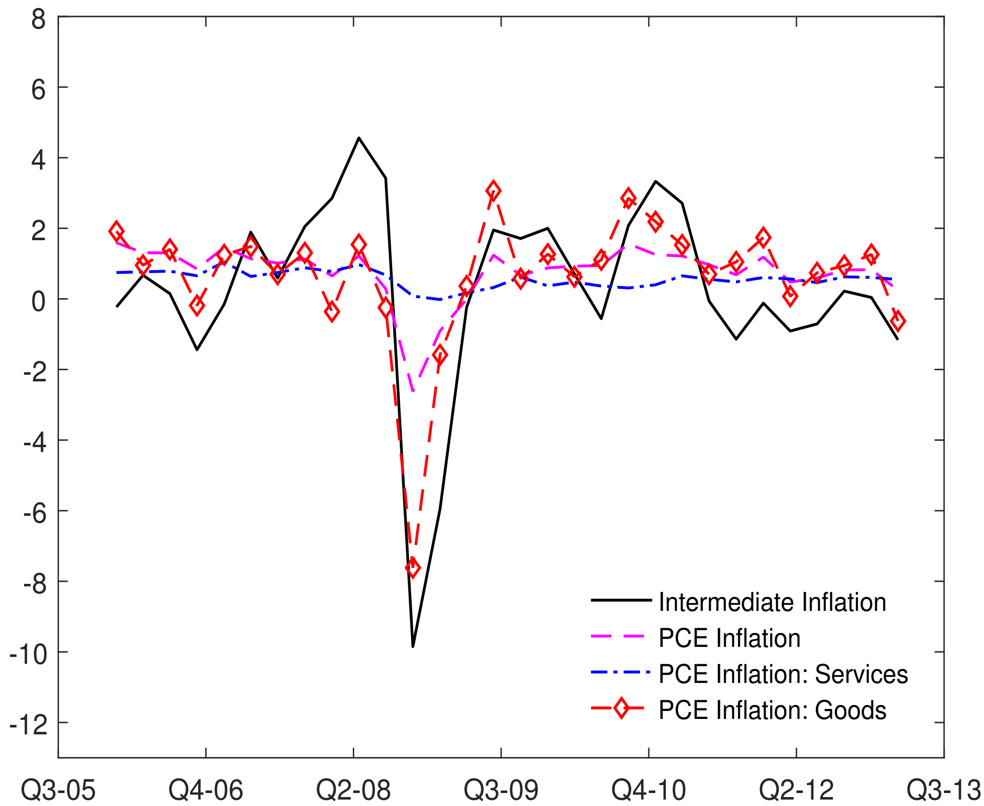
sticky than in the SW. However, the estimate for wage indexation is significantly lower than in the SW. Monetary policy in SW-BGG-I is also relatively less responsive to changes in inflation and output variables.

The supply-side shocks in the intermediate sector are relatively less persistent than the price markup shock in the SW (Table 4). The e_t shock in the SW-BGG-I, which is intended to capture abrupt disruptions in production process due to factors such as natural disasters, has an estimated persistence of only 0.03 and 0.01 for its two persistence parameters, ρ_{ei} and ρ_{ei^1}, respectively. Persistence of the intermediate input shock, ρ_{a^f}, is estimated at 0.30. The persistence of the price markup shock, ρ_{π}, in the SW, on the other hand, is much larger at 0.89. Reflecting the highly volatile nature of intermediate prices, the standard deviation of the intermediate input shock in the SW-BGG-I is large at around 2.55.

5 Intermediate Prices and the Great Recession

Before discussing the results, let us first discuss the behaviour of intermediate materials prices during the Great Recession. Figure 1 compares intermediate materials price inflation with Personal Consumption Expenditure (PCE) inflation. The plot shows that the PCE inflation for goods, which accounts for most of the usage of intermediate materials, moves closely with intermediate materials price inflation. The correlation between the two series is 0.79. A cursory look at the data, therefore, suggests that intermediate prices do play an important role in driving goods inflation and, consequently, aggregate inflation dynamics. At the start of the Great Recession, both intermediate price inflation and PCE goods inflation fell sharply. As a result, aggregate PCE inflation also fell to negative 2.6% in 2008Q4. Thereafter, both intermediate price inflation and PCE inflation recovered and remained positive for most of the subsequent period. This motivates our question: Would aggregate inflation be persistently negative in the absence of increase in intermediate materials prices, in line with persistent negative output gap following the Great Recession? We now turn to answering this question.

Figure 1: **Intermediate Materials and PCE Inflation**



Note: *This figure compares intermediate materials price inflation with Personal Consumption Expenditure (PCE) inflation. The PCE inflation is plotted at the aggregate level and as well for Goods and Services. The data series are seasonally adjusted and are obtained from the St. Louis FED database. We deflate the intermediate materials price series using the GDP deflator. The intermediate price series is the Producer Price Index by Commodity Intermediate Materials: Supplies & Components (PPIITM).*

5.1 Simulation Results

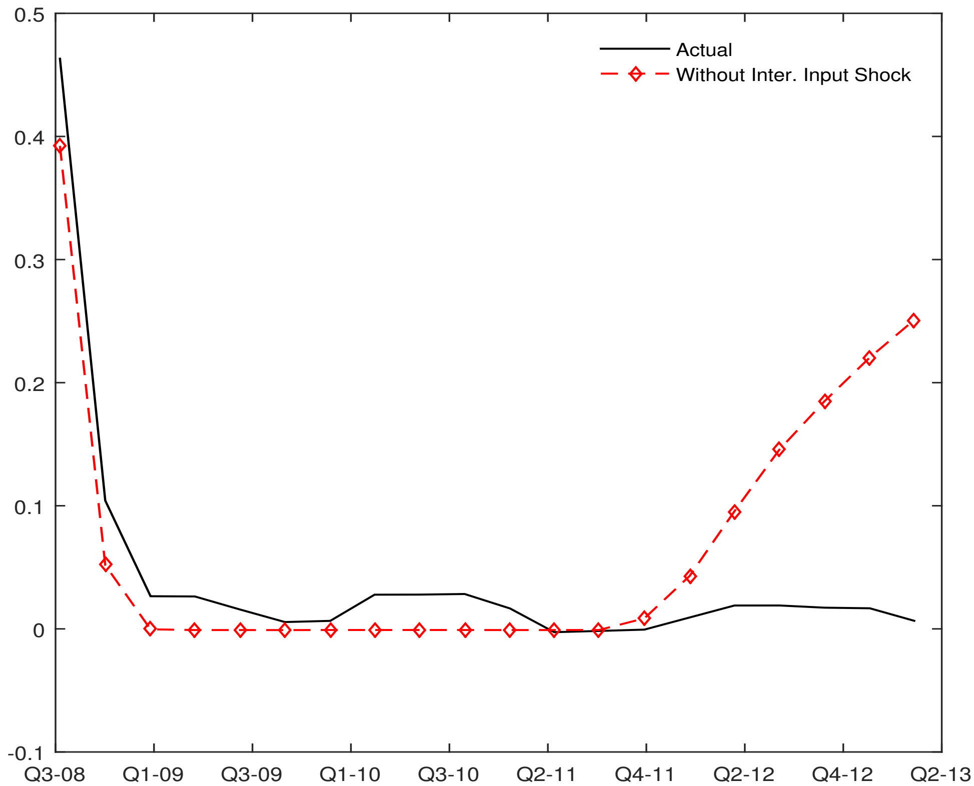
This section focuses on comparing simulation results from the SW-BGG-I model with and without intermediate input-price shocks. In another counterfactual exercise, we also analyse the role of BGG mechanism in driving observed output dynamics. To do so, we first estimate the model for the period from 1981Q1 to 2013Q2 using Bayesian estimation methods. We obtain estimates for the structural parameters and also the historical values for exogenous shocks over the full sample period. Next, we use this information to simulate the model.[8]

In the first counterfactual exercise, we investigate how inflation would have evolved over the period since Great Recession, from 2009Q1 to 2013Q2, had the economy not been hit by intermediate input-price shocks. To do so, we set the intermediate input shock to zero for the period since Great Recession (i.e. $\epsilon^{af}_{2009Q1:2013Q2}=0$) and do model simulations. In the second exercise, we investigate how output would have evolved in the absence of the BGG mechanism. We close the BGG mechanism in the simulation exercise for the full sample period by setting $\zeta_{sp,b}$ to equal zero and also setting the risk shock to zero (i.e. $\tilde{\sigma}_{w,1981Q1:2013Q2}=0$). We compare the simulation results from both the counterfactual exercises with the actual data. Moreover, since the simulation period corresponds to the period of zero lower bound on the federal funds rate, we impose zero lower bound on the interest rate throughout our analysis. Figure 3 and Figure 5 plots the simulation results for inflation and output growth along with the actual data over the Great Recession period. The corresponding interest rate dynamics are plotted in figure 2.

Figure 3 shows that intermediate materials prices has a significant effect on inflation during the Great Recession. The model suggests that in the absence of positive intermediate input shocks, inflation decreases much more sharply than it did. In-

[8]When we feed the exact information obtained from the estimation exercise back into the model, simulating the model generates series for observed variables which are similar to actual data.

Figure 2: **Federal Funds Rate with ZLB and no Intermediate Input Price Shock**

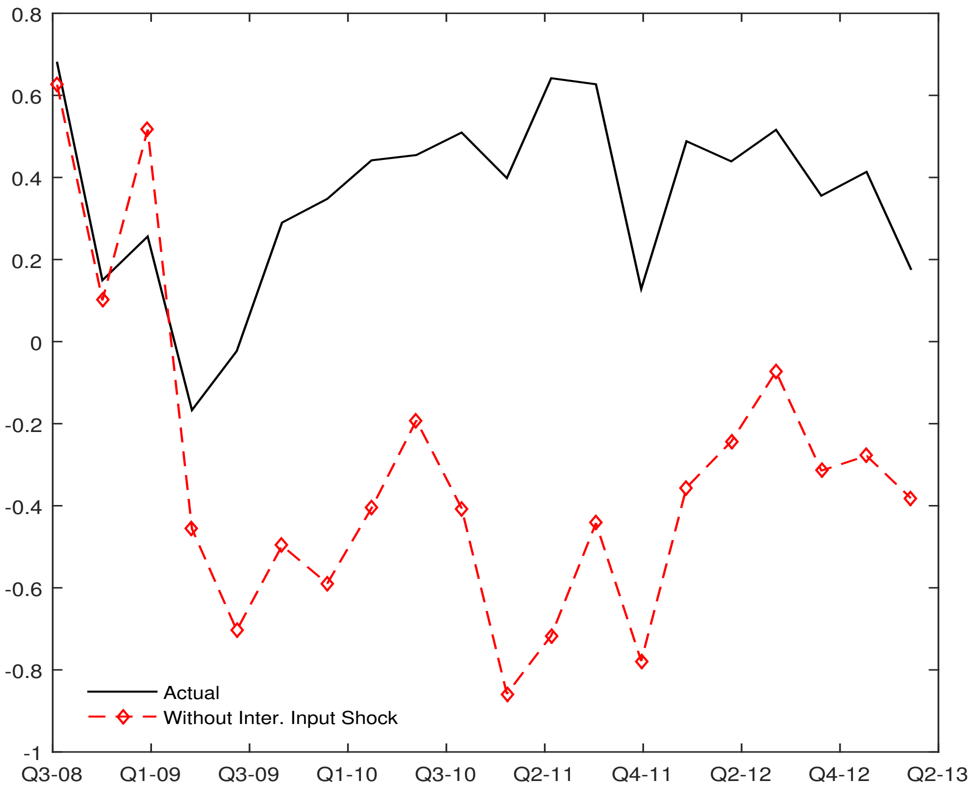


Note: *The solid black line is the observed federal funds rate. Dashed red line with diamonds is the simulation when zero lower bound is imposed and there are no intermediate input price shocks.*

flation continues to decline thereafter and remains significantly negative for most of the period. These findings suggest that there would have been no 'missing deflation' puzzle in the absence of increasing real intermediate materials prices.

To understand these results better, it is important to look at the implications of

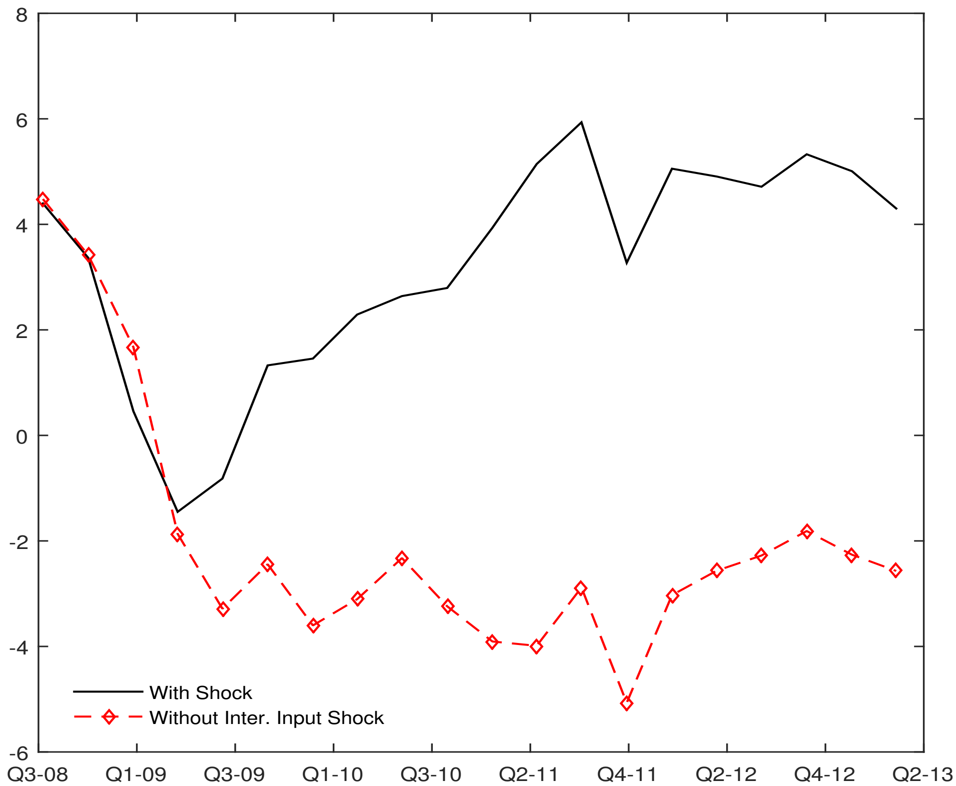
Figure 3: **Inflation Simulation without Intermediate Input Price Shock**



Note: *The solid black line is the observed inflation. Dashed red line with diamonds is the simulation when zero lower bound is imposed and there are no intermediate input price shocks.*

input-price shock for finished goods firms marginal costs. In the model, inflation is determined by future marginal costs, which depends on intermediate materials prices (see equation 14). Figure 4 plots the smoothed marginal costs (MC) both with and without the intermediate input shocks. Marginal costs behave very differently with and without intermediate input shocks. Marginal costs are much higher with the

Figure 4: **Marginal Cost with and without Intermediate Input Price Shock**

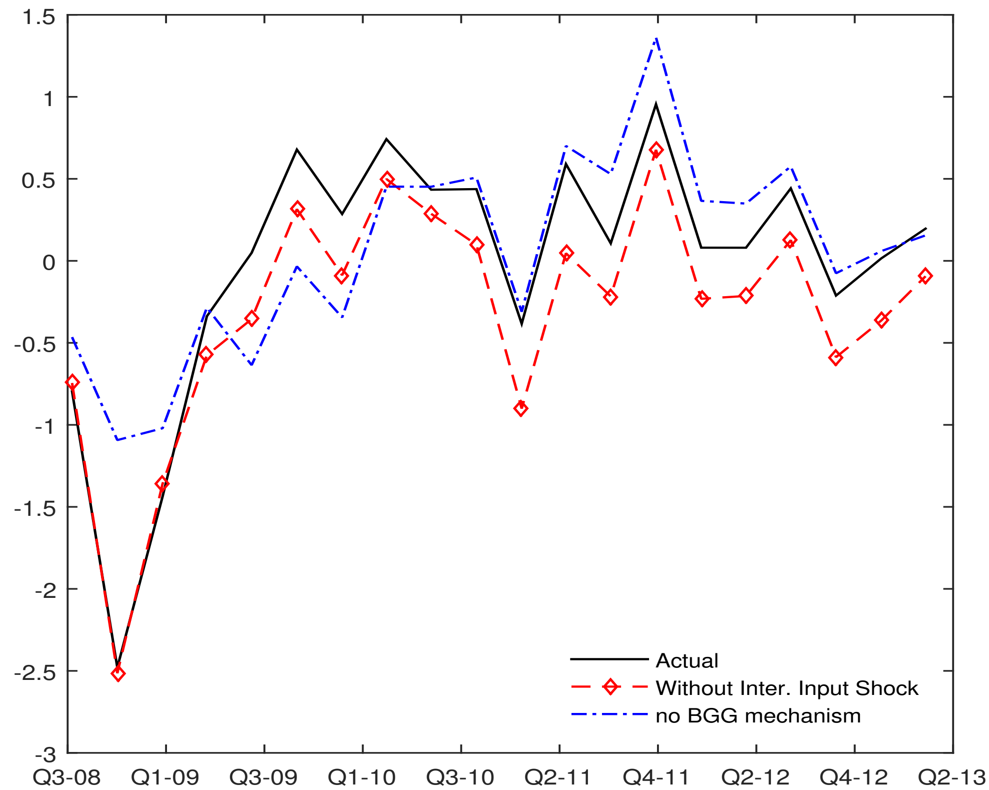


Note: *The solid black line is the smoothed marginal cost,* $E[mc_t|Y_{1:T_{full}}]$*. The dashed red line is the smoothed marginal cost without the intermediate input price shocks.*

shocks. It appears that increasing intermediate prices almost completely offset the fall in the marginal costs following the sharp contraction in economic activity. As a consequence, inflation did not fall much during the Great Recession.

We now turn to examine the output dynamics. Figure 5 suggests intermediate prices had limited effect on output growth. However, the BGG mechanism plays

Figure 5: **Output Growth Simulations**



Note: *The solid black line is the observed output growth. Dashed red line with diamonds is the simulation when zero lower bound is imposed and there are no intermediate input price shocks. Dotted-dashed blue line is the simulation with zero lower bound and no BGG mechanism.*

an important role in explaining output dynamics, especially at the start of Great Recession. To understand the role of the BGG, we also simulate the model without the BGG mechanism. As it is evident from the figure, output falls less without the BGG mechanism. The fall in output growth is only half of the observed fall.

The intuition behind these results is as follows. Let us first focus on the unanticipated component of the shock process. When the shock hits the economy, uncertainty in the economy increases. This results in banks increasing the interest rate charged on loans to the entrepreneurs. With increased interest rates, entrepreneurs borrow less, leading to a decrease in investment. Consequently, output falls following a contraction in investment.

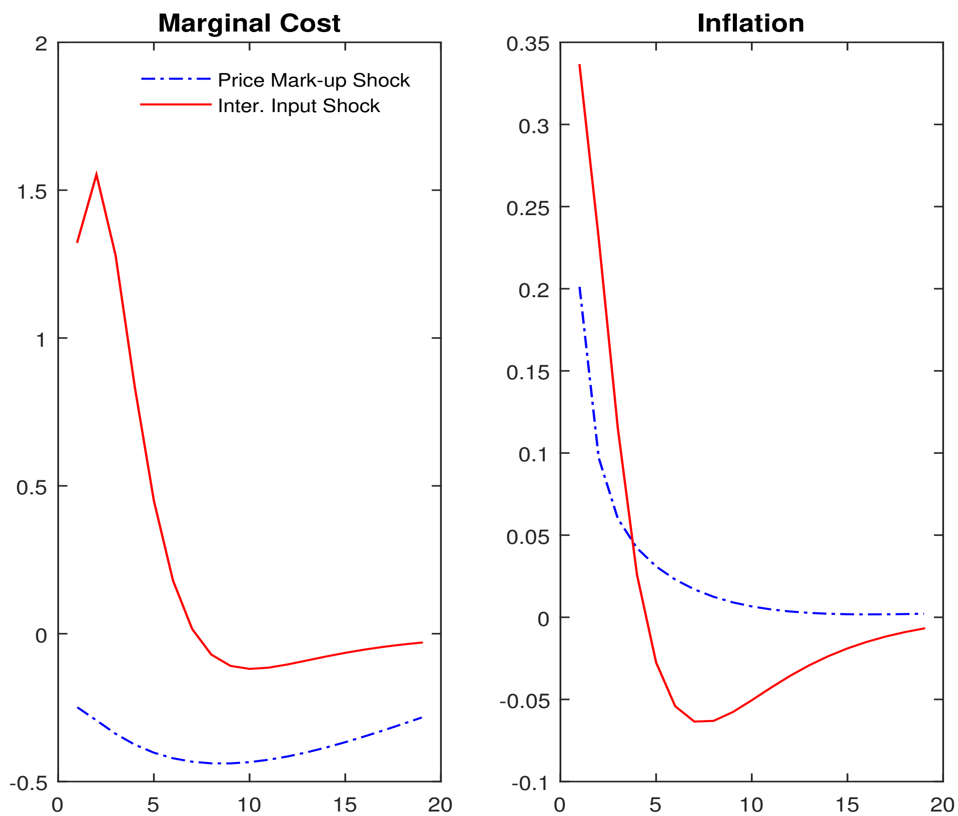
Adding an anticipated element to the shock process amplifies the fall in output, since the anticipation that future uncertainty will increase leads banks to further increase the interest rate on loans. Increased interest rates depress investment further, leading to a larger fall in output.

5.2 Price Shocks and Marginal Costs

It is important to note that price mark-up shocks in the SW framework are meant to capture the changes in energy prices (see, e.g. NGS). However, these shocks can have very different implications for the marginal costs than intermediate input shocks. When price mark-ups increase, marginal cost must fall. This is because of the fact that prices are sticky. A positive mark-up shock must, therefore, be compensated by reduced marginal cost. Firms achieve this by lowering their output. Since decrease in output leads to a fall in the prices of factor inputs, firms' marginal cost declines.

On the contrary, intermediate materials price shocks lead to an increase in marginal cost, since intermediate materials are an additional cost component of firms' marginal cost. Figure 6 highlights how these two shocks have different implications

Figure 6: **Impulse Responses to Intermediate Input and Price Markup shocks**



Note: *The dashed black blue line is the IRF to the price markup shock in the Smets and Wouters model with BGG type financial frictions. The solid red line is the IRF from SW-BGG model with intermediate materials price.*

for marginal cost. Both the shocks lead to an increase in inflation. However, since the size of intermediate shock is large, inflation increases more in response to an intermediate input shock. On the contrary, marginal cost increases in response to intermediate input shock and decreases following a price markup shock. It is also important to note that intermediate input shocks are significantly less persistent than price markup shocks.

These results imply decreasing price mark-ups for finished goods producing firms and increasing price mark-ups for intermediate goods producing firms. The implication for price mark-ups in this paper apears to be contrary to the empirical evidence provided in Gilchrist et al. (2016) and Gilchrist et al. (2015). They find evidence for increasing price mark-ups during the Great Recession. Montero and Urtasun (2014) also report similar findings for Spain. This is because financially constrained firms find it optimal to increase their prices in order to raise internal liquidity and protect themselves against the risk of default.

However, the implication for the sector-specific mark-ups in this paper do not have to contradict the findings in Gilchrist et al. and Montero and Urtasun (2014). It is possible that, following an adverse financial or demand shock, intermediate goods producing firms are also those which become relatively more financially constrained. This could be because, as finished goods producing firms use existing stock of intermediate-specific inventories to meet production needs, intermediate goods producing firms can experience a worsening of their balancesheets. An indirect evidence for this channel can be found in Alessandria et al. (2010) and Altomonte et al. (2012). They show that a significant portion of the decrease in international trade can be accounted for by the decrease in the trade in intermediate materials. This is because, following the crisis, finished goods firms use their existing stock of inventories to meet production needs. This generates a disproportionate reduction in the demand for intermediates. Since the model in this paper has a comparable supply-chain structure to that of global supply-chains studied in international trade literature, a similar argument can be forwarded here. A collapse in the demand for intermediate goods can worsen the financial position of the intermediate goods producing firms thus forcing them to raise their prices as explained in Gilchrist et al. (2016, 2015). We leave exploring evidence for this mechanism to future research.

5.3 Robustness

The implications of including intermediate materials prices for inflation dynamics are significant even for smaller share of intermediate materials in finished goods production. When the model is re-estimated with the share of intermediate materials in finished production reduced from 60% to 40%, the model still produces significant deflation in the absence of intermediate input shocks. The magnitude of deflation decreases as the share is reduced further to 20%. However, simulation experiments continue to suggest periods of deflation in the absence of intermediate input shocks.

Our posterior estimates for ξ_p^s and ξ_p^m suggest that the implied price duration is significantly lower compared to that implied by SW and NGS when estimated for the period including Great Recession. However, these estimates are still higher than those reported in micro studies (see Nakamura and Steinsson (2008)). We calibrate our model according to the values suggested by Nakamura and Steinsson (2008) (i.e. $\xi_p^s = 0.6$ and $\xi_p^m = 0.5$). The findings reported in this paper do not change significantly. Instead, in a similar analysis to that in section 5.1, inflation falls even more in the absence of intermediate input price shocks. In another exercise, we also set the prior mean for Calvo parameters in both sectors to equal 0.5. We reestimate the model. The results reported in this paper are robust to these alternate priors.

We also estimate the model with price indexation in both intermediate and finished goods sectors. The simulation results are robust to the inclusion of price indexation. Including indexation decreases the posterior estimate for Calvo parameters in both the sectors. Prices in the intermediate sector become significantly more flexible once indexation is included. Most of the other parameters are almost the same as reported in table 3 and table 4.

Following Bodenstein and Guerrieri (2010), Charlstrom and Fuerst (2006) and Krichene (2006), we have assumed that the intermediate input shock follows an AR(2) process. In an alternate setting, we assume an AR(1) process as in Dhawan and Jeske (2008) and Rotemberg and Woodford (1996). We find our results are robust to assuming an AR(1) process for the intermediate input shock.

6 Conclusions

In this paper, we have reformulated the standard New Keynesian model to include a Bernanke-Gertler-Gilchrist financial accelerator mechanism and to account for changes in intermediate materials prices. In the new model, intermediate materials are used as an additional factor input in the production of finished goods. A fraction of intermediate goods are also combined with finished goods to produce the final consumption good. We have estimated the model for the period from 1981Q1 to 2013Q2 using quarterly US data. The estimated model is then used to do simulation exercise over the period from 2008Q4 to 2013Q2 to see if the reformulated model can account for the evolution of the key macroeconomic variables during the Great Recession.

We have shown that accounting for the changes in intermediate prices provides an explanation for the 'missing deflation' puzzle noted during the Great Recession. Importantly, our model achieves this with an empirically relevant degree of price stickiness. The key difference across the models with and without the intermediate sector is that in the model with an intermediate sector, marginal cost does not decline during the Great Recession unlike in the model without an intermediate sector. This is because during the Great Recession intermediate prices were increasing. Since intermediate materials in our model are required to produce finished goods, during the Great Recession, the marginal cost in our model does not fall as much as it does in the model without intermediate materials. As a consequence, despite the substantial drop in output, just as in the data, inflation does not fall much, providing an explanation for the "missing deflation" puzzle.

7 Appendix

The rest of the model is the same as that in the SW model. The Consumption Euler equation is given by:

$$c_t = -\frac{1-\frac{h}{\gamma}}{\sigma_c(1+\frac{h}{\gamma})}(R_t - E_t\pi_{t+1} + b_t) + \frac{\frac{h}{\gamma}}{1+\frac{h}{\gamma}}c_{t-1} + \frac{1}{1+\frac{h}{\gamma}}E_t c_{t+1} + \frac{\sigma_c - 1}{\sigma_c(1+\frac{h}{\gamma})}\frac{w_*^h L_*}{c_*}(L_t - E_t L_{t+1}) \tag{29}$$

where c_t is consumption, L_t is labour supply, R_t is nominal riskless interest rate, and π_t is inflation. b_t is an exogenous shock such that a positive shock increases the required return on assets and increases the cost of capital and reduces the value of capital and investment. b_t follows an AR(1) process with parameters ρ_b and σ_b. h is the habit persistence parameter which makes consumption more persistent for higher values of h and vice versa. Finally, σ_c is the relative risk aversion parameter. The consumption process is derived from non-separable utility in labour and consumption. Variables with $*$ are the respective steady states.

The resource constraint is given by (30) with g_t as the exogenous government spending:

$$y_t = \frac{c_*}{y_*}c_t + \frac{i_*}{y_*}i_t + \frac{r_*^k k_*}{y_*}u_t + g_t \tag{30}$$

Exogenous government spending is also affected by the productivity shock such that:

$$g_t = \rho_g g_{t-1} + \epsilon_t^g + \rho_{ga}\epsilon_t^a \tag{31}$$

Investment Euler equation is derived from the capital producers' optimization decision:

$$i_t = \frac{1}{1+\beta\gamma^{1-\sigma_c}}i_{t-1} + \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}}E_t i_{t+1} + \frac{1}{(1+\beta\gamma^{1-\sigma_c})S''\gamma^2}q_t^k + \mu_t \tag{32}$$

where μ_t is the investment specific technology shock with parameters ρ_μ and σ_μ and is also called marginal efficiency of investment shock. β is the discount factor for the households. $S^{''}$ is the steady state elasticity of the capital adjustment cost function such that a higher value for it reduces the sensitivity of i_t to the real value of existing capital stock, q_t^k.

Existing capital stock itself evolves according to:

$$\bar{k}_t = (1 - \frac{i_*}{\bar{k}_*})\bar{k}_{t-1} + \frac{i_*}{\bar{k}_*} i_t + (1 + \beta\gamma^{1-\sigma_c})S^{''}\gamma^2 \frac{i_*}{\bar{k}_*}\mu_t \tag{33}$$

where $\bar{k}_t$ is the installed capital stock and $\frac{i_*}{\bar{k}_*}$ is the steady state ratio of investment to installed capital. Since there is a lag in the capital installation, capital services are a function of previously installed capital and the capital utilization decision taken by the entrepreneurs after observing the risk shock:

$$k_t = \bar{k}_{t-1} + u_t \tag{34}$$

where capital utilization, u_t, is a function of the rental rate of capital:

$$u_t = \frac{1 - \varphi}{\varphi} r_t^k$$

such that a higher value for φ ($\in$ 0,1) reflects high adjustment costs in terms of consumption goods. Rental rate of capital , r_t^k, is assumed to be identical across the two sectors:

$$r_t^k = -(k_t^i - L_t^i) + w_t \tag{35}$$

where $i = s, m$ represent the finished goods and intermediate sector, respectively.

Wages, w_t, are determined by the wage Phillips curves:

$$w_t = \frac{(1-\zeta_w\beta\gamma^{1-\sigma_c})(1-\zeta_w)}{(1+\beta\gamma^{1-\sigma_c})\zeta_w((\lambda_w-1)\epsilon_w+1)}(w_t^h - w_t) - \frac{1+\iota_w\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}}\pi_t + \frac{1}{1+\beta\gamma^{1-\sigma_c}}(w_{t-1}-\iota_w\pi_{t-1}) + \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}}\mathbb{E}_t[w_{t+1}+\pi_{t+1}] + \lambda_{w,t} \quad (36)$$

where ζ_w, ι_w and ϵ_w are the Calvo parameter for wage stickiness, degree of indexation and the curvature parameter in the Kimball aggregator for wages, respectively. $\lambda_{w,t}$ is the wage markup shock following an ARMA(1,1) process similar to SW with parameters ρ_w, σ_w and μ_w. w_t^h is the household's marginal rate of substitution between consumption and labor:

$$w_t^h = \frac{1}{1-\frac{h}{\gamma}}(c_t - \frac{h}{\gamma}c_{t-1}) + \sigma_l L_t \quad (37)$$

The model is closed with the central bank following a feedback rule of the type in equation (38). The central bank adjusts the nominal short-term interest rate in response to its lagged value, inflation and change in the inflation gap, in addition to output gap and change in the output gap:

$$R_t = \rho_R R_{t-1} + (1-\rho_R)[r_\pi(\pi_t - \pi_t^*) + r_y(y_t - y_t^*)] + r_{\triangle y}[(y_t - y_t^*) - (y_{t-1} - y_{t-1}^*)] + m_t^r \quad (38)$$

where y_t^* is the flexible level of output. π_t^* is the target level of inflation which evolves according to an AR(1) proces with parameters ρ_{π^*} and σ_{π^*}. The monetary policy shock, m_t^r, also follows an AR(1) process with parameters ρ_r and σ_r.

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