Joint Discussion Paper Series in Economics

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

No. 48-2013

Marcel Förster

The Great Moderation: Inventories, Shocks or Monetary Policy?

Coordination: Bernd Hayo • Philipps-University Marburg
Faculty of Business Administration and Economics • Universitätsstraße 24, D-35032 Marburg
Tel: +49-6421-2823091, Fax: +49-6421-2823088, e-mail: hayo@wiwi.uni-marburg.de

The Great Moderation: Inventories, Shocks or Monetary Policy?

Marcel Förster*,⋆

February 18, 2014

This paper presents a New Keynesian DSGE model with inventory holding firms. The model distinguishes between goods and materials, for both production as well as for inventories. The more detailed treatment of inventory holdings offers new insights into the determinants of business cycles before and during the Great Moderation. Via Bayesian estimation we determine the distributions of the parameters for U.S. data for two subsamples. Our results show that impulse responses change significantly in terms of magnitude and persistence over time. Shocks in the labor market have gained importance since the Great Moderation and they explain the volatility of many variables. We reject the hypothesis of better inventory management and improved monetary policy as explanations for the Great Moderation. Instead, labor supply developments and changes in cost associated with capital play a key role for the reduced fluctuations.

KEYWORDS: Inventories, Great Moderation, Bayesian Estimation, DSGE model, Business Cycles

JEL CLASSIFICATION: C13, E20, E30

*Justus Liebig University Giessen, Chair of Monetary Economics, Licher Str. 66, 35394 Giessen, Germany. Telephone: +49 641 99-22176. Telefax: +49 641 99-22179. E-mail: marcel.foerster@wirtschaft.uni-giessen.de.

⋆For comments and suggestions, I am grateful to Peter Tillmann, Markus Jorra, Roland Winkler, Stephen Sacht, Martin Mandler, Lothar Grall, and Jana Brandt.

1 Introduction

In the first half of the 1980s, the fluctuations of macroeconomic key variables such as GDP growth and inflation declined substantially. The U.S. economy and many other advanced economies entered a more stable path for several decades. This phenomenon is known as the Great Moderation. Table 1 shows the standard deviations for selected time series during two subsamples, beginning in 1957 and ranging to 2006.[1] The volatility of almost all variables declines within the second episode, for some observables can even a remarkably fall be noticed. An exception is the labor market, i.e. working hours per capita and real wage growth show larger fluctuations.

While we can be lucky with those developments, the reasons behind those observations are still not clear. Most research has tried to answer the question: was it good policy or was it just good luck? The latter leaves economic agents and policy makers as victims to exogenous circumstances. In order to maintain economic stability in the future, we would like policy and structural changes to have an effect.

Several studies investigated the sources of the Great Moderation. A stochastic volatility approach is introduced by Justiniano and Primiceri (2008) and Canova (2009), for example, to investigate the break in aggregate volatilities. Models with oil are employed in Herrera and Pesavento (2009) and Nakov and Pescatori (2010). Using Vector Autoregressions, Gambetti and Galí (2009), Giannone, Lenza, and Reichlin (2008), and Stock and Watson (2002) take a look at the transition from the high to the low volatility state. Smets and Wouters (2007) dedicate a short section to the investigation of this question in a standard New Keynesian DSGE model. Another attempt is made by Boivin and Giannoni (2006). The results are ambiguous and a consensus on this topic is still out of reach.

A component that is given less consideration in the Great Moderation discussion is inventory management. Leaving an omitted variables problem in estimations and potential model-misspecification aside, inventory investment creates a wedge between output and sales and contributes substantially to macroeconomic fluctuations. For example, the ratio of inventory investment to GDP amounts to less than 1% on average but it accounts for about 30% of output volatility (Khan and Thomas (2005)). Further data analysis reveals that output is typically more volatile than aggregate sales. This fact is pointed out by Ramey and West (1999) using data for G7 countries. Another stylized fact about U.S. post-war time series is that we

[1] Shown are standard deviations for logarithmic per-capita data as they are used for the estimation. Please see Section 4 for further information on data and breakpoint choice.

observe the variance (standard deviation) of gross private investment is about 2.5 (1.6) times larger than the one for fixed private investment since WWII. As for sales and production, both series differ only by the inventory investment series. Consequently, inventories matter when evaluating the movements in macroeconomic time series in terms of business cycle analysis and regarding the Great Moderation.

Inventories can further be distinguished between inventories of finished goods ready for sale, inventories of goods being processed, and the inventory stock of commodities (i.e. materials and supplies). According to the U.S. Census Bureau Survey the inventory stock in the manufacturing sector is approximately split equally into the three categories. Aggregating these components and considering inventories as uniform therefore may be an assumption too severe since. Consider a drop in aggregate demand. Finished goods inventories rise and firms therefore could respond by cutting production and spending on commodities. The result is a negative codependence between different inventory types. As Stock and Watson (2002) point out, the ratio of inventories to sales evolved differently over time for different types of inventories. For raw materials and work-in-progress it fell, for inventories of finished goods and trade it rose. A different pattern for different inventory types is also shown by Iacoviello, Schiantarelli, and Schuh (2011), saying that the change in inventories of goods is less procyclical than inventory investment in materials (inputs) and the former is comparatively more stable.

Another point that has to be considered is that in the U.S. about half of the industry output is used as input commodity for further processing, according to the tables for input-output accounts of the Bureau of Economic Analysis. This means, if the gross value added in products used as commodity and for final use is identical, the GDP consists by about 50% of goods produced that are used for other products, e.g. a gear for the construction of an automobile or ink and paper for printing a book.

Although the early contribution of Blinder (1981), amongst others, highlights many facts about inventory holding, only few studies have taken up this issue so far. Modern business cycle models leave aside changes in inventories, treating inventory adjustment as a part of investment in the aggregate capital stock. Remarkably, recent papers on investment shocks such as Justiniano, Primiceri, and Tambalotti (2011) and Khan and Tsoukalas (2011) are silent about inventories. With regard to research on business cycles and inventories, a first attempt is made by Christiano (1988) and Bils and Kahn (2000) who use real business cycle models. From a New Keynesian perspective Kryvtsov and Midrigan (2010) and Jung and Yun (2005) approach the inventory subject although with a narrow focus on monetary policy only. Furthermore, in a model with inventories Lubik and Teo (2009) conduct research on optimal monetary policy. Chang, Hornstein, and Sarte (2009) consider inventory holding in their investigation, trying to overcome the negative response of employment to productivity shocks when firms can exploit favorable labor costs and store labor services in terms of inventories. Lubik and Teo (2012) as well as Jung and Yun (2013) investigate empirically the New Keynesian Phillips Curve when inventory holding is considered.[2] The recent studies of Wen (2011) and Iacoviello, Schiantarelli, and Schuh (2011) present business cycle models with the distinction of input and output inventories. Their models can reproduce stylized facts and, for the latter, can fit the data reasonable well.

We contribute to the existing literature by developing a New Keynesian model with optimizing households, inventory holding firms, and a governmental sector, where we investigate the differences between the Great Moderation period and the previous episode. As in Bils and Kahn (2000), inventories are motivated by supply shortages and matching motives. While a higher stock of available goods relative to the average yields advantages to the representative firm over competitors in terms of additional demand, inventories are accompanied by dynamic costs of inventory holding. Thus, the inventory holding firm faces a trade-off. Furthermore, we extend the model in Förster (2014) and distinguish between finished goods and materials further processed during the production process of the finished good. The model allows to analyze the behavior of key macroeconomic variables sales, output and inventories with the distinction between finished products and work-in-process goods.

Similar to Iacoviello, Schiantarelli, and Schuh (2011) and Förster (2014) our dynamic stochastic general equilibrium model belongs to the class of inventory models that are successfully estimated using Bayesian techniques. We determine the distributions of the parameters for U.S. time series which we use for further analysis. With the obtained response functions and variance decompositions we analyze the shocks' impacts and propagation mechanisms as well as their contribution to the volatility in the macroeconomic series. In a next step, we perform counterfactual experiments in order to reveal the underlying changes that could have brought about the Great Moderation episode.

We proceed as follows. An overview of possible explanations for the causes of the Great Moderation can be found in Section 2. Section 3 presents our model with different types of

[2] Studies not so closely related to our exercise but mentionable are the works of Wen (2005), who analyze various theories in inventory modelling, and Teo (2011), who extends the research in Lubik and Teo (2009) to an open economy setup.

inventories in a New Keynesian model with several frictions. In Section 4 we describe our data and the estimation procedure. Section 5 shows the results. In Section 6 counterfactual experiments are performed. Section 7 concludes.

2 On the Causes of the Great Moderation

The breakdown of the volatility of macroeconomic variables such as GDP and Inflation since the 1980s has led to a diversified discussion of the underlying mechanisms. The debate, albeit several papers investigated this phenomenon, is still ongoing and the progress in economic tools and computation in recent years has not resulted in a convergence about what could have caused this shift. So far, improved inventory management of firms, better monetary policy, and simply good luck were the most popular reasons suggested for the so-called Great Moderation.

The *inventory management hypothesis* states that improvements in inventory adjustment and better reaction to final sales mainly caused the Great Moderation. As Kahn, McConnell, and Perez-Quiros (2002) note, the use of advanced information technology helps monitoring sales and adjustment in production, resulting in a smoother production with lower risk of oversupply and shortage. Just-in-time inventory management contributed to the decline in the inventories-sales ratio since the 1980s, causing lower inventory holding costs on average (Kahn (2008)).

So far, several authors are rather sceptical with regard to the *inventory management hypothesis*. Theoretical studies as conducted by Khan and Thomas (2007) do not find a strong role of inventories in the Great Moderation. This is supported by McMahon (2012), while Wen (2011) finds that better inventory management would even counteract macroeconomic volatility. Stock and Watson (2002) mention that the inventories-sales ratios fell only for inventories other than finished goods and for production there is large heterogeneity across different sectors. Thus inventory management in general is not able to explain the Great Moderation. Empirical studies are slighty more affirmative than their theoretical counterparts: Iacoviello, Schiantarelli, and Schuh (2011) and McCarthy and Zakrajsek (2007) find a supporting role of inventory behavior to the decline of macroeconomic fluctuations, although the effect is small.

A wide range of literature proposes that improvements in policy-making, especially regarding monetary policy, are responsible for the Great Moderation. The so-called *good policy hypothesis* attributes a large fraction of the decline in macroeconomic volatility to a stronger reaction of the nominal interest rate to inflation movements and, simultaneously, a better anchoring of inflation expectations.[3] Recent research rather admits that better policy per se had a significant impact on the standard deviations of macroeconomic key variables. Just to mention a few, Boivin and Giannoni (2006) and Benati and Surico (2009) belong to these proponents. Another study was conducted by Nakov and Pescatori (2010) who came to the conclusion that both, good policy and smaller shocks in general caused the Great Moderation. Incorporating an oil sector on the production side, Herrera and Pesavento (2009) find that monetary policy had no effect on the volatility changes that coincide with the Volcker-Greenspan period.

A less pleasing explanation for the Great Moderation, as it means that we are more vulnerable to exogenous events, is the *good luck hypothesis*.[4] As the argument goes, due to a stroke of good fortune we observed smaller shocks across the entire economy, or at least the composition and simultaneous appearance of different structural shocks resulted in a decline in aggregate volatility. Between economists the consensus exists that the change in shock sizes before about 1980 and afterwards definitely did not increase the fluctuations of macroeconomic variables. Studies that highlight that good luck is the main reason behind the Great Moderation are Smets and Wouters (2007) and Kim, Morley, and Piger (2008), for example. The results of Ahmed, Levin, and Wilson (2004) are more differentiated, they find good luck to explain the developments in GDP movements, but attribute the lower standard deviation of CPI to good policy.

Summing up, researchers do not agree on the causes of the Great Moderation yet. As it is often in real life, there seems to be no single cause. Our investigation aims at providing an analysis that allows to take the mentioned hypothesis into consideration, i.e. introducing inventory management besides good policy and good luck, in a structural model that is estimated and empirically validated.

3 The Model

We present a standard New Keynesian model in the spirit of Smets and Wouters (2003) and Christiano, Eichenbaum, and Evans (2005) with several rigidities, enriched with inventory holding by firms. Besides the stock of finished inventory goods, we distinguish between the quantities of output, sales and the stock of available goods. As done in Jung and Yun (2005)

[3] This comes at the "cost" for monetary policy of lower priority for output deviations, e.g. the output gap. As the standard New Keynesian model predicts, stabilizing inflation results in a stabilized output. Not considered in structural models is the better communication to the public and the stronger independence of central banks from the government and fiscal policy since the 1980s.

[4] Saying it more positively, we benefitted from structural (micro- and macroeconomic) developments during the last 65 years that are not captured by our models yet. Future research will fill this gap, hopefully.

and Lubik and Teo (2009), inventories are modeled on the basis of Bils and Kahn (2000). Demand can be satisfied either by current production or by the stock of goods previously produced. As in Förster (2014), the stock of inventories is stored in storage areas that firms must rent from households.

The household and government sector are standard. Price and wage setting are subject to adjustment cost à la Rotemberg (1982). Apart from the Rotemberg adjustment mechanism and inventory holding, our model is similar to the one in Justiniano, Primiceri, and Tambalotti (2010). Below we present the economic agents and describe their behavior in detail.

3.1 Final Good Firms

Final good firms sell the final good under perfect competition. It is produced using differentiated finished intermediate goods according to the Dixit-Stiglitz technology

$$s_t^g = \left[\int_0^1 \left(\frac{a_{i,t}^g}{a_t^g} \right)^{\theta_g \frac{\mu_t^p}{1+\mu_t^p}} \left(\frac{a_{i,t}^m}{a_t^m} \right)^{\theta_m \frac{\mu_t^p}{1+\mu_t^p}} \left(s_{i,t}^g \right)^{\frac{1}{1+\mu_t^p}} \mathrm{d}i \right]^{1+\mu_t^p} . \tag{1}$$

Here, the variables s_t^g and $s_{i,t}^g$ denote aggregate sales and sales of intermediate good i, respectively. We denote the economy-wide stock of available completed goods by a_t^g and its intermediate good firm-specific quantity by $a_{i,t}^g$. In addition, $a_{i,t}^m$ is the amount of materials available of intermediate good firm i and a_t^m is the entire stock of available materials in the economy.

Cost minimization implies that the demand for each intermediate good is

$$s_{i,t}^g = \left(\frac{p_{i,t}}{p_t} \right)^{-\frac{1+\mu_t^p}{\mu_t^p}} \left(\frac{a_{i,t}^g}{a_t^g} \right)^{\theta_g} \left(\frac{a_{i,t}^m}{a_t^m} \right)^{\theta_m} s_t^g , \tag{2}$$

where θ_g and θ_m are the demand elasticities of completed intermediate good i with respect to the firm-specific stock of available finished goods and materials in period t. Both θ_g and θ_m are assumed to be positive: final good firms prefer goods of intermediate firms that have a higher amount of goods on hand. As a result, stockouts occur more infrequently and the probability of a loss in production due to shortages is lower, i.e. a higher stock of available goods decreases the risk of stockouts. Moreover, as argued by Bils and Kahn (2000) and Lubik and Teo (2012), one can think of a variety of goods that are bundled in intermediate good i. Then, a higher stock of available goods increases the likelihood of matching specific demand

and supply on the market. We follow Justiniano and Primiceri (2008) and assume that the price markup over the differentiated intermediate good, μ_t^p, is autocorrelated of order one and driven by an exogenous force η_t^p which is IID, formally

$$\log \mu_t^p = (1-\rho_p) \log \mu^p + \rho_p \log \mu_{t-1}^p + \eta_t^p \,. \tag{3}$$

The aggregate price index in the economy is defined as

$$p_t = \left[\int_0^1 \left(\frac{a_{i,t}^g}{a_t^g} \right)^{\theta_g} \left(\frac{a_{i,t}^m}{a_t^m} \right)^{\theta_m} (p_{i,t})^{-\frac{1}{\mu_t^p}} \, \mathrm{d}i \right]^{-\mu_t^p} \,. \tag{4}$$

3.2 Intermediate Good Firms

In the economy there exists a continuum of intermediate good firms indexed by $i \in [0,1]$. Each firm produces a specific type of intermediate good. As a result, in the intermediate good market firms sell their goods under monopolistic competition. Furthermore, the production of each product is splitted into two parts. First, materials (indexed by m) are build using a linear transformation. Based on Cobb-Douglas technology, materials are processed into completed goods (indexed by g) ready for sale. Both types of goods can be stored and processed (materials) or sold (completed goods) later conditional to economic conditions. Subject to dynamic costs of inventory holding, the intermediate good firm optimizes production and storage given prices.

The representative intermediate good firm uses capital services $k_{i,t-1}$ rented from households for the production of materials $y_{i,t}^m$ via the linear technology

$$y_{i,t}^m = k_{i,t-1} \,. \tag{5}$$

Completed goods are produced with the help of labor services $l_{i,t}$ and the addition of materials. We denote by $s_{i,t}^m$ the amount of incomplete goods that are processed to finished goods within period t. The production function for the completed goods $y_{i,t}^g$ is

$$y_{i,t}^g = \left(s_{i,t}^m\right)^{\alpha} \left(z_t l_{i,t}\right)^{1-\alpha} \,, \tag{6}$$

where the variable z_t measures the economy-wide level of labor-augmenting technological progress. We denote its gross growth rate by $v_t \equiv z_t / z_{t-1}$ and assume that the stochastic growth rate of technological progress evolves according to

$$\log v_t = (1 - \rho_v) \log v + \rho_v \log v_{t-1} + \eta_t^v , \tag{7}$$

where η_t^v are IID innovations. Here and henceforth, variables without subscript indicate steady state values of the corresponding variables. Furthermore, we assume that the number of firms is constant over time.

The stock of available goods for sale and goods for further processing, $a_{i,t}$, consists of current production plus the end-of-period stock of inventories at the end of last period, $x_{i,t-1}$, so that we get

$$a^m_{i,t} = y^m_{i,t} + (a^m_{i,t-1} - s^m_{i,t-1}) , \tag{8}$$

$$a^g_{i,t} = y^g_{i,t} + (a^g_{i,t-1} - s^g_{i,t-1}) . \tag{9}$$

Note that the inventory stock equals the unsold and unprocessed stock of available goods for the stock of inventories of uncompleted and completed goods, respectively. Putting it differently, $x_{i,t} = a_{i,t} - s_{i,t}$. Thus, end-of-period inventory holding at time t equals inventories at date $t - 1$ plus the difference between production and sales within the actual period, i.e.

$$x^m_{i,t} = y^m_{i,t} - s^m_{i,t} + x^m_{i,t-1} , \tag{10}$$

$$x^g_{i,t} = y^g_{i,t} - s^g_{i,t} + x^g_{i,t-1} . \tag{11}$$

Keep in mind that both types of goods, materials and completed goods, each follow this law-of-motion. The complete stock of inventories intermediate good firm i holds at the end of period t is defined as

$$x_{i,t} = x^m_{i,t} + x^g_{i,t} . \tag{12}$$

At the end of each period intermediate firms rent storage areas, h_t, where the inventory stock is stored between two periods. Holding inventories is assumed to be costly. For every storage area the intermediate good firm pays a rental rate r^h_t to the households. We make the assumption that storage areas are related to the stock of inventories at the end of period t according to

$$h_{i,t} = \psi_m \, x^m_{i,t} + \psi_g \, x^g_{i,t} , \tag{13}$$

i.e. their relation is constant and positively linear over time since we assume that $\psi_m > 0$ and

$\psi_g > 0$. As a result, the elasticity of storage areas with respect to inventories is unity on the demand side. For the aggregate economy this is a realistic assumption that in addition simplifies the calculations. The intermediate good firm faces a trade-off: while higher production causes demand to rise according to equation (2), unsold and unprocessed goods have to be stored in costly storage areas.

The representative intermediate good firm maximizes the present value of current and future real profits

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \frac{\lambda_{t+\tau}}{\lambda_t} \Bigg\{ \frac{p_{i,t+\tau}}{p_{t+\tau}} s^g_{i,t+\tau} - w_{t+\tau} l_{i,t+\tau} - r^k_{t+\tau} k_{i,t+\tau-1} - r^h_{t+\tau-1} h_{i,t+\tau-1} - \frac{\kappa_p}{2} \left(\frac{p_{i,t+\tau}}{\pi^{\gamma_p}_{t+\tau-1} \pi^{1-\gamma_p} p_{i,t+\tau-1}} - 1 \right)^2 s^g_{t+\tau} \Bigg\}, \tag{14}$$

taking into account the demand for its specific completed good for sale in (2), the production technologies (5) and (6), the evolution of materials and finished inventories according to (12) as well as its need for storage areas for carrying the stock of inventories into next period, (13). In (14), w_t is the hourly real wage rate and r^k_t is the current rental rate of capital.

Revenues of the intermediate good firm depend on sales of completed goods $s^g_{i,t}$ and besides the costs associated with production inputs there exist inventory costs. In detail, the intermediate good firm settles the invoice for the rented storage areas that were needed in order to transfer inventory goods from the end of last period into the current period.

Price setting policy of the monopolistically competitive firm is subject to quadratic price adjustment cost à la Rotemberg (1982). These cost drop when actual inflation, defined as the gross growth rate of the economy-wide price level $\pi_t = p_t / p_{t-1}$, is equal to its steady state value. The parameters κ_p and γ_p measure the magnitude of adjustment costs and the degree of inflation persistence, respectively.

3.3 Households

A continuum of households indexed by $j \in [0, 1]$ populates the economy. They purchase consumption and investment goods and earn income by supplying labor services as well as renting capital and storage areas to intermediate firms. Furthermore, government bonds which yield an interest of r^m_t are available to households. Differentiated labor services supplied by each household to intermediate firms allow for wage setting through labor unions of which each household is a member of.

The representative household maximizes its discounted life time utility

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left[\epsilon^c_{t+\tau} \log \left(c_{t+\tau} - b c_{t+\tau-1} \right) - \frac{\left(l_{j,t+\tau} \right)^{1+\sigma_l}}{1+\sigma_l} \right] , \tag{15}$$

where c_t is the consumption good and $l_{j,t}$ denotes hours worked. We allow for internal habit formation in consumption measured by the parameter b. The choice of a logarithmic utility in consumption ensures that the steady state of the model features a balanced growth path.

Household's preferences are subject to a consumption shock ϵ^c_t which affects the marginal utility of consumption. It follows

$$\log \epsilon^c_t = \rho_c \log \epsilon^c_{t-1} + \eta^c_t , \tag{16}$$

and would take a value of unity if the IID innovations η^c_t were absent.

The intertemporal budget constraint each household has to take into account when maximizing its utility is

$$c_t + i^k_t + i^h_t + \frac{B_t}{p_t} = \frac{r^m_{t-1} B_{t-1}}{p_t} + \frac{W_{j,t}}{p_t} l_{j,t} + r^k_t u_t \bar{k}_{t-1} - a(u_t) \bar{k}_{t-1} + r^h_{t-1} h_{t-1} + div_{j,t} . \tag{17}$$

Government bonds purchased in period t, B_t, yield an interest of r^m_t to be received next period. The variable p_t denotes the aggregate price level. For every hour worked the household earns a nominal wage of $W_{j,t}$. Net flow of dividends from intermediate good firms, membership fees paid to labor unions and lump-sum taxes collected by the government are summarized in $div_{j,t}$.

Capital services k_{t-1} are defined as

$$k_{t-1} = u_t \bar{k}_{t-1} , \tag{18}$$

where u_t is the rate of capital utilization and $\bar{k}_{t-1}$ denotes the stock of physical capital at the end of period $t-1$. Renting out capital services to intermediate firms generates an income of $r^k_t u_t \bar{k}_{t-1}$. The rental rate r^k_t the household takes as given while it can decide freely about the utilization rate of capital. However, adjustment cost amounting to $a(u_t)\bar{k}_{t-1}$ occur if utilization deviates from its steady state value of unity. For the adjustment cost function we assume that $a(1) = 0$ as well as $\sigma_a = a''(1)/a'(1) > 0$ holds in steady state.

A constant fraction δ^k of the physical capital stock depreciates every period. For maintenance the household purchases capital investment goods i^k_t. Considering investment adjustment cost depending on the level of investment, i.e. $S\left(\frac{i_t^k}{i_{t-1}^k}\right)$, the end-of-period t physical stock of capital is

$$\bar{k}_t = (1-\delta^k)\bar{k}_{t-1} + \epsilon_t^k \left(1 - S\left(\frac{i_t^k}{i_{t-1}^k}\right)\right) i_t^k \,. \tag{19}$$

We assume that in steady state $S(\cdot) = S'(\cdot) = 0$ and $S''(\cdot) > 0$. The variable ϵ_t^k represents a shock to the efficiency of transforming capital investment goods into new physical capital, henceforth denoted as capital shock. It evolves according to

$$\log \epsilon_t^k = \rho_k \log \epsilon_{t-1}^k + \eta_t^k \,, \tag{20}$$

with IID innovations η_t^k.

Storage areas are treated analogously to the physical capital stock. They are lend to intermediate good firms at a rental rate of r_t^h. It provides an equilibrium in the storage area market at period t. The next quarter firms pay for the rented storage areas. Erosion of storehouses due to environmental influences and obsolescence lead to a depreciation of storage areas at a constant rate δ^h. By purchasing storage area investment goods, i_t^h, households can increase the stock of storage areas. The law of motion of storage areas is described by

$$h_t = (1-\delta^h)h_{t-1} + \epsilon_t^h \left(1 - S\left(\frac{i_t^h}{i_{t-1}^h}\right)\right) i_t^h \,, \tag{21}$$

where ϵ_t^h is a shock affecting the transformation of storage area investment goods into new and rebuilt storage areas. We assume that the log of the shock is autocorrelated of order one and is driven by exogenous IID disturbances η_t^h so that

$$\log \epsilon_t^h = \rho_h \log \epsilon_{t-1}^h + \eta_t^h \,. \tag{22}$$

The storage area investment shock captures unexplained fluctuations in the costs of inventory holding. In light of a positive shock the supply of storage area increases and thus the rental rate is lower than in an equilibrium where we do not observe shocks to storage area investment. As a result, for the firm sector the cost per unit of stored goods decrease.

3.4 Labor Unions

Cost minimization by intermediate good firms yields that the demand for a specific type of labor is

$$l_{j,t} = \left(\frac{W_{j,t}}{W_t}\right)^{-\frac{1+\mu_t^w}{\mu_t^w}} l_t\,, \tag{23}$$

where l_t is aggregate hours worked. The underlying composition of the aggregate variable by the households' differentiated labor services are given by the Dixit-Stiglitz function

$$l_t = \left[\int_0^1 \left(l_{j,t}\right)^{\frac{1}{1+\mu_t^w}} \,\mathrm{d}j\right]^{1+\mu_t^w}. \tag{24}$$

The aggregate nominal wage rate W_t is defined as

$$W_t = \left[\int_0^1 \left(W_{j,t}\right)^{-\frac{1}{\mu_t^w}} \,\mathrm{d}j\right]^{-\mu_t^w}. \tag{25}$$

For each household there exists a labor union which sets the nominal wage rate in a monopolistic manner due to specialized labor services. Labor unions minimize the disutility over work for its members and take account of the demand for differentiated labor in (23). When setting the wage quadratic adjustment cost to be financed by membership fees arise. The size depends on the ratio between nominal wage growth and inflation as well as technological progress. Being acquainted with household's utility and its budget constraint the representative labor union optimizes (leaving out irrelevant parts)

$$\begin{aligned} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \Bigg\{ & -\frac{\left(l_{j,t+\tau}\right)^{1+\sigma_l}}{1+\sigma_l} \\ +\lambda_{t+\tau} & \left[\frac{W_{j,t+\tau}}{p_{t+\tau}} l_{j,t+\tau} - \frac{\kappa_w}{2} \left(\frac{W_{j,t+\tau}}{\left(\pi_{t+\tau-1} v_{t+\tau-1}\right)^{\gamma_w} \left(\pi v\right)^{1-\gamma_w} W_{j,t+\tau-1}} - 1 \right)^2 \frac{W_{t+\tau}}{p_{t+\tau}} l_{t+\tau} \right] \Bigg\} \end{aligned} \tag{26}$$

and considers that the demand for the differentiated labor service is given by (23). The parameters κ_w and γ_w measure the degree of adjustment cost in the nominal wage rate and partial indexation to past inflation and technology growth, respectively. In (26), λ_t is the Lagrange multiplier associated with the budget constraint in the household's optimization problem and equals the marginal utility of consumption.

In the optimum wages and the amount of hours worked satisfy

$$
\begin{aligned}
&(1+\mu_t^w)\left(l_{j,t}\right)^{1+\sigma_l} + E_t \frac{\mu_t^w \beta \kappa_w \lambda_{t+1} W_{j,t+1}}{(\pi_t v_t)^{\gamma_w} (\pi v)^{1-\gamma_w} W_{j,t}} \left(\frac{W_{j,t+1}}{(\pi_t v_t)^{\gamma_w} (\pi v)^{1-\gamma_w} W_{j,t}} - 1 \right) \frac{W_{t+1}}{p_{t+1}} l_{t+1} \\
&= \lambda_t \frac{W_{j,t}}{p_t} l_{j,t} + \frac{\mu_t^w \kappa_w \lambda_t W_{j,t}}{(\pi_{t-1} v_{t-1})^{\gamma_w} (\pi v)^{1-\gamma_w} W_{j,t-1}} \left(\frac{W_{j,t}}{(\pi_{t-1} v_{t-1})^{\gamma_w} (\pi v)^{1-\gamma_w} W_{j,t-1}} - 1 \right) \frac{W_t}{p_t} l_t \, . \quad (27)
\end{aligned}
$$

With fully flexible wages ($\kappa_w = 0$), the real hourly wage rate would be a markup over the ratio of marginal disutility of work to marginal utility of consumption. We assume that the wage markup, μ_t^w, follows

$$
\log \mu_t^w = (1-\rho_w) \log \mu^w + \rho_w \log \mu_{t-1}^w + \eta_t^w \, , \quad (28)
$$

where η_t^w is the exogenous driving force with IID normal distribution.

3.5 Government and Market Clearing

Monetary Policy is described by the generalized Taylor rule

$$
\frac{r_t^m}{r^m} = \left(\frac{r_{t-1}^m}{r^m} \right)^{\rho_m} \left[\left(\frac{\pi_{t-1}}{\pi} \right)^{\phi_\pi} \left(\frac{y_{t-1}}{z_{t-1} y^*} \right)^{\phi_y} \right]^{1-\rho_m} \left(\frac{\pi_t}{\pi_{t-1}} \right)^{\phi_{\Delta\pi}} \left(\frac{y_t}{v_t y_{t-1}} \right)^{\phi_{\Delta y}} e^{\eta_t^r} \, , \quad (29)
$$

where y_t^* is stationary output obtained by scaling real output by the level of technology. Deviations of the nominal interest rate r_t^m from the Taylor rule are attributed to a monetary policy shock η_t^r assumed to be IID, i.e. we do not take into consideration that the monetary authority departs systematically from its formulated interest rate rule.

The economy's aggregate resource constraint is

$$
\begin{aligned}
s_t^g = {} & c_t + i_t^k + i_t^h + g_t + a(u_t) \bar{k}_{t-1} \\
& + \frac{\kappa_w}{2} \left(\frac{w_t \pi_t}{(\pi_{t-1} v_{t-1})^{\gamma_w} (\pi v)^{1-\gamma_w} w_{t-1}} - 1 \right)^2 w_t l_t + \frac{\kappa_p}{2} \left(\frac{\pi_t}{\pi_{t-1}^{\gamma_p} \pi^{1-\gamma_p}} - 1 \right)^2 s_t^g \, . \quad (30)
\end{aligned}
$$

We assume that government spending $g_t = \epsilon_t^s$ is an exogenous stochastic process that captures deviations from long-run averages for public spending and the current account. It follows the law of motion

$$
\log \epsilon_t^s = (1-\rho_s) \log \epsilon^s + \rho_s \log \epsilon_{t-1}^s + \eta_t^s \, , \quad (31)
$$

with IID normal innovations η_t^s.

Gross domestic product y_t in the economy equals the sum of value added by produced materials and completed goods less consumed uncompleted goods used for the production of the finished product

$$y_t = y_t^g - s_t^m + y_t^m \,, \tag{32}$$

$$y_t = y_t^{va,g} + y_t^{va,m} \,. \tag{33}$$

The aggregate resource constraint therefore can be rewritten as

$$\begin{aligned} y_t = c_t + i_t^k + i_t^h + g_t + (x_t^m - x_{t-1}^m) + (x_t^g - x_{t-1}^g) + a(u_t)\bar{k}_{t-1} \\ + \frac{\kappa_w}{2}\left(\frac{w_t \pi_t}{(\pi_{t-1} v_{t-1})^{\gamma_w} (\pi v)^{1-\gamma_w} w_{t-1}} - 1\right)^2 w_t l_t + \frac{\kappa_p}{2}\left(\frac{\pi_t}{\pi_{t-1}^{\gamma_p} \pi^{1-\gamma_p}} - 1\right)^2 s_t^g \,, \end{aligned} \tag{34}$$

when we use the law of motion for the aggregate inventory stocks as defined in (10) and (11). Thus, gross domestic product on the expenditure side is the sum of consumption, investments (including the change in inventories), governmental spending and cost associated with economic frictions.

Henceforth, we name the sum of investments in newly installed physical capital and storage areas as fixed investment i_t^f,

$$i_t^f = i_t^k + i_t^h \,. \tag{35}$$

Furthermore, gross investment i_t^t in the economy consists of fixed investment plus the changes in inventories, i.e.

$$i_t^t = i_t^f + (x_t^m - x_{t-1}^m) + (x_t^g - x_{t-1}^g) = i_t^f + (x_t - x_{t-1}) \,, \tag{36}$$

when $x_t = x_t^m + x_t^g$. Therefore, our model allows us to divide the investment series into (relatively stable) fixed investment and (relatively volatile) changes in inventories, both time series are published in national account data for the U.S. economy on which we estimate our model.

We re-scale the model's quantity variables by the level of economy-wide labor-augmenting technological progress to obtain the stationary counterparts. The equations describing the economy's equilibrium are then log-linearized around the non-stochastic balanced growth path.[5]

[5] The log-linearized equations are not reported here to save space.

4 Estimation

4.1 Data

For the estimation we use quarterly U.S. data on real consumption of non-durable goods and services (*PCND* plus *PCESV*), real fixed private investment (*FPI*), real compensation per hour (*COMPNFB*), obtained by dividing nominal terms by the GDP deflator. The GDP deflator is derived by dividing nominal GDP (*GDP*) by real GDP (*GDPC96*). We assign expenditures for durable consumption goods (*PCDG*) to private investment expenditures. Furthermore, we use observations on real GDP (*GDPC96*), the federal funds rate (*FEDFUNDS*) and hours worked in the nonfarm business sector (*HOANBS*) to estimate our model. Note that we normalize the hours worked series such that its logarithmic sample average is zero. All time series are provided by the FRED Database.

From the National Income and Product Account table 5.7.6 of the Bureau of Economic Analysis we take the time series "real private inventories: nonfarm industries". If appropiate, the mentioned time series are transformed into per capita terms by employing data on civilian noninstitutional population aged over 16 (*CPN16OV*) from FRED. Except for the nominal interest rate and hours worked, we use quarterly logarithmic growth rates for the estimation of the parameters. Our sample ranges from the first quarter of 1957 until the last quarter of 2006, excluding the recent history of strong reactions of our time series during and after the global financial crisis.[6] Similar to Iacoviello, Schiantarelli, and Schuh (2011), Gambetti and Galí (2009) and Giannone, Lenza, and Reichlin (2008), we divide the time series into two subperiods: the first comprises 108 observations and covers the time interval from 1957Q1 to 1983Q4 when most macroeconomic variables were subject to strong distortions. The second period runs from 1984Q1 to 2006Q4 (92 observations), where most industrialized economys evolved more constantly and less volatile than under the former Bretton Woods system and the inflationary and recessive phase afterwards around 1980.[7]

4.2 Bayesian Estimation

We estimate the distribution of the model parameters using a Bayesian approach similar to Smets and Wouters (2003) and Justiniano, Primiceri, and Tambalotti (2011). The likelihood

[6] We do not consider the recent period of the financial crisis and the large economic downturn because of non-linearities of the nominal interest rate near the zero lower bound and the absence of a financial sector in our model.

[7] This choice of sample split is also supported by findings of Stock and Watson (2002) who reveal a break between 1983Q2 and 1987 and choose 1984 as the start for the Great Moderation sample in their VAR estimation.

function and the prior distribution form the posterior distribution.[8] The prior distributions are build upon results of various micro- and macroeconomic studies and are described in more detail below.

Maximization of the posterior regarding the parameter results in obtaining the posterior mode. It is also the starting point for the Random-Walk Metropolis-Hastings algorithm that walks the area around the posterior mode to generate the distribution of the parameters given the data and the model.

We take two different starting values around the posterior mode and let the Random-Walk Metropolis-Hastings algorithm do 200,000 iterations in each of the two separate chains. The first 75,000 iterations are disregarded and of the remaining overall 250,000 candidates we retain every 25th draw. Thus, we end up with 10,000 draws to perform the analysis. Model-based standard deviations are obtained by simulating artificial time series 100 times for each of the 500 parameter draws, i.e. taking every 20th draw from the total of 10,000 retained draws (see Justiniano, Primiceri, and Tambalotti (2010)). The length of the time series equals the corresponding subsample plus 100 observations. In each sequence we drop the first 100 observations and then compute the standard deviations.

Several parameters are set to certain values and will not be estimated. Both the physical capital stock and storage areas are assumed to depreciate at an annual rate of 10%, i.e. $\delta^k = \delta^h = 0.025$. The steady state markup over wages, μ^w, is set to 0.25.[9] According to our data we set the long-run ratios of consumption to output to 0.56, the one of fixed private investment to output to 0.24, the ratio of total private investment to output equals 0.25 and the ratio of governmental spending to output is 0.20.

We set the steady state ratio of the value added of unfinished goods (materials) to GDP to 0.42 using the input-output tables provided by the U.S. Bureau of Economic Analysis. We do so by assuming that the average value added by any industry is the same among produced goods used as intermediate commodity and produced goods for final sale. The ratios of materials inventories and completed goods inventories to GDP are set to 0.36 and 0.30, respectively. Thus total inventories to GDP is 0.66. For the manufacturing sector we employ data from the U.S. Census Bureau on inventories of finished goods, work in process as well as materials and supplies. For the other categories, namely wholesale trade, retail trade and mining, utilities, construction, the share of materials (and work-in-process) and finished

[8] The likelihood function is evaluated via the Kalman filter in order to calculate the unobserved state variables.

[9] Our parameterization requires that either the steady state wage markup or the wage adjustment cost parameter must be fixed during estimation in order to have identified parameters.

goods in the inventory stock is oriented towards the industries' ratio of its entire commodity output to its overall industry output.[10]

In Table 2 and Table 3 we present the prior distributions for the parameters to be estimated. Our assumptions are standard and follow the literature on business cycle research, i.e. mainly Smets and Wouters (2007), Adolfson, Laseen, Linde, and Villani (2007), and Justiniano, Primiceri, and Tambalotti (2010). For the demand elasticity with respect to the stock of goods, θ, we apply a beta distribution with values between 0 and 1 as prior.

4.3 Posteriors

Table 2 and Table 3 show the posterior distribution of the structural parameters and those belonging to the shock processes, respectively, for the two subsamples. Several results are worth mentioning.

It is surprising that inflation in the recent period is estimated somewhat higher, not lower, than in the first sample. The inverse Frisch elasticity is estimated significantly higher since the beginning of the Great Moderation, meaning that households do not change their supply of labor as easily as before 1984. Inventory holding is less effective in facilitating sales since the start of the Great Moderation: both elasticity parameters shrink to half their values when compared to the subsample 57-83. Interestingly, cost associated with capital services are estimated slightly lower in the Pre-Great Moderation sample, presumably to make the model match the decline in volatility in the data. Another important point to note is that price adjustment cost increased over time while wage adjustment cost shrunk significantly. Whether this phenomenon, i.e. overall higher costs except for wage adjustments, is crucial for the decline in macroeconomic volatility is investigated in Section 6. Monetary policy nowadays smoothes more the path of the nominal interest rate with a more hawkish reaction to inflation. Note that even during the Pre-Great Moderation phase the Taylor principle, i.e. a reaction of the interest rate higher than the inflation change, is clearly met.

The persistence of the shock processes is stable over time. A difference can only be observed for the consumption shock that lasts longer since 1984 than revealed in the older subsample. Remarkably, in sum the size of the innovations is significantly lower since the beginning of the Great Moderation. However, this statement does not hold for shocks to wage markups and consumption which increased substantially and remain constant, respectively, in the recent period in comparison to the Pre-Great Moderation sample.

[10]Precisely, the ratio of materials inventories to total inventories is set to 0.81 for the manufacturing sector, 0.45 for wholesale trade, 0.1 for retail, 0.51 in mining, utilities, construction, and 0.6 for other categories.

For the parameters we could substitute using the steady state conditions the ones related to inventory holding are of further interest. The storage areas needed to store goods and materials, i.e. ψ_m and ψ_g, declined from 2.55 (subsample 57-83) to 1.41 (subsample 84-06) and from 2.93 to 1.51, respectively. Thus, this is consistent with the hypothesis that inventory management has been improved such that storage room per unit of goods and materials decreased or, more likely, the duration of inventories fell.

5 Results

5.1 Second Moments

The volatility for selected variables is displayed in Table 1. As our measure for volatility we employ the standard deviations of macroeconomic key variables and evaluate the performance of the model in the two subsamples. Overall, the model is able to reproduce the volatility in the data. Especially for the Pre-Great Moderation sample the model performs fairly well in terms of replicating the empirical standard deviations. Nevertheless, the model slightly overestimates the fluctuations in GDP, investment and consumption. Remarkably, with the chosen inventory mechanism our model is able to match the larger volatility in gross investment compared to fixed investment.

The model captures the decline in macroeconomic volatility since the mid 80s quite well, although it underestimates a little bit the gain in stability. Our model produces a higher standard deviation of the real wage growth rate in the second sample in comparison to the older sample, but has difficulties to create this result for hours worked as shown in the data. The model with oil in Nakov and Pescatori (2010) performes slighty better in terms of second moments matching during the Great Moderation phase, while our model with inventories seems to have advantages in mimicking the older subperiod, especially GDP growth. Summing up, considering the hard job DSGE models seem to have with the reproduction of empirical standard deviations in a subsample analysis, see e.g. Smets and Wouters (2007) and Iacoviello, Schiantarelli, and Schuh (2011), we conclude that our inventory model does quite a good job in terms of replicating the change in volatility since the 1950s.

5.2 Impulse Responses

The reader finds the plots showing the reaction of selected variables to different shocks in Figure 1 to Figure 6. This analysis serves as a tool for the disclosure of the transmission process of shocks on the economy due to specific parameter values. As we showed before, the estimated parameter differ across subsamples, likely implying a change in the response of variables to shocks.

The response to a shock to the growth rate of technological progress is presented in Figure 1. The results are consistent to results found by Smets and Wouters (2007) and Gertler, Sala, and Trigari (2008), regardless of the subperiod considered.[11] Remarkably, for a technology shock of one standard size the responses of the variables are less pronounced in the Great Moderation period than in the older sample, especially for GDP, sales, inventories and investments. Note that GDP and sales as well as goods and materials production behave differently. Hours worked for both subperiods show the same reaction during the first year, i.e. a fall in hours worked with a hereinafter rise above steady state, as in Smets and Wouters (2007). As a result, we cannot confirm the findings of Gambetti and Galí (2009) who suggest a stronger decline in work activity during 1957-1983 than in the later sample.

Looking at the impulse responses of a price markup shock in Figure 2 we see a slighty stronger effect on sales than on GDP, both exceeding the values published in Smets and Wouters (2005). After 2.5 years we observe that most of the variables are significantly closer to their steady state values during the subperiod with lower volatility. While the rise in inventories is more explicit before 1984, for gross investment this means that the fall in fixed investment is partly compensated by inventory investment. Thus, gross investment reacts significantly weaker to a rise in the price markup during the fist phase of our sample. Note the different responses in terms of magnitudes of the different investment types across the entire sample.

Next we turn to Figure 3 and examine the effect of a wage markup shock. Due to the rise in wages, which has become significantly stronger for short-term deviations from steady state over time, production of goods falls as marginal cost increase. Materials production also falls but shows a different pattern. Although the higher wage markup has a higher impact on the real wage since the Great Moderation, inflation and the nominal interest rate exhibit a less pronounced reaction since 1984. The fall in hours worked is stable over time and fits values found by Smets and Wouters (2007) over the complete sample. In addition, investment measures are similar across types and subperiods.

Shocks to capital investment, shown in Figure 4, had a significantly larger impact on GDP, sales and production before the Great Moderation. On the labor market we obtain similar

[11]It must be mentioned that Gertler, Sala, and Trigari (2008) find a noticeably stronger reaction of output, investment and real wages for a standard shock to technology.

results to Gertler, Sala, and Trigari (2008) and Justiniano, Primiceri, and Tambalotti (2010), with a substantially lower adjustment of hours worked in the first year since the Great Moderation started. All kinds of investments are significantly higher during 1957-83, especially for capital investment we observe a quite strong reaction. Note that the magnitude of the reaction of gross investment with inventories is substantially lower than the ones revealed by Gertler, Sala, and Trigari (2008) and Justiniano, Primiceri, and Tambalotti (2010). Nevertheless, inflation reacts stronger within the first quarters after the shock for the subperiod 1984-2006.

In the Great Moderation sample private consumption shocks have a stronger permanent effect on production, sales, and GDP, see Figure 5. Aggregate inventories were more stable in the Pre-Great Moderation phase. The nominal interest rate stays longer above its steady state value, as inflation does, but both deviate substantially smaller than Smets and Wouters (2005) point out. Our results contradict Boivin and Giannoni (2006) who revealed a lower effect of demand shocks during the Great Moderation. Interestingly, we obtain a tiny decline in real wages after a shock, where Smets and Wouters (2005) find a small increase, but for hours worked the results are similar. Gross investment declines more than capital investment regardless the subsample, and the estimates for both subperiods suggest that all investment categories suffer much more from consumption shocks in the recent period.

In Figure 6 the impulse responses to a monetary policy shock are drawn. As Boivin and Giannoni (2006), we find lower inflation and nominal interest rate movements in the recent subsample. Furthermore, we confirm the findings in Boivin and Giannoni (2006) and Herrera and Pesavento (2009), i.e. the lower reaction of GDP since the beginning of the Great Moderation. Looking at the plot we see that all variables exhibit lower volatility in the second period in comparison to the Pre-Great Moderation sample. Only for the real wage we see an insignificant rise in the reaction to interest rate shocks, the size being equivalent to values found in Gertler, Sala, and Trigari (2008) and Smets and Wouters (2005). In contrast to both studies, the investment types do not fall approximately that much according to our model, thus implying more stable investment with inventories given unexpected interest rate shifts. A main reason for the decline in volatility is that the median value of the standard shock fell from 0.34 to 0.12 over time. Regarding inventories, we are not able to match the results in Kryvtsov and Midrigan (2010).

5.3 Variance Decompositions

The contribution of the shocks to the forecast error variance of selected variables are shown in Table 4 to Table 6, i.e. for a given time period we calculate the share of variance a specific one-time shock of unit size has on a variable of interest. This way we can investigate what shocks are responsible for the macroeconomic volatility presented in Subsection 5.1.

Similar to Smets and Wouters (2005) and Smets and Wouters (2007), in the medium- to long-term GDP and sales are most sensitive to shocks to wage markups and, as in Nakov and Pescatori (2010), technological progress. While Justiniano, Primiceri, and Tambalotti (2010) found capital investment shocks to be important over business cycle frequencies, we reveal that capital investment shocks account for movements in GDP only in the short-run. Moreover, GDP is substantially influenced by inventory cost shocks only in the very short-run. We do not find any role for public spending, as suggested by Smets and Wouters (2005) and Smets and Wouters (2007). Our statements are time robust, i.e. hold regardless the subsample considered. Moreover, production also is not affected differently over time, only for materials the sensivity to technology shocks has increased lately while price markup shocks are now responsible for a larger share of the long-run forecast error.

For the ratio of inventories to GDP, the most important shock in the short-run are shocks to the efficiency of capital investment. Its importance slightly declines over time. In the medium and long-run storage holding cost shocks are the major source of fluctuations in the inventories-GDP ratio. During the subsample 1957-83, price markup shocks explained a large fraction of the variance in the long-run. In the Great Moderation period this changes and cost shocks to inventory holding are the most dominant shocks. Looking at Table 5 it is obvious that this shock explains by far most of the movements in inventories. As for the ratio of inventories to GDP, both types of inventories have become under less pressure due to price markup shocks over time. Instead, wage markup shocks and to some degree consumption shocks are more important for the volatility in inventories in the medium- to long-run in the second subsample. Note that according to our model GDP and inventories mainly are pushed by different sets of shocks.

Turning to the inflation rate, markup shocks are responsible for more than 80% of its forecast error variance. This is congruent with the results of Smets and Wouters (2007) and Justiniano, Primiceri, and Tambalotti (2010), but differs from Smets and Wouters (2005) where price markups contribute substantially to inflation movements. While Nakov and Pescatori (2010) find monetary policy to explain more of the volatility in inflation during the Great Moderation than before, we do not. Moreover, we are not able to confirm that preference shocks force the interest rate to move, as do Nakov and Pescatori (2010), but markup shocks do. Consequently, markup shocks let the nominal interest rate deviate at most. Again we contradict Justiniano, Primiceri, and Tambalotti (2010) with a significantly lower influence of capital shocks. Our results are similar to Smets and Wouters (2007), with the exception that the price markup shock is estimated to have a larger influence on interest rate deviations here. Shocks to the Taylor rule important, especially for shorter time horizons, but price markup and monetary shocks contribute slightly less since 1984 than they did in the earlier subsample. In recent years shocks to capital investment and wage markups gained influence.

For the different types of investment we observe a stable susceptibility over the entire sample. Only for capital investment in the medium/long time horizon, comparing the second half of the sample to the Pre-Great Moderation phase, a shift from price markup shocks to wage markup shocks and technology shocks can be observed. Note that storage area investment shocks matter solely for gross investment in the very short-run and the effect of capital investment shocks decreases the broader the specific investment measure is defined.

What about the labor market? During the Great Moderation, shocks to the price markup and technology growth as well as in the short-run shocks to the wage markup caused unexpected deviations of the real wage from its steady state value. That outcome underlines the one in Smets and Wouters (2005), although we assign a higher relevance to price markup shocks, similar as for the nominal interest rate. Other shocks such as the capital investment shock are irrelevant. Prior to 1984, no important role was assigned to wage markup shocks, but changing price markups had a higher short-term impact on real wages at that time. For hours worked, the sources of fluctuations do not change over time. It depends on shocks to capital investment as well as to the wage markup, with adjustments to exogenous shocks to inventory holding costs only in the very short-run.

6 Counterfactual Experiments

In this section we investigate whether better inventory management, good policy or good luck could have caused the Great Moderation. In Subsection 5.1 the standard deviations of standard macro variables were presented, where our model matched the empirical counterparts quite well. We now check what the volatility would have been when some of the parameters remained unchanged. For this purpose we perform a counterfactual exercise by substituting a subset of parameters from the older subsample for the parameter vector of the recent subsample. Here we ask the following question: would we have observed the Great Moderation if a specific group of parameters would have been the same as before 1984. Table 7 displays the results.

The volatility of GDP growth benefited from the change in structural parameters and shock processes, otherwise the standard deviation would have been much larger in the recent subsample. Both subset of parameters contributed substantially to the decline in movements of all variables displayed. An exception is the standard deviation of the growth rate of real wages. In the counterfactual exercise it would even be considerably lower than it has been estimated since 1984 if the structural parameters remained stable since 1957. Interestingly and consistent with Boivin and Giannoni (2006), the second moments of the inflation rate as well as the nominal interest rate are higher when we assume the parameters of the older subsample, this observation is independent from the parameter classification.

Overall, the most important contribution to the Great Moderation is attributed to the change in the shock processes and, significantly more, in the structural parameters. We do not find strong evidence for the *good luck hypothesis*, in contrast to Smets and Wouters (2007). In line with their findings we find that monetary policy did even slightly worse recently, according to the results. While it was able to somewhat reduce the fluctuations in the nominal interest rate and inflation, it increased the standard deviations of several key variables.

We proceed by splitting the structural parameter group into further subsets to gain more insight how the private sector contributed to the Great Moderation. Changing inventory parameters reveals that the developments in this area are almost negligible, they contributed hardly anything to the reduction in volatility.[12] Note that real wages and hours worked would have been more stable.[13] Thus, we reject the *inventory management hypothesis*. Turning to the next column, parameters capturing the rigidities in the economy are able to explain to some degree the decline in volatility. However, considering shifts in the households' parameters, i.e. concerning productive capital and labor supply, we see that a large fraction of the decrease in standard deviations can be attributed to this small number of parameters. Therefore, we conclude that a change in productive capital, i.e. investment smoothing or utilization of

[12]The results depend mainly on the parameters measuring the elasticities of final sales to available goods and available materials, θ_g and θ_m, respectively. The other parameters related to inventory holding do not substantially change our findings.

[13]Presumably smoother inventory adjustment in combination with more stable inventory holding cost as well as lower volatility of goods production cost are responsible for this result. Materials production is more volatile under this scenario, and our investigations yield that finished goods inventories remain stable while the movements of materials inventories go up, indicating that the covariance of both inventory types changes under both parameter setups. Moreover, the series processed materials is more volatile meaning that this input factor could be used to offset the marginal productivity of labor whenever needed, thus balancing labor demand intertemporally.

capital, and labor supply developments play a major role in explaining the Great Moderation. This is interesting since the cost associated with capital are estimated to be higher in the recent subsample.

The last category illustrates the fit of our model in case of no inventory holding. We leave inventories and the differentiation of sales and available goods aside and estimate the model with these assumptions where sales equal output and GDP.[14] While in the subsample 84-06 the model performs equally to the inventory model, for the period 57-83 the model with inventories is closer to the data. Considering that gross investment equals fixed investment when we abstract from inventories, the non-inventory model performs substantially worse than its counterpart. Besides the possibility to investigate inventory management as possible explanation for the Great Moderation, the better fit of our model with inventories with respect to second moments of the data justifies our approach.[15]

7 Conclusion

A New Keynesian model with inventory holding and different stages of production is used to investigate the change in volatility in macroeconomic key variables since WWII. The model allows to distinguish between goods sales, production of materials used for further processing and the production of goods for end use. In addition, both goods and materials can be stored. Thus, total production does not equal total value added since materials are processed into finished goods. Furthermore, we differentiate between different types of investment. This way we can analyze the contribution of inventory management to the Great Moderation. Using a Bayesian approach on U.S. data we estimate the parameters for two subsamples on which we build our analysis.

The results reveal that the responses to structural shocks do not remain stable between the two subsamples, more in terms of the magnitude and the persistence of the reaction than a change in the sign of the response. There exists no clear-cut pattern in terms of the relation between GDP and inventories. Neither does GDP fluctuate less given a constant reaction of inventories over the entire sample nor have both inventories and GDP become significantly less vulnerable to shocks over time (see price shocks and public spending shocks). Only for

[14] This way our model is similar to the one in Justiniano, Primiceri, and Tambalotti (2010), with the distinction of quadratic adjustment cost in prices and wages as it is done in the inventory model.

[15] Other models without inventories exist that are able to produce a satisfactorily fit of the empirical standard deviations as well, e.g. Smets and Wouters (2007) and Nakov and Pescatori (2010). These models differ with regard to several assumptions, i.e. the shocks (e.g. external finance premium) and their persistence as well as an extended firm sector with productivity changes in commodity mining.

monetary and technological shocks where the first has declined significantly lately we see a more solid behavior of these variables since 1984. Generally, goods production and materials production show a completely different pattern to various shocks, the same holds for goods inventories and materials inventories, logically.

We find that the forecast error variances of GDP, production and sales on one side and inventories on the other side depend on a different set of shocks, i.e. they have different driving forces. While price markup shocks were more important during 1957-83, since 1984 the wage markup shock or shocks associated with the labor market are responsible for a greater share of the variance in many variables. Interestingly, governmental and preference shocks do not matter in terms of forecast errors.

For the volatility of inventories, the Great Moderation led to an even larger contribution of inventory cost shocks. Given that the decline in the average size of this shock is quite equivalent to the average decline for all shocks from 1957-83 to 1984-2006, this could mean that inventories are indeed subject to faster adjustments since the 1980s. Moreover, parameter estimates indicate that the efficiency of storing has risen and/or the average duration of storage has declined substantially from the first to the second subsample. However, counterfactual exercises show this is not the main reason for the Great Moderation. In this regard, we confirm the outcomes in Iacoviello, Schiantarelli, and Schuh (2011) and McCarthy and Zakrajsek (2007), i.e. inventory behavior contributed at most slightly to the reduction of macroeconomic volatility.

Counterfactual exercises show that the most important contribution to the Great Moderation is attributed to the change in the shock processes and, significantly more, in the structural parameters. Therefore, the *good policy hypothesis* as explanation for the Great Moderation must be rejected. For inflation, all subsets of parameters contributed equally to the decline in its standard deviation. We conclude that changes related to productive capital, i.e. investment smoothing or utilization of capital, and labor supply developments play a major role for the reduced fluctuations we saw in recent decades. The increase in capacity utilization cost may indicate that finding the optimal effective use of capital is now more difficult due to more and more complex production processes or higher fixed cost, making the variation more costly. Higher adjustment costs in investment could indicate more subdivided expenditures for long-term investment projects, less flexibility in changing investment projects to economic changes and thus, as mentioned by Groth and Khan (2010), time-to-build constraints. According to our results, the Great Moderation will continue unless the circumstances mentioned change, i.e. labor market rigidities increase or the effective use of the capital stock is subject to larger changes. A good starting point for further research would be to analyze what determines the increase in cost associated with capital and how this contributed to the decline in overall volatility.

References

Adolfson, M., S. Laseen, J. Linde, and M. Villani (2007): "Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through," *Journal of International Economics*, 72(2), 481–511.

Ahmed, S., A. Levin, and B. A. Wilson (2004): "Recent U.S. Macroeconomic Stability: Good Policies, Good Practices, or Good Luck?," *The Review of Economics and Statistics*, 86(3), 824–832.

Benati, L., and P. Surico (2009): "VAR Analysis and the Great Moderation," *American Economic Review*, 99(4), 1636–1652.

Bils, M., and J. A. Kahn (2000): "What Inventory Behavior Tells us about Business Cycles," *American Economic Review*, 90(3), 458–481.

Blinder, A. S. (1981): "Retail Inventory Behavior and Business Fluctuations," *Brookings Papers on Economic Activity*, 2, 443–505.

Boivin, J., and M. P. Giannoni (2006): "Has Monetary Policy Become More Effective?," *The Review of Economics and Statistics*, 88(3), pp. 445–462.

Canova, F. (2009): "What Explains the Great Moderation in the U.S.? A Structural Analysis," *Journal of the European Economic Association*, 7(4), 697–721.

Chang, Y., A. Hornstein, and P.-D. Sarte (2009): "On the Employment Effects of Productivity Shocks: The Role of Inventories, Demand Elasticity, and Sticky Prices," *Journal of Monetary Economics*, 56(3), 328–343.

Christiano, L. J. (1988): "Why Does Inventory Investment Fluctuate so Much?," *Journal of Monetary Economics*, 21(2-3), 247–280.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113(1), 1–45.

Förster, M. (2014): "An Empirical Analysis of Business Cycles in a New Keynesian Model with Inventories," MAGKS Discussion Papers on Economics No. 13-2014, Philipps-Universität Marburg.

Gambetti, L., and J. Galí (2009): "On the Sources of the Great Moderation," *American Economic Journal: Macroeconomics*, 1(1), 26–57.

Gertler, M., L. Sala, and A. Trigari (2008): "An Estimated Monetary DSGE Model with Unemployment and Staggered Nominal Wage Bargaining," *Journal of Money, Credit and Banking*, 40(8), 1713–1764.

Giannone, D., M. Lenza, and L. Reichlin (2008): "Explaining the Great Moderation: It Is not the Shocks," *Journal of the European Economic Association*, 6(2-3), 621–633.

Groth, C., and H. Khan (2010): "Investment Adjustment Costs: An Empirical Assessment," *Journal of Money, Credit and Banking*, 42(8), 1469–1494.

Herrera, A. M., and E. Pesavento (2009): "Oil Price Shocks, Systematic Monetary Policy, and the "Great Moderation"," *Macroeconomic Dynamics*, 13, 107–137.

Iacoviello, M., F. Schiantarelli, and S. Schuh (2011): “Input and Output Inventories in General Equilibrium,” *International Economic Review*, 52(4), 1179–1213.

Jung, Y., and T. Yun (2005): “Monetary Policy Shocks, Inventory Dynamics, and Price-Setting Behavior,” Working Paper Series 2006-02, Federal Reserve Bank of San Francisco.

——— (2013): “Inventory Investment and the Empirical Phillips Curve,” *Journal of Money, Credit and Banking*, 45(1), 201–231.

Justiniano, A., and G. E. Primiceri (2008): “The Time-Varying Volatility of Macroeconomic Fluctuations,” *American Economic Review*, 98(3), 604–41.

Justiniano, A., G. E. Primiceri, and A. Tambalotti (2010): “Investment Shocks and Business Cycles,” *Journal of Monetary Economics*, 57(2), 132–145.

——— (2011): “Investment Shocks and the Relative Price of Investment,” *Review of Economic Dynamics*, 14(1), 102–121, Special issue: Sources of Business Cycles.

Kahn, J. A. (2008): “Durable Goods Inventories and the Great Moderation,” Staff Reports 325, Federal Reserve Bank of New York.

Kahn, J. A., M. M. McConnell, and G. Perez-Quiros (2002): “On the Causes of the Increased Stability of the U.S. Economy,” *Economic Policy Review*, (May), 183–202.

Khan, A., and J. K. Thomas (2005): “Modeling Inventories over the Business Cycle,” 2005 Meeting Papers 182, Society for Economic Dynamics.

——— (2007): “Inventories and the Business Cycle: An Equilibrium Analysis of (S, s) Policies,” *The American Economic Review*, 97(4), pp. 1165–1188.

Khan, H., and J. Tsoukalas (2011): “Investment Shocks and the Comovement Problem,” *Journal of Economic Dynamics and Control*, 35(1), 115–130.

Kim, C.-J., J. Morley, and J. Piger (2008): “Bayesian Counterfactual Analysis of the Sources of the Great Moderation,” *Journal of Applied Econometrics*, 23(2), 173–191.

Kryvtsov, O., and V. Midrigan (2010): “Inventories and Real Rigidities in New Keynesian Business Cycle Models,” *Journal of the Japanese and International Economies*, 24(2), 259–281, Special Conference Issue Sticky Prices and Inflation Dynamics, TRIO Conference.

Lubik, T. A., and W. L. Teo (2009): “Inventories and Optimal Monetary Policy,” *Economic Quarterly*, (Fall), 357–382.

——— (2012): “Inventories, Inflation Dynamics and the New Keynesian Phillips Curve,” *European Economic Review*, 56(3), 327–346.

McCarthy, J., and E. Zakrajsek (2007): “Inventory Dynamics and Business Cycles: What Has Changed?,” *Journal of Money, Credit and Banking*, 39(2-3), 591–613.

McMahon, M. F. (2012): “Inventories in Motion: A New Approach to Inventories over the Business Cycle,” Working paper, Coventry.

Nakov, A., and A. Pescatori (2010): “Oil and the Great Moderation,” *The Economic Journal*, 120(543), 131–156.

Ramey, V. A., and K. D. West (1999): "Inventories," in *Handbook of Macroeconomics*, ed. by J. B. Taylor, and M. Woodford, vol. 1 of *Handbook of Macroeconomics*, chap. 13, pp. 863–923. Elsevier.

Rotemberg, J. J. (1982): "Sticky Prices in the United States," *Journal of Political Economy*, 90(6), 1187–1211.

Smets, F., and R. Wouters (2003): "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area," *Journal of the European Economic Association*, 1(5), 1123–1175.

——— (2005): "Comparing Shocks and Frictions in US and Euro Area Business Cycles: A Bayesian DSGE approach," *Journal of Applied Econometrics*, 20(2), 161–183.

——— (2007): "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *The American Economic Review*, 97(3), 586–606.

Stock, J. H., and M. W. Watson (2002): "Has the Business Cycle Changed and Why?," *NBER Macroeconomics Annual*, 17, pp. 159–218.

Teo, W. L. (2011): "Inventories and Optimal Monetary Policy in a Small Open Economy," *Journal of International Money and Finance*, 30(8), 1719–1748.

Wen, Y. (2005): "Understanding the Inventory Cycle," *Journal of Monetary Economics*, 52(8), 1533–1555.

——— (2011): "Input and Output Inventory Dynamics," *American Economic Journal: Macroeconomics*, 3(4), 181–212.

8 Tables and Figures

8.1 Tables

Table 1. Standard Deviations

Variable	Model			Data		
	Subsample 57-83	Subsample 84-06	Ratio	Subsample 57-83	Subsample 84-06	Ratio
GDP Growth	1.3252	0.9208	0.6948	1.1436	0.5460	0.4774
Gross Investment Growth	4.4379	3.0560	0.6886	4.3195	1.9634	0.4545
Fixed Investment Growth	3.3468	2.2560	0.6741	2.7383	1.5961	0.5829
Inventory Growth	1.0768	0.8442	0.7840	1.0110	0.7072	0.6995
Inflation	0.7605	0.4118	0.5415	0.7092	0.2387	0.3366
Nominal Interest Rate	0.8356	0.4019	0.4810	0.9045	0.5869	0.6489
Real Wage Growth	0.6761	0.7079	1.0470	0.4860	0.6652	1.3687
Hours Worked	3.6836	2.9305	0.7956	3.2604	3.4800	1.0674
Consumption Growth	0.6761	0.6416	0.9490	0.5751	0.5108	0.8882

For the model median values over 100 simulated periods for 500 retained parameter draws each are reported. For the data we depict the empirical means.

Table 2. Estimation Results I

		Prior			Posterior 57-83						Posterior 84-06					
		Dis.	Mean	SD	Mode	SD (Hes.)	5%	Med.	Mean	95%	Mode	SD (Hes.)	5%	Med.	Mean	95%
α	Prod. share commodity	N	0.3	0.05	0.18	0.02	0.15	0.18	0.18	0.22	0.20	0.02	0.16	0.20	0.20	0.24
$100\left(\frac{1}{\beta}-1\right)$	Discount factor	G	0.25	0.1	0.17	0.07	0.10	0.19	0.20	0.32	0.20	0.06	0.12	0.21	0.22	0.33
$100(v-1)$	StSt technology growth	N	0.4	0.1	0.40	0.06	0.31	0.40	0.40	0.49	0.43	0.05	0.35	0.43	0.43	0.51
$100(\pi-1)$	StSt inflation	G	0.62	0.1	0.64	0.11	0.49	0.65	0.65	0.83	0.69	0.07	0.56	0.69	0.69	0.83
l_{stst}	StSt hours worked	N	0	2	-0.28	0.93	-1.82	-0.46	-0.41	1.21	1.69	1.05	-0.05	1.72	1.71	3.44
b	Consumption habit	B	0.6	0.1	0.79	0.03	0.73	0.79	0.79	0.85	0.76	0.04	0.70	0.78	0.78	0.85
σ_l	Inverse Frisch elasticity	G	2	0.75	0.59	0.27	0.34	0.66	0.69	1.14	1.30	0.42	0.75	1.37	1.44	2.40
θ_g	Demand elas. goods	B	0.5	0.2	0.52	0.06	0.43	0.53	0.53	0.63	0.22	0.07	0.16	0.27	0.27	0.39
θ_m	Demand elas. materials	B	0.5	0.2	0.26	0.03	0.22	0.27	0.27	0.32	0.12	0.04	0.09	0.14	0.15	0.22
μ^p	Price markup	G	0.2	0.1	0.29	0.07	0.21	0.30	0.32	0.46	0.34	0.10	0.22	0.35	0.36	0.55
S''	Investment adj. cost	N	4	1.5	4.85	0.75	3.80	5.13	5.16	6.64	5.94	1.03	4.77	6.38	6.39	8.11
σ_a	Elasticity cap. adj. cost	G	4	1.5	2.85	1.36	1.65	2.96	3.15	5.30	4.39	1.52	2.79	4.60	4.78	7.37
κ_p	Price adjustment cost	G	50	20	64.48	17.79	41.51	65.44	67.72	101.69	71.83	22.93	47.07	79.51	82.29	126.28
κ_w	Wage adjustment cost	G	50	20	97.27	27.05	67.76	104.25	107.62	157.94	56.03	20.44	36.97	64.93	67.47	106.04
γ_p	Price indexation	B	0.5	0.15	0.13	0.07	0.07	0.16	0.16	0.27	0.20	0.08	0.11	0.24	0.25	0.42
γ_w	Wage indexation	B	0.5	0.15	0.68	0.07	0.58	0.69	0.70	0.82	0.79	0.06	0.69	0.80	0.80	0.90
ρ_m	Interest rate smoothing	B	0.75	0.1	0.73	0.04	0.66	0.73	0.73	0.79	0.83	0.02	0.79	0.83	0.83	0.86
φ_π	Response to inflation	N	1.5	0.2	1.55	0.12	1.38	1.55	1.56	1.77	2.05	0.15	1.78	2.03	2.03	2.29
φ_y	Response to output	N	0.13	0.05	0.11	0.03	0.07	0.11	0.12	0.17	0.09	0.02	0.05	0.09	0.09	0.12
$\varphi_{\Delta\pi}$	Response to infl. diff.	N	0.3	0.1	0.35	0.07	0.23	0.34	0.34	0.46	0.17	0.06	0.08	0.17	0.17	0.26
$\varphi_{\Delta y}$	Response to output diff.	N	0.06	0.05	0.10	0.02	0.06	0.10	0.10	0.14	0.08	0.02	0.05	0.08	0.08	0.11

Prior distributions (*Dis.*) are the Normal distribution (*N*), the Gamma distribution (*G*), and the Beta distribution (*B*).

Table 3. Estimation Results II

		Prior			Posterior 57-83						Posterior 84-06					
		Dis.	Mean	SD	Mode	SD (Hes.)	5%	Med.	Mean	95%	Mode	SD (Hes.)	5%	Med.	Mean	95%
ρ_v	Technological progress	B	0.5	0.2	0.12	0.06	0.05	0.14	0.14	0.26	0.07	0.05	0.03	0.09	0.09	0.17
ρ_k	Capital investment	B	0.5	0.2	0.56	0.09	0.41	0.55	0.55	0.68	0.65	0.07	0.49	0.63	0.62	0.74
ρ_h	Storage area investment	B	0.5	0.2	0.33	0.08	0.19	0.32	0.32	0.45	0.39	0.09	0.23	0.36	0.36	0.50
ρ_w	Wage markup	B	0.5	0.2	0.88	0.07	0.73	0.85	0.85	0.94	0.88	0.07	0.72	0.86	0.86	0.98
ρ_s	Government	B	0.5	0.2	0.97	0.02	0.93	0.97	0.96	0.99	0.98	0.01	0.96	0.98	0.98	0.99
ρ_c	Consumption	B	0.5	0.2	0.55	0.09	0.38	0.57	0.56	0.73	0.86	0.06	0.71	0.85	0.84	0.93
ρ_p	Price markup	B	0.5	0.2	0.94	0.04	0.86	0.92	0.92	0.96	0.87	0.07	0.67	0.83	0.82	0.92
σ_c	Consumption	I	0.1	1	0.50	0.04	0.45	0.51	0.52	0.59	0.52	0.05	0.43	0.52	0.52	0.63
σ_k	Capital investment	I	0.1	1	0.31	0.07	0.24	0.34	0.35	0.47	0.19	0.04	0.16	0.22	0.22	0.30
σ_w	Wage markup	I	0.1	1	0.07	0.02	0.06	0.08	0.08	0.11	0.13	0.02	0.10	0.14	0.14	0.19
σ_v	Technological progress	I	0.1	1	0.67	0.06	0.58	0.67	0.67	0.77	0.60	0.06	0.52	0.60	0.60	0.70
σ_p	Price markup	I	0.1	1	0.10	0.02	0.08	0.10	0.10	0.14	0.07	0.01	0.05	0.07	0.07	0.09
σ_s	Government	I	0.1	1	0.41	0.03	0.37	0.42	0.42	0.47	0.28	0.02	0.26	0.29	0.29	0.33
σ_r	Interest rate	I	0.1	1	0.33	0.02	0.30	0.34	0.34	0.38	0.11	0.01	0.10	0.12	0.12	0.13
σ_h	Storage area investment	I	0.1	1	0.62	0.05	0.56	0.64	0.64	0.72	0.51	0.04	0.46	0.53	0.53	0.60

Prior distributions (*Dis.*) are the Beta distribution (*B*) and the Inverse Gamma distribution (*I*).

Table 4. Variance Decomposition I

Variable	**Time**	**Subsample 57-83**								**Subsample 84-06**							
		η_t^c *cons.*	η_t^k *cap.*	η_t^w *wage*	η_t^v *tech.*	η_t^p *price*	η_t^s *gov.*	η_t^r *mon.*	η_t^h *stor.*	η_t^c *cons.*	η_t^k *cap.*	η_t^w *wage*	η_t^v *tech.*	η_t^p *price*	η_t^s *gov.*	η_t^r *mon.*	η_t^h *stor.*
GDP	t=0	5.3	27.7	6.8	3.9	0.7	12.1	0.3	41.8	6.5	22.2	7.7	7.6	2.2	10.9	0.3	40.9
	t=4	4.3	33.1	15.6	22.1	4.7	5.4	1.4	10.8	8.6	26.9	19.7	22.8	7.1	3.7	0.6	7.7
	t=10	2.2	21.1	24.3	33.3	5.8	3.7	0.8	5.2	5.5	16.7	29.2	32.0	6.5	2.2	0.3	3.3
	t=20	1.4	13.7	20.2	47.6	5.6	3.1	0.5	3.8	3.6	11.3	24.8	46.3	4.6	1.8	0.2	2.3
	t=40	0.9	8.9	13.1	63.0	5.2	2.4	0.3	2.7	2.3	7.3	16.1	63.9	3.0	1.5	0.1	1.5
Goods	t=0	1.6	24.6	3.3	34.4	2.2	4.8	7.3	20.5	1.0	27.2	4.2	34.7	2.1	4.7	3.9	20.6
Production	t=4	3.7	35.1	21.5	19.6	5.0	4.3	2.2	6.3	6.4	26.5	29.9	19.5	7.0	2.7	1.1	4.6
	t=10	2.1	22.5	27.7	30.8	6.1	3.3	1.1	3.2	4.9	17.0	34.6	29.1	6.0	1.9	0.5	2.2
	t=20	1.3	14.8	22.1	45.5	6.3	2.8	0.7	2.5	3.4	11.8	27.7	44.1	4.5	1.7	0.4	1.6
	t=40	0.9	9.7	14.4	61.4	5.6	2.3	0.5	1.8	2.2	7.7	18.2	62.0	3.0	1.4	0.2	1.1
Materials	t=0	5.8	11.1	39.4	2.7	1.0	11.1	3.5	22.6	8.1	2.5	33.2	21.0	3.4	7.3	1.8	19.7
Production	t=4	0.6	81.7	4.3	8.1	1.3	0.9	1.0	1.4	0.6	85.0	1.9	5.5	4.3	0.4	0.5	1.0
	t=10	0.2	77.8	6.9	7.5	4.3	0.2	0.4	1.3	0.5	79.6	6.7	5.9	5.2	0.1	0.2	0.6
	t=20	0.1	63.7	7.6	12.0	11.4	0.1	0.2	2.1	1.4	67.9	10.2	11.0	5.3	0.1	0.1	0.9
	t=40	0.1	43.3	5.5	24.2	20.0	0.1	0.1	2.0	1.6	50.2	9.4	26.1	4.7	0.1	0.1	0.9
Sales	t=0	7.9	46.7	5.5	10.4	2.0	18.2	1.2	6.6	10.7	40.2	8.4	14.6	4.1	17.6	0.6	1.9
	t=4	4.8	38.5	15.0	22.4	7.4	6.0	1.4	1.8	10.3	31.4	18.4	23.4	8.6	4.1	0.6	0.3
	t=10	2.5	23.4	22.2	33.3	9.4	4.0	0.7	1.0	6.7	19.0	26.4	32.4	7.9	2.4	0.3	0.3
	t=20	1.5	14.9	18.1	47.5	8.9	3.3	0.5	0.9	4.5	12.6	22.4	46.9	5.6	2.0	0.2	0.2
	t=40	1.0	9.7	11.8	63.3	7.1	2.6	0.3	0.7	2.8	8.0	14.5	64.4	3.6	1.6	0.1	0.2
Ratio	t=0	8.0	50.4	3.6	13.7	2.7	18.5	1.7	0.1	10.3	40.6	6.5	15.1	4.1	16.9	0.7	4.1
Inventories	t=4	2.8	26.4	3.3	12.2	10.2	3.2	1.0	38.5	6.6	20.9	4.8	11.1	6.1	2.2	0.4	45.5
to GDP	t=10	1.1	13.1	1.8	9.1	21.6	1.7	0.3	48.2	5.9	13.2	2.7	10.1	6.7	1.3	0.1	55.5
	t=20	0.6	5.8	3.6	6.5	40.7	1.3	0.1	39.2	7.2	8.3	4.6	10.1	7.5	1.5	0.1	54.4
	t=40	0.4	4.9	7.8	4.9	52.1	1.2	0.1	25.4	9.6	7.7	11.7	10.7	6.8	2.3	0.0	42.0

Medians as percentage values.

Table 5. Variance Decomposition II

Variable	Time	Subsample 57-83								Subsample 84-06							
		η_t^c *cons.*	η_t^k *cap.*	η_t^w *wage*	η_t^v *tech.*	η_t^p *price*	η_t^s *gov.*	η_t^r *mon.*	η_t^h *stor.*	η_t^c *cons.*	η_t^k *cap.*	η_t^w *wage*	η_t^v *tech.*	η_t^p *price*	η_t^s *gov.*	η_t^r *mon.*	η_t^h *stor.*
Total	t=0	0.0	0.1	2.6	1.7	0.4	0.0	0.4	94.4	0.0	0.2	0.8	0.3	0.0	0.0	0.0	98.5
Inventories	t=4	0.0	0.6	2.1	0.3	2.3	0.0	0.1	94.2	0.4	1.1	1.6	0.1	0.4	0.0	0.0	95.9
	t=10	0.1	1.3	5.7	0.6	15.2	0.1	0.1	75.9	2.1	2.5	5.7	0.2	1.6	0.2	0.0	85.7
	t=20	0.2	0.7	10.4	1.0	36.7	0.2	0.0	48.2	5.6	2.0	13.1	0.3	4.2	0.5	0.0	68.8
	t=40	0.2	2.1	12.7	2.9	48.3	0.3	0.0	28.9	9.1	4.6	21.1	1.5	4.4	1.2	0.0	48.6
Goods	t=0	0.9	0.5	29.5	35.2	0.7	1.1	10.0	20.1	1.9	4.6	30.2	27.4	0.3	0.2	4.8	28.4
Inventories	t=4	1.4	2.1	18.7	12.1	1.3	2.3	8.4	51.4	6.3	5.3	20.5	8.6	0.6	1.1	4.9	49.9
	t=10	0.9	1.9	19.2	4.7	14.4	1.6	3.1	51.7	8.6	2.6	35.5	3.2	2.4	1.1	1.7	42.3
	t=20	0.6	1.6	20.6	1.9	34.1	1.1	1.2	36.0	10.2	1.6	35.1	1.7	5.8	1.2	0.9	38.5
	t=40	0.5	3.9	21.1	1.7	42.7	1.1	0.7	23.7	11.6	4.0	36.3	1.3	5.2	1.9	0.6	31.0
Materials	t=0	1.0	0.7	38.0	41.8	1.5	1.2	11.7	1.8	2.2	7.2	44.2	37.0	0.5	0.2	6.4	0.2
Inventories	t=4	1.3	6.6	32.9	17.0	3.9	2.4	10.6	21.2	5.3	15.3	30.8	13.6	2.3	1.1	7.5	18.1
	t=10	0.8	13.4	18.4	12.7	5.6	1.7	5.5	36.6	4.3	11.3	30.5	7.6	1.7	0.9	3.5	35.7
	t=20	0.4	12.2	10.8	11.0	20.4	0.9	2.9	35.2	3.5	10.8	22.1	7.8	1.8	0.6	2.3	45.2
	t=40	0.3	7.8	9.3	12.2	38.2	0.6	1.7	24.1	5.5	9.4	23.2	10.5	2.7	0.6	1.6	38.7
Inflation	t=0	0.1	0.2	33.3	3.4	57.3	0.1	1.9	2.5	0.6	2.0	32.8	1.5	58.8	0.0	1.5	1.3
	t=4	0.1	0.3	48.6	1.1	43.6	0.5	2.5	2.3	1.1	2.4	50.2	0.5	40.2	0.1	2.6	1.3
	t=10	0.1	0.8	49.7	1.0	41.6	0.8	2.2	2.6	1.2	2.8	51.4	0.7	38.0	0.2	2.7	1.3
	t=20	0.1	1.2	46.5	0.9	43.3	1.2	2.0	2.8	1.2	3.9	50.9	0.8	37.3	0.2	2.6	1.3
	t=40	0.1	1.2	44.0	0.9	45.4	1.4	1.9	2.8	1.2	4.1	50.8	0.7	37.1	0.3	2.5	1.3
Nominal	t=0	0.7	3.4	1.6	3.8	6.2	1.0	75.1	7.0	1.9	6.7	0.2	7.3	2.3	2.4	66.9	10.9
Interest Rate	t=4	1.3	6.8	23.4	2.3	27.5	0.5	29.4	6.7	5.9	17.8	22.9	2.8	24.1	1.0	17.8	5.2
	t=10	1.1	5.6	30.3	1.7	31.6	0.5	20.4	6.3	7.8	17.5	32.2	1.9	21.4	0.7	11.4	4.2
	t=20	1.0	5.3	28.5	1.5	35.3	0.7	18.2	6.0	8.2	17.2	32.6	2.2	20.7	0.7	10.8	4.0
	t=40	0.9	5.2	26.8	1.4	38.0	0.8	17.0	5.7	8.1	17.9	32.4	2.3	20.3	0.8	10.4	3.8

Medians as percentage values.

Table 6. Variance Decomposition III

Variable	Time	Subsample 57-83								Subsample 84-06							
		η_t^c *cons.*	η_t^k *cap.*	η_t^w *wage*	η_t^v *tech.*	η_t^p *price*	η_t^s *gov.*	η_t^r *mon.*	η_t^h *stor.*	η_t^c *cons.*	η_t^k *cap.*	η_t^w *wage*	η_t^v *tech.*	η_t^p *price*	η_t^s *gov.*	η_t^r *mon.*	η_t^h *stor.*
Gross	t=0	0.1	38.7	4.1	0.1	0.1	0.0	0.2	56.2	0.7	35.8	3.8	0.5	0.7	0.1	0.1	57.7
Investment	t=4	0.6	59.5	12.6	4.9	0.5	0.3	1.0	18.8	4.2	56.5	14.8	4.6	3.3	0.2	0.3	14.4
	t=10	0.7	47.4	26.0	9.8	0.7	0.4	0.7	11.2	7.5	41.3	27.3	8.9	3.7	0.3	0.2	7.4
	t=20	0.6	38.8	27.2	16.9	0.9	0.4	0.6	10.4	8.1	32.8	28.3	15.4	3.1	0.4	0.2	6.3
	t=40	0.6	33.7	23.6	25.2	2.2	0.4	0.5	9.6	7.0	28.5	24.6	24.7	2.7	0.4	0.2	5.7
Fixed	t=0	0.2	83.0	2.7	1.5	0.4	0.1	1.1	10.3	1.4	86.4	4.0	1.8	2.0	0.1	0.5	3.1
Investment	t=4	0.6	74.5	12.5	4.3	1.6	0.3	1.0	3.8	3.7	70.5	13.9	4.4	4.8	0.2	0.4	0.8
	t=10	0.7	57.1	24.2	9.4	2.6	0.3	0.7	2.3	6.4	50.3	24.7	8.8	5.6	0.3	0.2	0.5
	t=20	0.6	46.7	25.5	16.8	3.1	0.4	0.5	2.7	6.9	40.1	25.7	15.7	4.9	0.3	0.2	0.6
	t=40	0.5	41.3	22.1	25.2	3.4	0.3	0.5	2.6	6.0	35.4	22.3	24.8	4.1	0.3	0.2	0.6
Capital	t=0	0.1	93.9	1.1	1.0	2.4	0.1	0.7	0.5	0.8	91.6	2.4	1.5	2.6	0.1	0.4	0.3
Investment	t=4	0.2	80.4	4.9	2.9	8.6	0.1	0.6	1.3	2.2	77.0	8.5	3.8	6.4	0.1	0.3	0.7
	t=10	0.3	61.2	9.1	6.5	18.0	0.1	0.4	2.2	3.8	58.6	16.0	8.2	8.7	0.1	0.2	1.2
	t=20	0.2	49.1	8.9	11.3	24.4	0.1	0.3	2.2	4.1	48.4	16.9	15.2	8.1	0.1	0.2	1.2
	t=40	0.2	46.5	8.0	16.2	23.0	0.1	0.3	2.0	3.5	44.2	14.7	23.0	6.9	0.1	0.1	1.1
Real Wage	t=0	0.1	0.1	9.9	6.6	80.8	0.1	0.5	1.0	0.3	1.5	47.7	0.9	47.1	0.0	0.9	0.1
	t=4	0.0	1.0	10.2	42.6	44.7	0.1	0.3	0.4	0.1	3.1	29.5	31.7	33.4	0.0	0.6	0.0
	t=10	0.0	2.4	7.0	45.5	43.6	0.1	0.2	0.4	0.1	4.5	18.7	42.0	32.3	0.0	0.4	0.1
	t=20	0.0	3.0	4.1	54.2	37.5	0.1	0.1	0.4	0.1	4.8	11.6	57.6	23.2	0.1	0.2	0.2
	t=40	0.0	2.1	2.3	68.4	26.2	0.0	0.1	0.3	0.1	3.4	6.8	74.1	13.7	0.1	0.1	0.1
Hours	t=0	3.6	37.2	0.3	0.1	2.5	9.7	6.2	39.2	3.4	38.1	0.3	0.4	3.0	9.7	3.3	40.2
Worked	t=4	5.6	37.2	25.5	2.3	6.8	6.6	2.3	11.3	10.4	27.2	35.1	2.5	8.8	4.4	1.1	8.0
	t=10	3.8	25.2	42.5	2.0	9.0	6.1	1.4	6.8	9.7	16.9	50.8	1.6	8.7	3.5	0.6	4.4
	t=20	3.2	22.3	43.7	2.7	9.5	7.0	1.2	6.3	9.3	15.0	52.7	1.8	7.8	4.2	0.5	3.9
	t=40	3.0	23.1	41.2	3.0	9.7	8.1	1.1	6.1	9.3	15.2	50.9	2.0	7.5	5.3	0.5	3.7

Medians as percentage values.

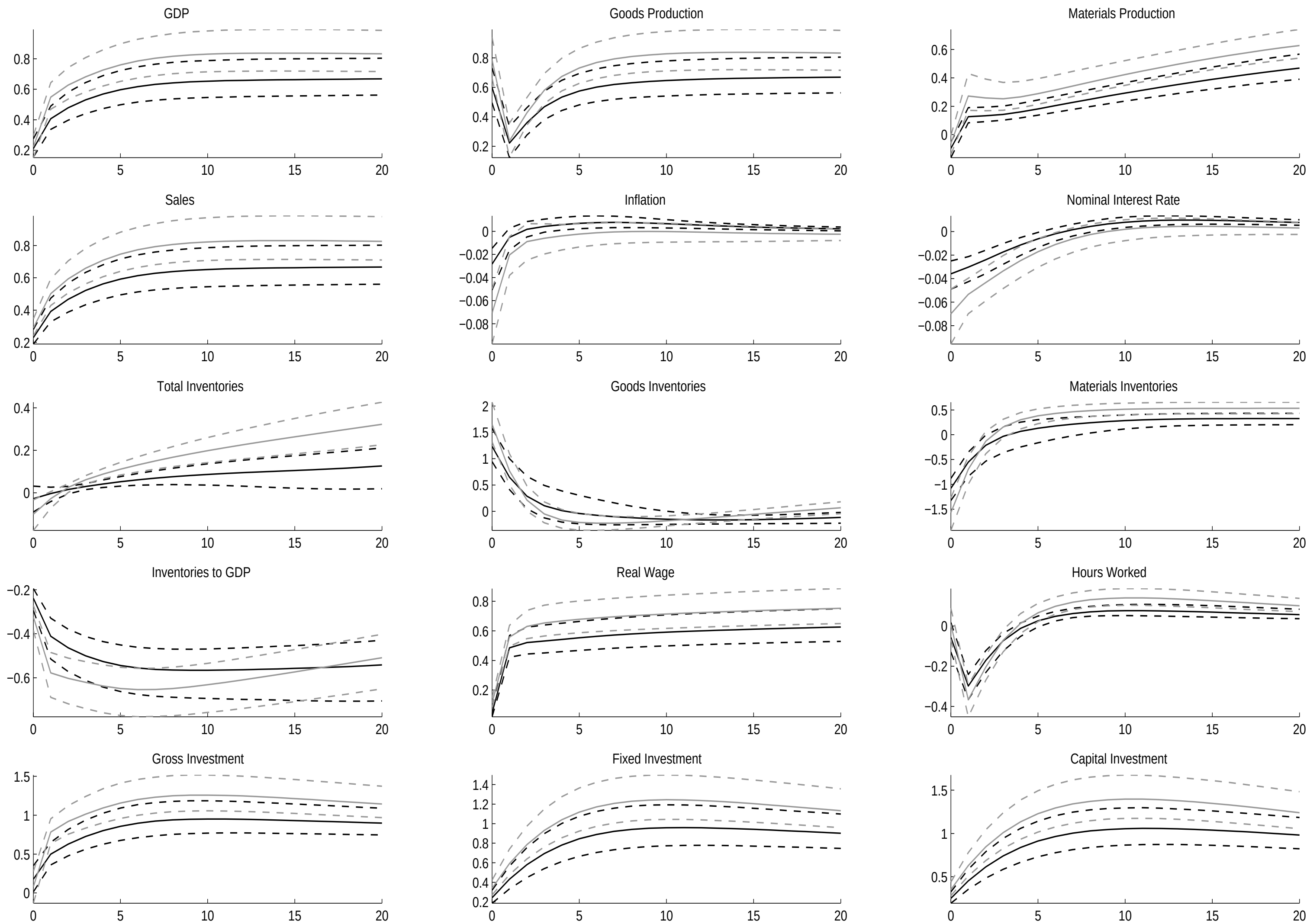
Table 7. Counterfactual Standard Deviations

Variable	Model		Counterfactuals			Counterfactual Struc. Parameters			Model w/o Inventories	
	Subsample 57-83	Subsample 84-06	Shocks	Policy	Structure	Inventories	Rigidities	Households	Subsample 57-83	Subsample 84-06
GDP Growth	1.2954	0.8939	1.1301	0.8739	1.3065	0.9266	1.0608	1.2145	1.4567	0.8068
Gross Investment Growth	4.3227	2.9526	3.6375	2.9208	4.1308	3.1059	3.4568	3.8192	5.0428	2.5833
Fixed Investment Growth	3.2956	2.2529	2.9307	2.2031	3.2604	2.1491	2.8108	3.2084	–	–
Inventory Growth	1.1674	0.8448	1.3231	0.8514	0.9830	0.8185	0.9433	1.0135	–	–
Inflation	0.7408	0.3884	0.4947	0.5538	0.7008	0.4059	0.4946	0.6367	0.6325	0.3795
Nominal Interest Rate	0.7991	0.3908	0.5872	0.5483	0.5839	0.4018	0.4572	0.5431	0.6872	0.4532
Real Wage Growth	0.6613	0.6875	0.9479	0.6783	0.5868	0.5858	0.6656	0.7104	0.8087	0.8549
Hours Worked	3.8403	2.9846	3.3004	2.8328	6.0639	2.9068	4.2312	5.8932	2.8635	2.8003
Consumption Growth	0.6669	0.6296	0.6842	0.6181	0.7312	0.6361	0.6636	0.7173	0.6916	0.6855

Median standard deviations based on 10,000 simulated samples for parameter values from the posterior modes. For the data we depict the empirical means. The counterfactual structural parameters we split into the following categories (parameters): Inventories (θ_g, θ_m, μ_p, α, β, υ), Rigidities (S'', σ_a, κ_w, γ_w, κ_p, γ_p), and Households (S'', σ_a, κ_w, γ_w, σ_l, b).

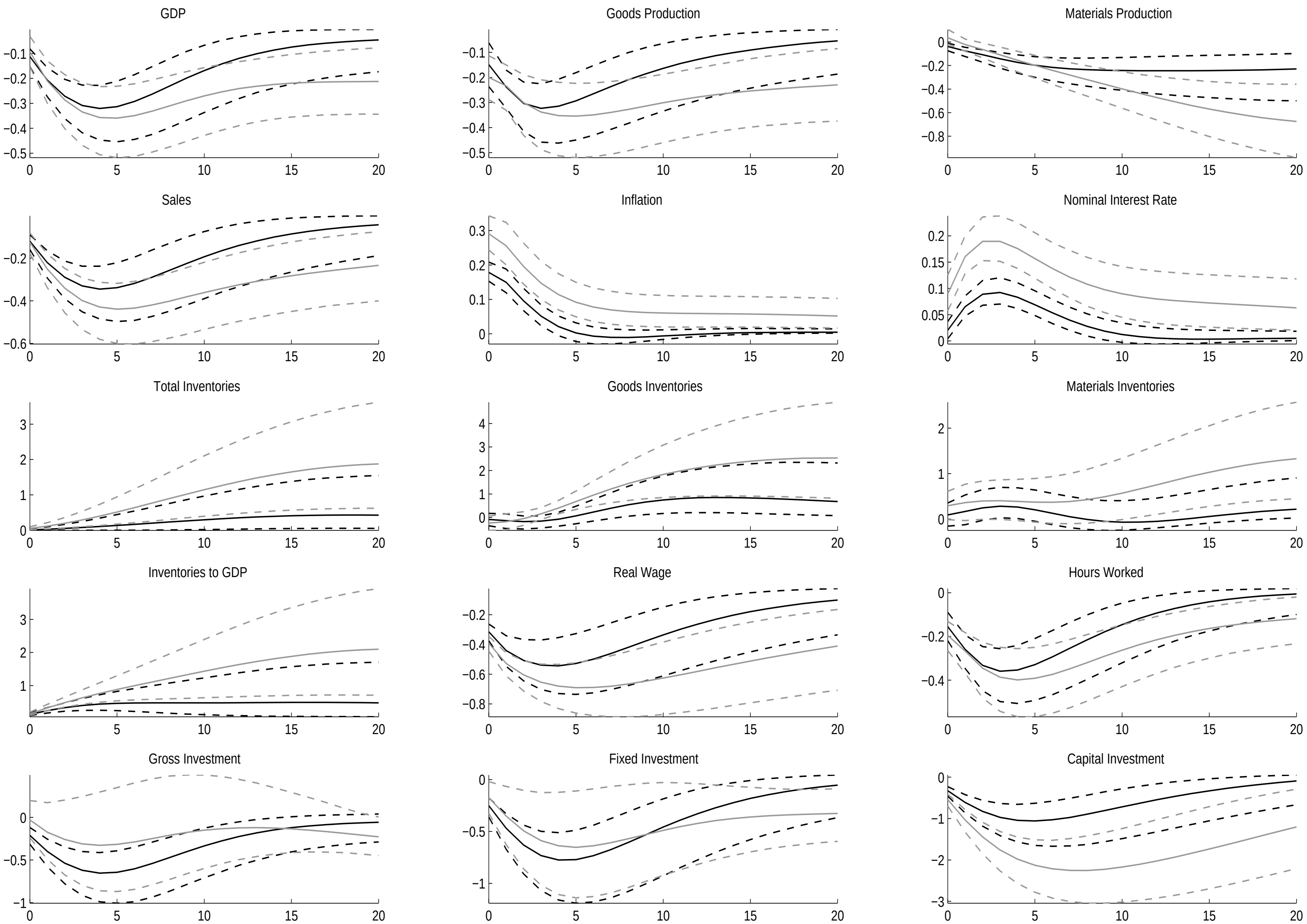
8.2 Figures

Figure 1. Response to Technological Progress Shock



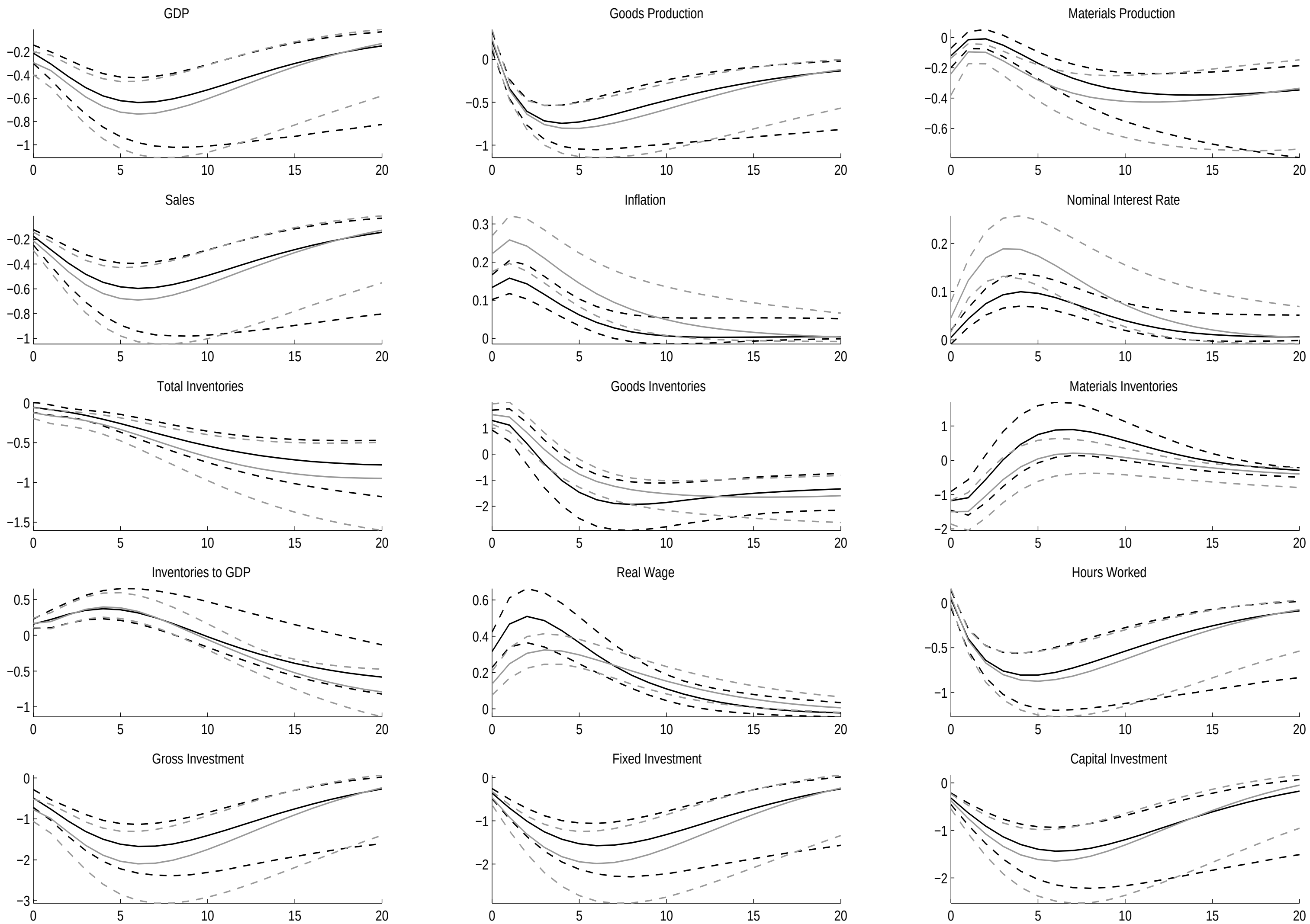
Medians as well as 5% and 95% percentile responses for subsamples 57-83 (gray) and 84-06 (black).

Figure 2. Response to Price Markup Shock



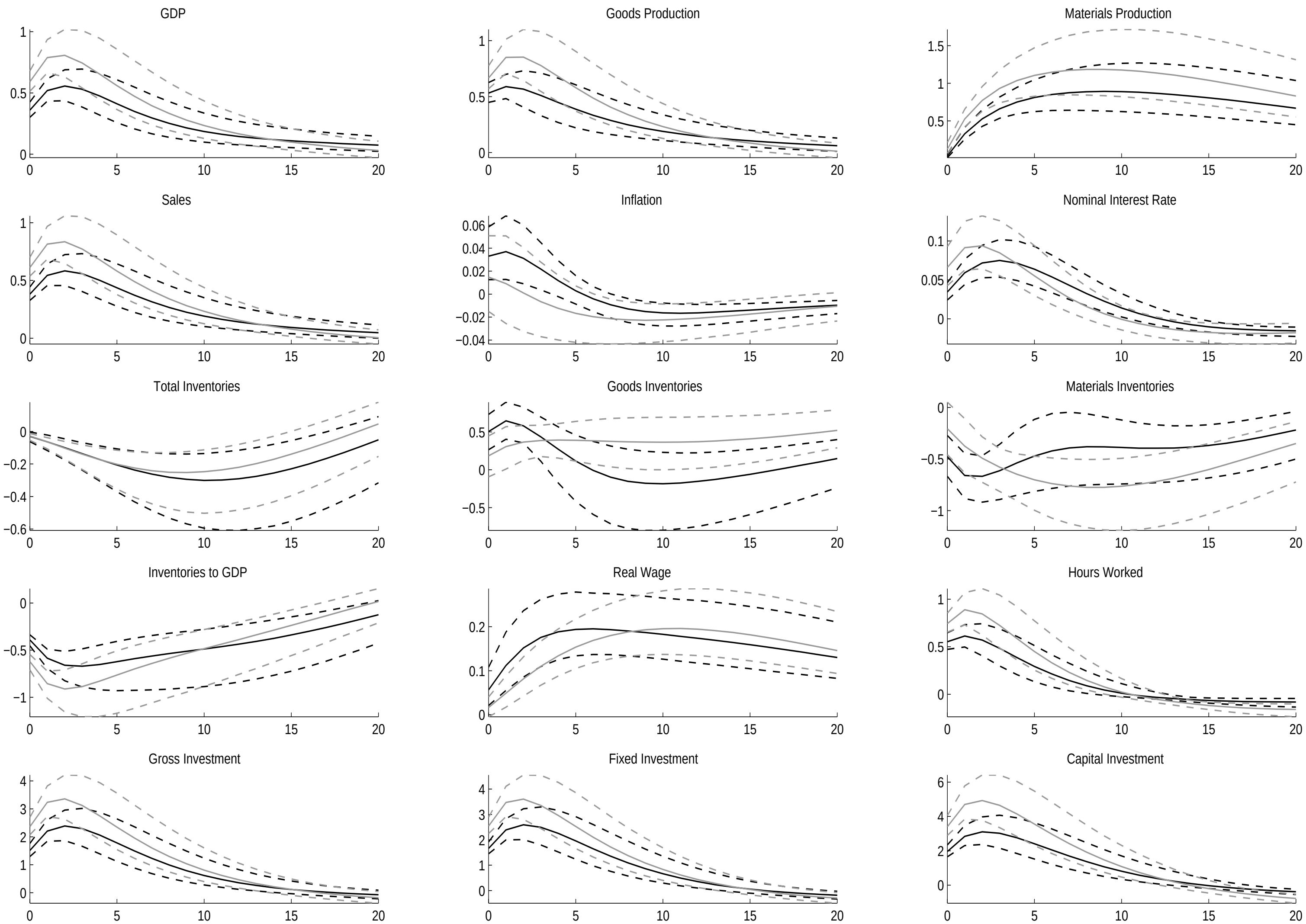
Medians as well as 5% and 95% percentile responses for subsamples 57-83 (gray) and 84-06 (black).

Figure 3. Response to Wage Markup Shock



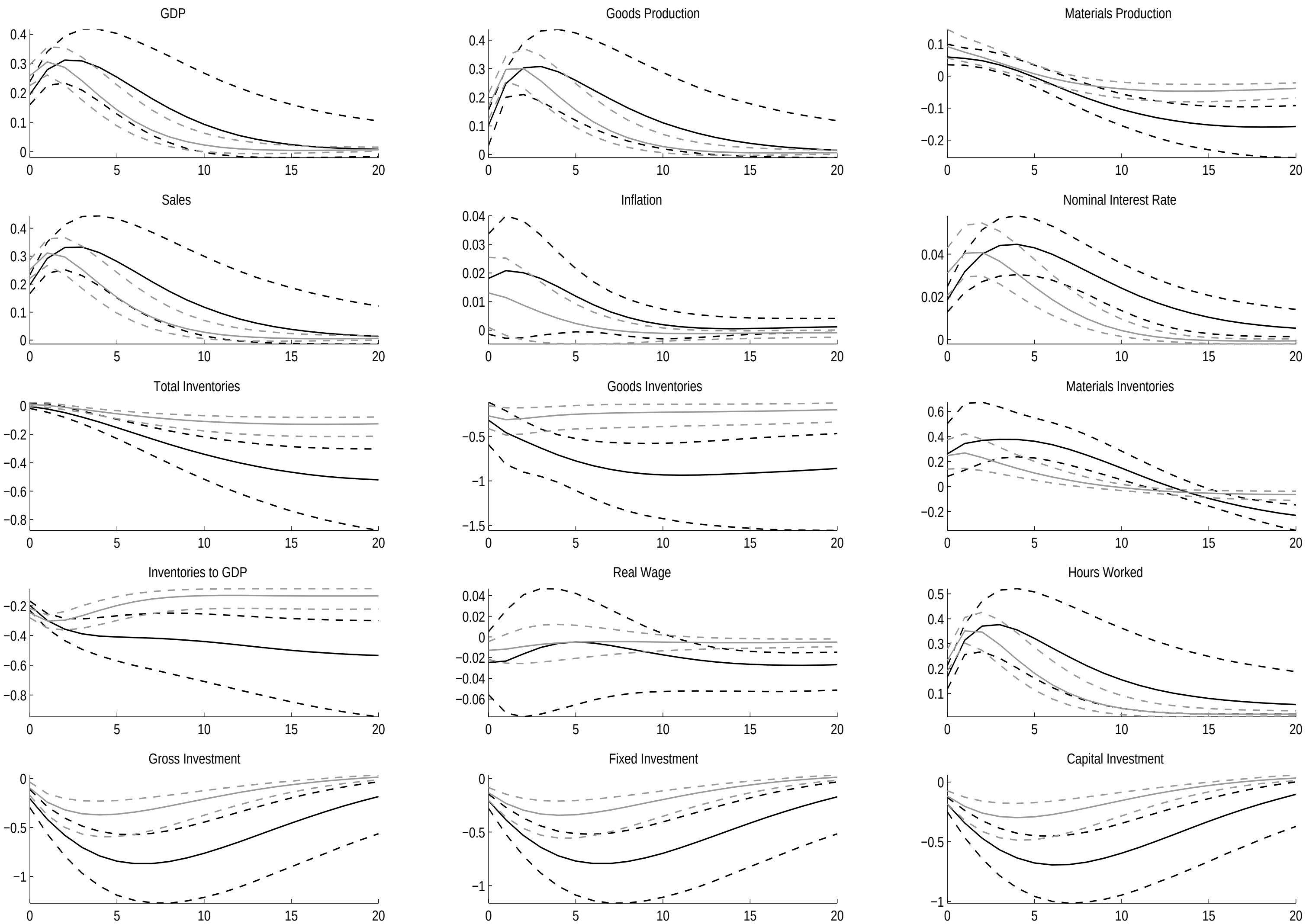
Medians as well as 5% and 95% percentile responses for subsamples 57-83 (gray) and 84-06 (black).

Figure 4. Response to Capital Investment Shock



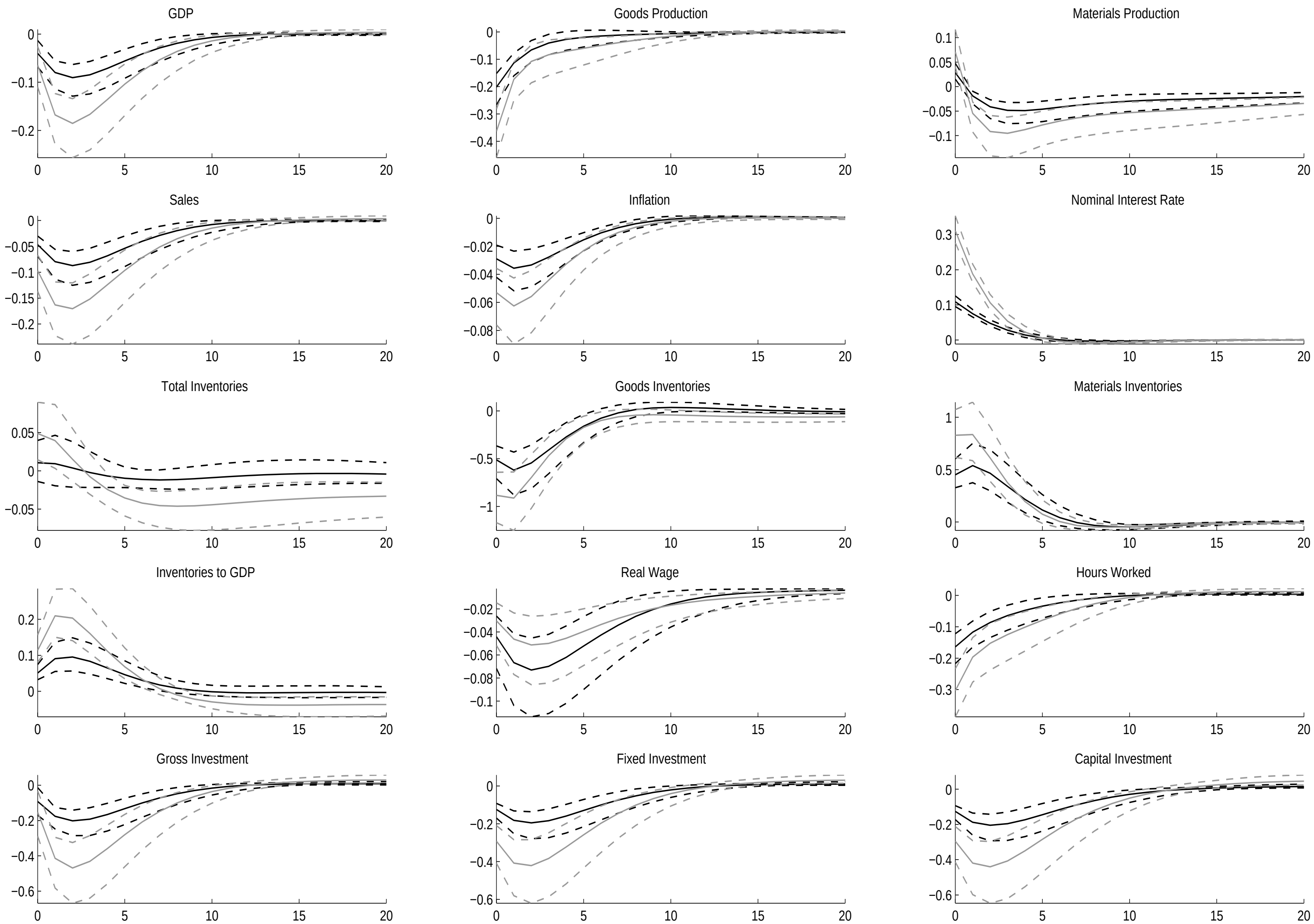
Medians as well as 5% and 95% percentile responses for subsamples 57-83 (gray) and 84-06 (black).

Figure 5. Response to Consumption Shock



Medians as well as 5% and 95% percentile responses for subsamples 57-83 (gray) and 84-06 (black).

Figure 6. Response to Monetary Policy Shock



Medians as well as 5% and 95% percentile responses for subsamples 57-83 (gray) and 84-06 (black).